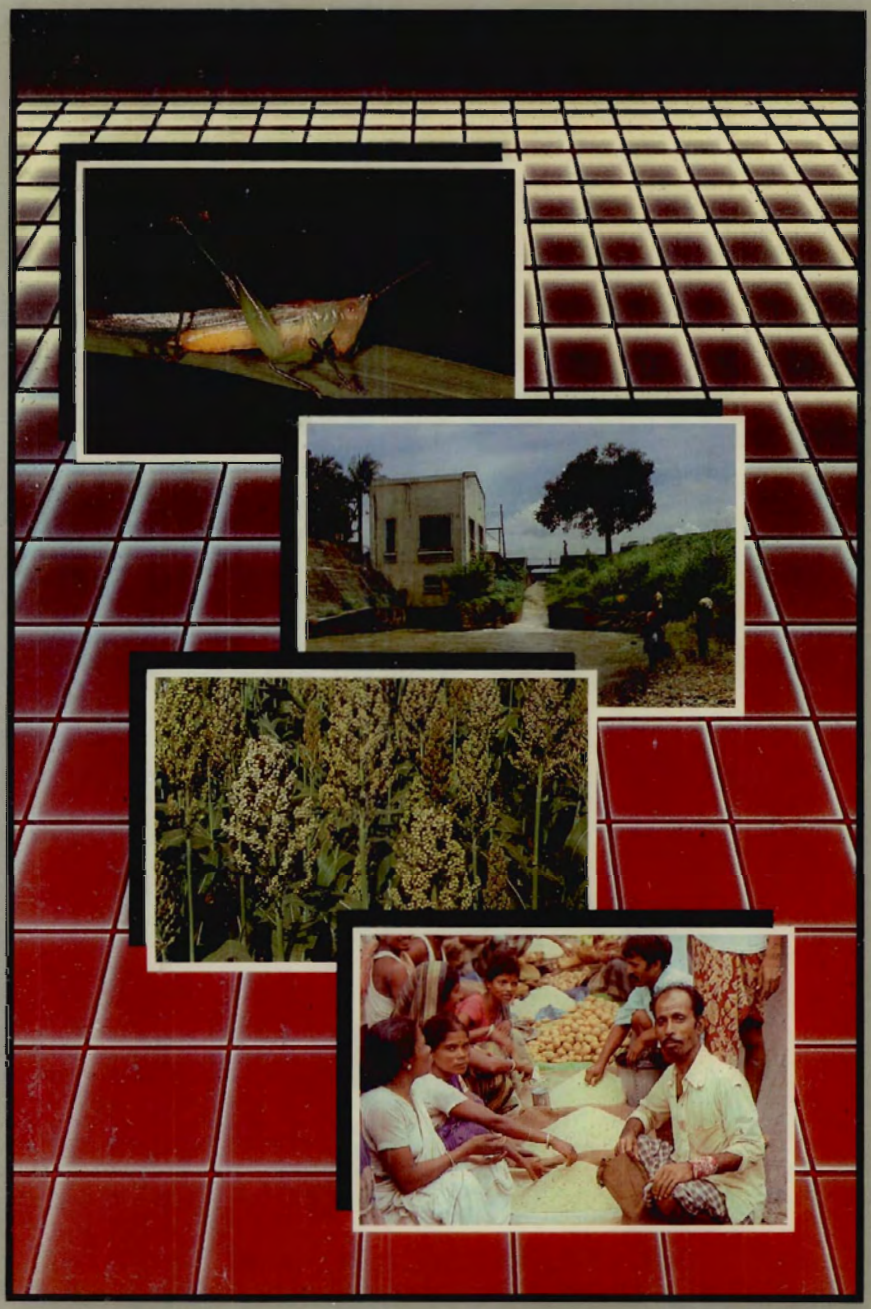
GLOBAL ASPECTS OF FOOD PRODUCTION

M.S. Swaminathan and S.K. Sinha (Editors)



INTERNATIONAL RICE RESEARCH INSTITUTE
TYCOOLY INTERNATIONAL

Natural Resources and the Environment Series
Volume 20

Global Aspects of Food Production

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M.S. SWAMINATHAN and S.K. SINHA
(*editors*)

TYCOOLY INTERNATIONAL
OXFORD – RIVERTON (N.J.) – DEHRA DUN

U.K. Tycooly Publishing Ltd,
P.O. Box 213, London E5 8UG, United Kingdom

U.S.A. Tycooly Publishing USA
P.O. Box C–166, Riverton, New Jersey 08077, United States

INDIA Tycooly Publishing
17 Rajpur Road, Dehra Dun, U.P. 248001, India

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Library of Congress Cataloging in Publication Data
Global aspects of food production.

(Natural resources and the environment series ; v. 20)
Bibliography: p.
Includes index.
1. Agriculture. 2. Food supply. I. Swaminathan, Monkombu Sambasivan. II. Sinha, S.K. III. Series.
S523.G584 1986 363.8 86–7020

British Library Cataloguing in Publication Data
Global aspects of food production. — (Natural resources and the environment series; 20)
1. Food supply
I. Swaminathan, M.S. II. Sinha, S.K. III. Series
338.1'9 HD9000.5
ISBN 1–85148–009–9

Typeset by TJB Photosetting Ltd, South Witham, Lincolnshire.
Printed in Great Britain

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Foreword

THE GLOBAL FOOD scenario reveals uncomfortable gluts of food grains and animal products in countries of North America, the European Economic Community, and Oceania, and acute food scarcities in many developing countries. According to the Food and Agriculture Organization of the United Nations (FAO), world cereal production during 1984 was 1804 million tons which represents a nine percent increase over the production in 1983. Food production as a whole rose during 1984 by over 4 percent. The sharpest gains in production were in North America and Europe. Africa produced more food in 1984 but population growth held production per capita to a level only 1% higher than in 1983 and 11% below the average of 1974–76. The 1984–85 African Food Emergency has been extremely severe in terms of human suffering. FAO has estimated that 21 severely affected countries in Africa would need cereal imports of 12.2 million tons during 1985.

In global terms there is abundance of food stocks which are expected to reach nearly 300 million tons by the end of 1985. Thus pockets of plenty and scarcity coexist in different parts of the world. It is ironical that several countries facing acute food scarcity now are also those where the domestication of plants and animals took place long ago and which are important centres of origin and diversity of crop plants. A country like Ethiopia is often described as a land with "13 months of sunshine." Since agriculture is predominantly a solar energy harvesting enterprise, Ethiopia is fortunately placed with regard to its agricultural production potential. Why then is it facing difficulties on the food front?

Knowledgeable scientists have indicated in this book the multifaceted nature of the agricultural production process. They have described the problems and needs as well as the potentials and opportunities. Unless there is a systems approach to the whole process of agricultural transformation with concurrent attention to all the links in the chain starting from sowing and ending with consumption, it will be difficult to achieve sustained progress.

There is today an impressive sense of unity both in the diagnosis of major global agricultural maladies and in the prescription of remedies. The time is hence ripe for introducing a Symbiotic International Agricultural System based on five major principles.

First, the global agricultural scene reveals considerable diversity in per capita productivity. Some countries and some parts within large countries in all the continents have very little gap between potential and actual yields at currently available levels of technology. In contrast, the yield gap may be as high as 80% or more in others. The constraints responsible for the prevailing yield gap may be ecological, technological, educational, socio-economic, and/or political. Socio-economic and political factors may be both internal and external and their relative importance may vary. National and international action is needed to identify and remove the constraints responsible

for inadequate progress in improving the productivity, profitability, stability and sustainability of major terrestrial and aquatic farming systems.

Secondly, in spite of much patchiness in agricultural progress, more than enough food is already produced in the world to provide a balanced diet for all its inhabitants. Global, regional and national policies for equitable distribution and improved consumption by the rural and urban poor are therefore urgently needed. Also, the concept of food security needs to be enlarged into one of nutrition security. The major components of a national nutrition security system are dealt with in the last chapter.

Thirdly, people with purchasing power seldom go hungry. Greater opportunities for both on-farm and off-farm employment are essential for higher household purchasing power. In this context, specific attention to technologies which can enhance the income of rural women and reduce drudgery in women-specific occupations is particularly important. The poorer the household, the greater is the need for an independent access to income among women. Continued food imports by predominantly agricultural countries possessing a large untapped food production potential will have the same impact as importing unemployment, since imports will lead to keeping local farmers and landless labour families at low levels of productivity and employment. Hence, a livelihood security plan based on opportunities for earning one's daily bread will have to be developed based on an appropriate blend of technologies, services, and government policies.

Fourthly, small and subsistence farmers who constitute the majority of the farming population in many developing countries will not produce more than what they need for themselves, unless they are assured cash and/or goods acceptable in exchange for the surplus. Remunerative prices coupled with the timely and adequate supplies of agricultural inputs and of basic consumer goods will enable and stimulate small farmers to produce and earn more. Hence, it will be desirable to reserve a certain proportion of the funds available for aid and relief for purchasing at remunerative prices surplus produce from small farmers and for providing essential consumer goods. The grains thus purchased could be used in the same country for a "Food for Work" programme for promoting agricultural and ecological rehabilitation and a "Food for Nutrition" programme for insulating old and infirm persons, pregnant and nursing mothers, and preschool children from starvation. Agricultural and ecological programmes should be integrated at the operational level, since the conservation and effective management of land, water, flora and fauna is essential for sustained agricultural advance.

Finally, current trade, aid, and investment patterns need a thorough review. Shrinking commitment to multilateral and concessional assistance, expanding debts and debt servicing burdens, import restrictions and export subsidies, trade wars, an increasingly unfavourable cost, risk, and return structure of farming to the world's small producers, inadequate availability of capital for the modernisation of agriculture and in some cases, the very model of agricultural modernisation adopted having built-in seeds of ecological and social biases, are all areas which deserve concerted attention and equitable solutions.

The different chapters in this book provide information relevant to the promotion of an international agricultural system based on principles of ecology, efficiency and equity. We are grateful to the eminent scientists who gave time willingly to write the chapters and to Tycooly International for the speedy publication of the book.

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CHAPTER 1

Food Production Needs in a Consumption Perspective

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INTRODUCTION

THE GLOBAL FOOD situation will be unusually dynamic in the closing decades of the twentieth century. Total demand for food will rise at unprecedented rates. That growth in demand will occur largely in the rapidly developing countries of Asia, Africa, and Latin America. To match it will require unprecedented increases in production in both the developing and developed countries. Such growth will be achieved partly by expanded area in production, but an increased proportion will have to come from extraordinary increases in yields per hectare. Failure to provide such rapid rates of growth will result in rising real food prices and consequent depressed incomes, food consumption and nutritional status for low income people. This will be particularly so in those countries, principally in Africa, not yet experiencing the general increase in productivity that occurs when dynamic economic development commences. Rising real food prices will also tend to raise nominal wages and to slow employment growth. In the face of continued population growth that too will depress real incomes of low income people.

Rising incomes will make demand for food more rigid and thus add to the instability of food prices in the face of inevitable fluctuations in production. Weather-induced production fluctuations have been unusually small in the past few decades, while the modernization of agriculture so essential to increased production seems to add to production variation. Thus instability of food supplies is bound to be an increasing problem with consequent burden on low income people and on political systems, placing a further requirement for increased production to establish stocks.

A further consequence of accelerating growth in developing countries is rapid increase in agricultural trade. This relieves the burden of rapidly growing food demand for some countries. It also greatly complicates policy as agricultural output is adjusted to the dynamics of domestic production and consumption as well as to import and export potentials. This in turn influences the direction of agricultural research and other elements of agricultural development.

Thus in the next few decades accelerated growth in agricultural production will be

central to successful strategies of growth in developing countries. That will be much more the case than in the 1950s and 1960s when burdensome surpluses of food were built up by the major food exporters.

SOURCES OF THE GLOBAL FOOD PROBLEM

The basic source of the world food problem is incipient high growth rates of per capita income – the very processes of development. Those forces take place in a background of population growth that is very rapid by historical standards.

Income Growth

The basic source of dynamism in the global food scene is rising real per capita incomes for large numbers of people in the developing countries of Asia, Africa, and Latin America. This growth follows a fluctuating pattern, with intermittent periods of global recession and particularly of retarded trade. In this discussion we abstract from these fluctuations.

Following World War II and the rapid decline of colonialism, powerful forces of economic growth were unleashed in the former colonial areas. For the first few decades of independence little growth occurred in per capita income, as these countries labored at building the transport systems, the power grids, the institutions and most of all the large numbers of trained people essential to a modern, differentiated economy capable of rapid growth. For an increasing number of countries that base is effectively in place. Others will follow over the next decades. In addition, the rapid increase in oil prices has caused a large aggregate of population to experience accelerated growth in income much sooner than would be possible purely on the basis of development processes. The very success of the rapidly developing and the oil exporting countries has added to the problems of the lowest income countries which are lagging in the processes of development.

Thus, eight major oil exporting Third World countries (Algeria, Indonesia, Iran, Iraq, Mexico, Nigeria, Saudi Arabia, and Venezuela) had an aggregate 1977 population of approximately 361 million people. A simple average of per capita income growth rates (1970-1977) for these countries is 5.6 percent per year, and the average per capita income in 1977 was $2078. Food imports have risen in real terms by an average of 19 percent a year. Even if real energy prices were to stabilize, an increasing proportion of income in the future is likely to be allocated to consumption; thus the demand for food will continue to increase rapidly. Expected growth in population and per capita income will lead to a rise in the real expenditure for food of more than 6% per year. Agricultural production has rarely achieved such a rate and, given the early stage of development of many of these countries, certainly will not do so in the near future.

More symptomatic of the future are the 12 rapid growth Third World countries that are not major exporters of oil. Their average growth rate of per capita income was also 5.6 percent for the period 1970–1977. The average per capita income of these economies in 1977 was $800 per year. These countries include Brazil, Hong Kong, the Democratic People's Republic of Korea, the Republic of Korea, Malaysia, the Philippines, Singapore, Syria, Taiwan, Thailand, Tunisia, and Turkey. Taken together they had a 1977 population of 349 million people and an average population increase of 2.4 percent a year in the 1970–1977 period. The demand for food rose by well over 5 percent a year.

If these income growth rates continue, as is likely for at least the group aggregate, it will be difficult for food production growth to keep pace. Given the dynamic nature of these countries, it is possible that some will achieve these extraordinary growth rates in agricultural production. On the other hand, the historical record shows that developing countries experiencing rapid agricultural growth tend to increase their food imports (Bachman and Paulino, 1979). This is because rapid growth in agriculture is normally associated with and even causal of even more rapid growth in other sectors. That accelerated overall growth drives up demand for food even more rapidly than production.

Thus an aggregate population of more than 700 million people in Third World countries will be experiencing growth in demand for food at rates rarely matched in the past by growth in food production. The resultant pressure to import is clearly presaged by the doubling of net food imports, in real terms, by the developing countries from 1970 to 1977.

In the 1960s, very few developing countries were achieving the growth rates which move demand for food so far ahead of capacity to increase production. Taiwan did so, commencing in the late 1950s, and despite being a major success story in agricultural production quickly moved from being a major food exporter to a very substantial importer. Similar development occurred in South Korea. But it is only in the present decade that we can see these forces occurring in enough countries to have a major aggregate impact on the global food scene.

When India, with a population of over 700 million people, makes its imminent move to accelerated economic growth, the effect on global aggregates will be large. India has developed the institutional basis to sustain a 3.5 percent growth rate in foodgrain production and overall growth rates in gross national product of 5 to 6 percent. Failure to provide adequate expansion of key support sectors, such as power and transport, accounts for the peculiar phenomenon of industrial growth rates that are only slightly higher than those of agricultural growth. For countries at India's stage of development it is normal for industrial growth rates to be some three times higher than agricultural growth rates.

India's success in agriculture and unusually low growth in demand for food resulted by the end of the 1970s in a shift from being an annual importer of 4–6 million metric tons of foodgrains to being a slight exporter – a trade shift at present grain prices of about $1 billion. However, India has moved from being a net exporter of vegetable oil to a $1 billion-a-year importer. So even this story of relative success in agriculture has served more to shift the composition of agricultural imports than to eliminate

them. A significant acceleration in overall growth rates, in employment and hence in food consumption would be difficult to meet with domestic food production alone.

The manner in which income forces work to cause food demand to burgeon in early stages of economic development is illustrated in Table 1.1. In early stages of economic growth people are very poor, desperately wish to consume more food, but can't because their incomes are rising little if at all. Poverty causes high death rates and hence only modest rates of population growth. The result is 3 percent or less growth rates in effective demand for food – a rate that the enlarged labor force derived from population growth may roughly provide by more effort on existing and added farmed area.

Table 1.1. Comparison of growth of demand for agricultural commodities, at different stages of development, hypothetical cases[a]

Levels of development	Percent of population in agriculture	Rate of population growth	Rate of per capita income growth	Income elasticity of demand	Rate of growth of demand
Very low income	70	2.5	0.5	1.0	3.0
Low income	60	3.0	1.0	0.9	3.9
Medium income	50	3.0	3.0	0.7	5.1
High income	35	2.0	4.0	0.5	4.0
Very high income	10	1.0	3.0	0.1	1.3

a/ Adapted from John W. Mellor, 1966.

As development occurs, the population growth rate increases. But, even more important, income begins to grow more rapidly and the two together increase the growth rate of demand by some 30 percent and exceed all but the most rapid known rates of food production growth. To achieve production growth rates as high as 4 percent in general requires both large unexploited land areas and major improvements in technology.

Further development efforts further accelerate income growth. Even though the percentage effect of income increases on food consumption diminishes, it is still high in this medium income context and the growth rate of demand for food surpasses all but the most extraordinary of past experiences with food production growth rates. It is this stage that so many people in the world are now entering. Later, of course, population growth rates decline and growth in income begins to have little effect on food consumption. Meeting demand growth becomes much more manageable. Indeed, food production growth may by then be institutionalized at the high levels needed to meet past demand growth rates and surpluses may accrue.

The problem for world agriculture in the 1950s and 1960s was large populations in the very high income phase, generating surpluses, and a huge population in the very low income phase, with effective demand modest, despite the poor nutritional status of people in those countries. The food problem for the world in the 1980s and 1990s is that such vast populations are likely to move into the high growth, medium income

stage as to sorely tax the export capabilities of the more mature economies. During this period of rapid growth in demand for food, the problems of instability will be particularly onerous.

Thus the closing of the 20th century will see a period of great pressure for developing countries to increase food production so as to accelerate their overall development and to minimize their need for imports of food and for the developed countries to increase food production to meet the increase in import needs of the developing countries inevitable in their transition phase.

Population Growth

Although income growth will be the major cause of rising food demand in the next decade, population growth will play an indirect role in enforcing transfer payments and in interacting with other growth processes. It will also enlarge the number of people in absolute poverty and deficient in food.

It is not an accident that food production growth in low income countries usually keeps pace with population growth. In such countries population growth enlarges the rural labor force and hence the capacity to produce food. If mounting pressure on land resources reduces labor productivity, per capita income declines, and per capita food consumption decreases by roughly the same amount. These effects may be reduced by working longer hours or by cutting back on production and consumption of nonfood goods and services.

Population growth may push more rural youth into urban areas, bringing about increased unemployment and depression of wage rates. The resulting national political pressures may then cause governments to provide transfer payments to lower income people through food subsidy and distribution programs. Foreign assistance programs, motivated by concerns for equity or stability, may help to relieve the foreign exchange burden of consequent food imports. These programs, interacting with rapid population growth, may be important sources of growth in demand for food in the next decade in low income countries still not experiencing rapid growth in productivity and income. This effect will be noted later in the form of rapidly growing food imports in low-income slow-growth countries.

When an economy undergoes transformation, with capital formation and technological change occurring rapidly in the nonagricultural sector, rapid population growth fuels that process. Consequently difficult-to-match growth in the demand for food takes place. Unless rapid technological change in agriculture accompanies it, the growth momentum will be difficult to sustain. If technological advances occur, the extent of pressure on food prices to rise is then the product of complex relations between the rate and nature of technological change in agriculture and the rate of growth in nonagricultural employment and income. Rapid application of modern high-yield agricultural technology will in itself restrain the rise in agricultural prices; large capital transfers, including higher oil revenues, will have the opposite effect.

There should, of course, be no misunderstanding about the deleterious economic

effects of rapid population growth simply because the effective demand for food keeps roughly in pace with supply or eventually encourages faster overall economic growth. Rapid population growth tends to decrease labor productivity in agriculture, reduce the pace of transformation of the economy from agricultural to nonagricultural, and hence discourage growth in per capita income, in food intake, and in nutritional status. Its burden falls on the poor, whose income is derived solely from labor.

THE GLOBAL FOOD PRODUCTION

World production of major food crops during 1976–80 averaged 1,609 million metric tons a year, of which 53% was accounted for by the developed economies * (Table 1.2). Third World countries, which represent more than three billion people or about three-fourths of the world's population, produce less than half of its output of these commodities. The 1976–80 estimates also reveal that the per capita food production in the developing countries is only a third of the per capita food production in the developed economies.

Table 1.2. World population and food production, 1976–1980 averages [a]

Country Group[b]	Population (millions)	Major Food Crop Production Total (million metric tons)	Per Capita (kilograms)
World	4,258	1,609	380
Developed economies	1,147	851	740
Developing economies	3,111	758	240

a Sources: *FAO Production Yearbook, 1980* and *World Population Trends and Prospects by Country, 1950–2000.*
b Following FAO's economic classification.

Table 1.3 shows the distribution of population and food production among country groups in the Third World. With Asia containing China and India, the two most populous countries that are also the largest producers of major food crops in the developing countries, the region accounted for about seven-tenths each of population and food production in the Third World in 1977. Population and food production had the same proportionate shares of 8 percent and 10 percent in both North Africa/Middle East and Sub-Saharan Africa respectively. Of the developing regions, only Latin America had a relative share in Third World food production that exceeded that of population.

If the developing countries are grouped according to their average yearly rate of

*/ Major food crops here include cereals, roots and tubers, pulses, groundnuts, plantains, and bananas. For purposes of aggregation, rice is expressed in milled form and the noncereals are converted to cereal equivalents based on their calorie content relative to wheat.

growth in GNP/capita during the 1966–1977 period, 30 "very slow growth" economies (with less than 1% growth rate) would represent about 10 percent of both population and food production in the Third World during 1977.* A third each of the population and food output in the developing countries would be in the 36 "slow growth" economies (between 1% and 3% growth rate). About 45 percent of Third World food production in that year was accounted for by 21 "medium growth" economies (between 3% and 5% growth rate) which contain two-fifths of the population in the developing world. Eighteen "rapid growth" economies (with rates of 5% and above)

Table 1.3. Population and major food crop production in the developing countries, 1977 estimates and 1961–1977 average annual growth rates [a]

Country Group	Population			Major Food Crop Production[b]		
	1977 Estimate (millions)	(percent)	1961–77 Average Growth Rate (percent)	1977 Estimate (million tons)	(percent)	1961–77 Average Growth Rate (percent)
Total	3,069	100	2.5	726.2	100	*d*
(Excluding China	(2,092)	(-)	(2.6)	(483.0)	(-)	(2.7)
By Region						
Asia	2,184	71	2.4	495.2	68	*d*
(Exluding China)	(1,207)	(-)	(2.5)	(252.1)	(-)	(2.8)
North Africa & Middle East	240	8	2.6	59.8	8	2.6
Sub-Saharan Africa	311	10	2.7	67.7	10	1.6
Latin America	334	11	2.7	103.4	14	3.2
By GNP/capita growth rate[c]						
Less than 1.0%	338	11	2.5	63.4	9	1.3
1.0%–2.9%	1,019	33	2.5	236.5	32	2.9
3.0%–4.9%	1,256	41	2.4	317.1	44	*d/*
(Excluding China)	(279)	(-)	(2.8)	(73.2)	(-)	(3.0)
5.0% and over	456	15	2.7	109.9	15	2.8

a For the 105 countries covered by IFPRI's food gap analysis.
b Includes cereals, roots and tubers, pulses, groundnuts and bananas and plantains; rice is in terms of milled form and the data for the noncereal components have been converted into cereal equivalents.
c During the 1966–77 period.
d The inclusion of China, where major disruptions occurred in the early 1960s, would show exaggerated growth rates.
Sources of basic data: *World Population Trends and Prospects by Country, 1950–2000, World Bank Atlas, 1979* and "FAO Production Yearbook Tape, 1978." The data on China are from the set of statistics assembled by Bruce Stone of IFPRI.

* See Appendix A for developing country groupings.

would represent about 15 percent each of population and major food crop production. The relative contributions of both the very slow – and the slow-growing economies to the 1977 food production in the developing countries were less than proportionate to their population shares while the relative share of food output by the medium – growth countries significantly exceeded their population share.

The growth rate of food output in Third World economies (excluding China) during 1961–77 of 2.7 percent was slightly faster than their population growth rate.* Among geographical regions, output increases in Asia and Latin America were faster than population growth by 0.3% and 0.5%, respectively. The production of major food crops in North Africa/Middle East during the period just kept pace with population but in Sub-Saharan Africa the rate of output increase was very slow and lagged behind the region's population growth by more than one percentage point.

Data for the developing countries grouped on the basis of income growth show increases in population nearly twice as fast as the growth of food production in the very slow-growing countries. Except in two of these countries (Kuwait and Libya) which are oil producing and where population growth has been exceedingly high due to labor migration, agriculture is the dominant sector and thus the main source of economic growth. The growth of food output outpaced population increases in the three other country categories, especially in the slow-growth and medium-growth economies. Growth of food production exceeded population growth by nearly half a percent in the slow-growth countries but just barely in the rapid-growth countries.

TRENDS IN FOOD TRADE, DEMAND AND PRODUCTION

The dynamic forces of economic development are gathering momentum in the Third World. Their force, complexity and variety is reflected by the food trends for the past decade. The following analysis of those trends makes use of data for the years 1961 to 1977, a period long enough to iron out the bulk of weather and other short term changes. The major exception to this generalization is the People's Republic of China (PRC) for which the 1961–1977 period is strongly biased by the several years of major disruption of agriculture occasioned by the Great Leap Forward period and the slow recovery from those disruptions. Inclusion in the analysis of data for the PRC, which accounts for a substantial share of food production and consumption in developing countries, would tend to distort the food trends for Asia and the Third World as a whole. Thus China has been excluded in these general discussions.

(In general, China's food production growth rate has increased slightly faster than population. Imports held relatively steady until the mid-1970s when they grew from roughly 5 million metric tons annually to over 15 million metric tons in the early 1980s. Trends in consumption of food in China's centrally planned economy have also changed more sharply from one period to another than in market economies. For example, per capita consumption held relatively constant for much of the period

* For reasons given in the next section, the discussion of trends and projections exclude China.

from the mid-1950s to the 1970s and then with a policy change increased significantly in conjunction with rapidly rising imports of the late 1970s.)

Trends in food trade

Trade data reflecting the difference between domestic production and consumption show dramatically the increasing dependence of developing countries on food imports.

Net imports of major food staples by the developing countries rose from a yearly average of 5.3 million metric tons in 1961–65 to 23.0 million metric tons in 1973–77 (Table 1.4). The annual growth rate of aggregate exports during the period was slightly over 2 percent while that of aggregate imports was nearly 5½ percent, resulting in increasing net imports of about 13 percent a year. It is striking that in each major geographic area and income growth rate class imports grew more rapidly than exports.

North Africa/Middle East and Sub-Saharan Africa both recorded declines in food exports and more than a doubling of food imports during the period. Net imports of North Africa/Middle East expanded by more than 9 percent a year which increased its share of the total food imports of developing countries from 18 percent in 1961–65 to 23 percent in 1973–77. Sub-Saharan Africa's shift in food trade position resulted from its 4.6 percent yearly rate of decline in food exports combined with a 7.1 percent yearly growth rate of food imports. Although similar in magnitudes, the two areas are very dissimilar in the causes of this rapid growth in imports. In the case of North Africa/Middle East it is due to rapid increase in incomes from oil and oil-related sources. In the case of Africa (except for Nigeria which also benefits from oil prices increase) it is a product of an exceptionally poor production record, and large foreign assistance flows to help pay for food imports.

Asia's net imports expanded from 6 million metric tons to 11 million metric tons, or a yearly growth in net imports of 4.7%. Although Asia is the second major food exporter among the developing regions, its total imports of these commodities represented more than 40% of Third World food imports during the 1973–77 period.

Between 1961–65 and 1973–77, food imports of Latin America more than doubled while its food exports increased by only 50%. Imports of major food staples in the later period reached about 90% of the level of the region's exports of these commodities. Latin America's relatively much faster growth of food imports than of food exports led to the decline of its net exports at the fast rate of 8 percent a year.

Among the income growth categories of developing countries, the very slow-growth economies had the most rapid growth of food imports and the only country group with declining food exports from 1961–65 to 1973–77. Food exports decreased at the rate of more than 5 percent a year and food imports rose by nearly 8 percent a year; as a result net food imports of these countries expanded fivefold during the period. In 1973–77, their imports of major food staples accounted for about one-sixth of total food imports in the Third World. This very slow-growth group imports heavily because of a large inflow of foreign aid, e.g., for Bangladesh and Sub-Saharan Africa.

Table 1.4. Annual exports, imports and net trade of major food crops in the developing countries, 1961/65 and 1973/77 averages [a]

Country Group	Exports			Imports			Net Trade[b]		Annual Growth Rate,[c] 1961/65 – 1973/77	
	1961/65 (million	1973/77 tons)	Change (percent)	1961/65 (million	1973/77 tons)	Change (percent)	1961/65 (million	1973/77 tons)	Exports (percent)	Imports
Total	21.9	28.3	+29	27.2	51.3	+88	−5.3	−23.0	2.1	5.4
By region										
Asia	7.6	10.2	+34	13.9	21.2	+52	−6.3	−10.9	2.5	3.5
North Africa/Middle East	1.4	1.1	−21	5.0	11.6	+133	−3.6	−10.6	−2.0	7.3
Sub-Saharan Africa	2.9	1.7	−43	2.0	4.5	+127	+0.9	−2.9	−4.6	7.1
Latin America	10.0	15.3	+53	6.3	13.9	+122	+3.7	+1.4	3.6	6.9
By GNP/capita growth rate [d]										
Less than 1.0%	2.2	1.2	−47	3.8	9.2	+143	−1.6	−8.0	−5.1	7.7
1.0% – 2.9%	13.2	16.4	+24	10.4	15.3	+47	+2.8	+1.1	1.8	3.3
3.0% – 4.9%	4.1	7.2	+76	5.8	11.2	+93	−1.7	−4.0	4.8	5.6
5.0% and over	2.5	3.5	+41	7.2	15.6	+116	−4.7	−12.1	2.9	6.6

a Trade data include bran and cakes for feed use; to minimize double counting, partial adjustments were made for wheat flour based on available figures for this commodity as reported in the 1978 FAO Trade Yearbook. Parts may not add up to totals due to rounding.
b Exports minus imports.
c Calculated between the mid-years of the indicated periods.
d During the period 1966–77.

Source of basic data: "FAO Global Programming System Supply Utilization Accounts Tape."

The slow-growth economies, which accounted for over half of the aggregate exports of major food staples by the developing countries, were the only net food exporters of the four income growth groups during both 1961–65 and 1973–77. However, their favourable food trade position had been declining with the faster growth of food imports (3.3 percent a year) relative to the growth of food exports (1.8 percent a year). Net exports of major staples by these countries decreased from nearly 3 million metric tons in the earlier period to just over a million metric tons in 1973–77.

For the medium-growth countries, net imports of major food staples amounting to about 2 million metric tons in 1961–65 increased to 4 million metric tons in 1973–77 as their food imports expanded almost a percentage point faster than the 4.8-percent annual growth of food exports. The rapid-growth developing ecomonies accounted for about one-fourth of Third World food imports in 1961–65 and about 30 percent in 1973–77. Between these periods, growth in imports of major food staples by this group was more than twice as fast as exports, and net food imports rose from less than 5 million metric tons in 1961–65 to more than 12 million metric tons in 1973–77. These are of course rapidly growing countries with ample capacity to pay for rapidly increasing food imports.

Thus we see a pattern of very slow-growth countries increasing net imports rapidly on the basis of foreign aid and of medium and very fast-growth countries increasing rapidly on the basis of commercial capability. Only the slow-growth countries have net exports and slow growth in imports.

Trends in food consumption*

Total consumption of major food crops in Third World countries expanded at an average yearly rate of 2.9 percent between the early 1960s and the mid-1970s (Table 1.5). The rapid growth in the use of these commodities for animal feed (4.1 percent a year) increased the proportion of feed use in their total domestic utilization from 15 percent in 1961–65 to 17 percent in 1973–77. Direct use for food, which forms the bulk (about 70 percent) of the total consumption of major food crops in developing countries, grew at a slower annual rate of 2.7 percent and its share absorbed the corresponding decline of two percentage points arising from expanded feed use, as the proportion accounted for by other uses remained unchanged at 14 percent. Growth in the use for direct human consumption was a little faster than the growth of population and would suggest that average per capita intake of basic food staples in Third World countries improved during the period.

The 2.5-percent annual growth of total consumption of major food crops in Asia between 1961–65 and 1973–77 was about as fast as population growth. This rate of increase essentially reflected the growth in the use of these commodities directly for human consumption, which represents nearly 80 percent of total consumption in the region. Although Asia's 3.0-percent yearly growth in the use of major food crops for animal feed was faster than the increase in food use, the relative share of feed use in total domestic utilization of 10 percent in 1961–65 remained about the same until 1973–77.

* Consumption here refers to domestic utilization and includes food, feed, seeds, allowances for waste, and nonfood uses. For this analysis, the data on feed include rice bran.

Table 1.5. Trends in the consumption of major food crops in the developing countries, 1961–/65 to 1973–/77 [a]
(percent)

Country Group	Relative Distribution Among Uses						Average Annual Growth Rate of Domestic Utilization, 1961–65 to 1973–7 [b]			
	1961–65			1973–77						
	Food	Feed [c]	Others [d]	Food	Feed [c]	Others [d]	Total	Food	Feed [c]	Others [d]
Total	71	15	14	69	17	14	2.9	2.7	4.1	2.4
By region										
Asia	78	10	12	78	10	12	2.5	2.5	3.0	2.3
North Africa/Middle East	60	23	17	59	24	17	3.5	3.3	3.8	3.5
Sub-Saharan Africa	75	5	20	76	6	18	2.4	2.5	3.1	1.5
Latin America	55	31	15	49	38	13	3.6	2.8	5.4	2.6
By GNP/Capita Growth Rate [e]										
Less than 1.0%	77	10	13	77	11	12	2.3	2.3	3.2	1.8
1.0% – 2.9%	75	12	13	72	15	13	2.6	2.3	4.4	2.6
3.0% – 4.9%	60	23	17	60	23	17	3.3	3.3	3.6	3.2
5.0% and over	64	19	17	65	21	14	3.3	3.3	4.5	1.8

a Consumption here refers to total domestic utilization.
b Calculated based on the central years of the indicated periods.
c Including bran and cakes.
d Include seeds, allowances for waste, and amounts for nonfood uses.
e During the 1966–77 period.

Source of basic data: "FAO Global Agriculture Programming System Supply Utilization Accounts Tape."

The slowest growth of total consumption from the early 1960s to the mid-1970s occurred in Sub-Saharan Africa where it expanded by only 2.4 percent a year which was well below population growth. Population increase also outpaced the growth in the use of major food crops directly for food, suggesting a decline of average per capita food intake in the region. Although the use of these commodities for animal feed in Sub-Saharan Africa is still low and represents only about 5 percent of total domestic utilization, its fairly rapid growth of more than 3 percent a year increased the relative share of feed use by one percentage point between 1961–65 and 1973–77.

Average yearly increases in the use of major food crops for animal feed in the developing countries were particularly rapid in Latin America (5.4 percent) and North Africa/Middle East (3.8 percent). Food consumption patterns in these regions, where per capita incomes are rising fast, have been shifting to more livestock products. Because of very rapid growth in the use of major food crops for feed in Latin America, the region achieved the fastest growth (3.6 percent) in the total consumption of these commodities. Of the four developing regions, it has the largest relative share of feed use and the smallest share of food use in total domestic utilization. Between 1961–65 and 1973–77, the share of feed use in Latin America increased from about 30 percent to nearly 40 percent while the share of direct food use declined from 54 percent to less than half of total consumption. The fast growth in the use of major food crops for animal feed substantially increased food demand in the region. As reflected by trade data, this expanded demand has led to the declining role of Latin America as a net exporter of food.

In North Africa/Middle East, growth in the total consumption of major food crops reached 3.5 percent a year. Rapid increase in the use of major food crops for feed, which represents more than one-fifth of the region's food crop consumption, raised its relative share by one percentage point from 1961–65 to 1973–77. The region's 3.3-percent annual growth in the use of these commodities directly for food was much faster than population growth and is indicative of a substantial improvement of average per capita food intake between the early 1960s and the mid-1970s.

Among income growth categories, the very slow-growth economies in the Third World have the highest percentage share of food use and the lowest percentage share of feed use in the domestic utilization of major food crops. More than three-fourths of the domestic use of these commodities was for direct food use which mainly sets the pace of total consumption in these countries. Both food use and total consumption expanded at 2.3 percent a year from 1961–65 to 1973–77 and had lagged behind population increase. Annual growth in the use of major food crops for animal feed was fairly rapid (3.2 percent) but its share of domestic utilization increased only slightly because of the relatively low levels of feed use in these countries. In the slow-growth economies a more rapid growth in feed utilization (4.4 percent a year) led to a significant increase in the relative share of feed use from 12 percent in 1961–65 to 15 percent in 1973–77. With the share of other domestic uses remaining constant, food use, which accounted for more than 70 percent of total consumption, absorbed a corresponding decline of 3 percentage points during the period. Like in the very slow-growing economies, however, population growth of this group of countries was faster than the rate of increase in the use of major food crops for direct human consumption.

The rapid-growth economies showed the fastest growth (4.5 percent) in the utilization of major food crops for animal feed. Total consumption and direct food use both expanded at 3.3 percent a year in these countries. While the share of food use in total consumption of these commodities stayed almost unchanged from 1961–65 to 1973–77, that of feed utilization increased by 2 percentage points. In the medium-growth group, all three components of domestic utilization expanded by more than 3 percent a year between the early 1960s and the mid-1970s and their relative shares in total consumption remained about the same.

Trends in food crop production, area and yields*

Third World countries achieved an average yearly growth rate of 2.6 percent in the production of major food crops between the early 1960s and the mid-1970s (Table 1.6). The most rapid increase in food output was in Latin America at 3.2 percent, followed by Asia with about 2.8 percent, and then North Africa/Middle East with 2.5 percent. Sub-Saharan Africa's slow growth of only 1.5 percent clearly shows its very poor performance in food production during the period compared to the other three developing regions.

Table 1.6. Average annual growth rates of production, area harvested, and output per hectare of major food crops in the developing countries, 1961–77 [a]

	Average & Annual Growth Rate, 1961–77			Relative Contribution to Production Growth	
Country Group	Production	Area Harvested	Output per Hectare	Area Harvested	Output per Hectare
		(percent)			(percent)
Total	2.6	1.0	1.6	38	62
By region					
Asia	2.8	0.7	2.1	24	76
North Africa and Middle East	2.5	1.1	1.4	44	56
Sub-Saharan Africa	1.5	1.3	0.2	85	15
Latin America	3.2	1.8	1.4	56	44
By GNP/Capita Growth Rate [b]					
Less than 1.0%	1.3	0.6	0.7	49	51
1.0%–2.9%	2.9	0.8	2.1	28	72
3.0–4.9%	3.0	1.0	2.1	32	68
5.0% and over	2.7	1.9	0.8	70	30

a Excluding bananas and plantains.
b During the 1966–77 period.

Source of basic data: "FAO Production Yearbook Tapes, 1975 and 1978."

* The output growth rates presented here may differ slightly from those cited earlier as production data exclude bananas and plantains for which estimates of harvest area are not available.

Improvement in crop yields was the major contributor to the growth of food production in Third World countries in 1961–77. Output per hectare of the major food crops increased at 1.6 percent a year and accounted for about 60 percent of output growth while the expansion in harvest area averaged 1.0 percent a year and contributed the other 40 percent. The faster growth of output per hectare planted to these crops reflects the impact of the technological gains achieved in food production by the developing countries starting in the second half of the 1960s, particularly in wheat and rice. The dominant role of output per hectare in increased food output was most pronounced in Asia where its growth exceeded 2 percent a year and accounted for more than three-fourths of the increase in food production. Expansion of harvest area of major food crops in that region averaged less than one percent a year during the period. Like Asia, but to a lesser degree, the North Africa/Middle East region showed the bigger role of crop yields (56 percent) than of harvest area (44 percent) in the growth of food output.

Area expansion, on the other hand, was largely responsible for the production gains achieved in Latin America and Sub-Saharan Africa. In Latin America, the harvest area of major food crops increased by 1.8 percent a year and contributed more than half of the production growth of these commodities in the region. Although expanding at the moderate rate of 1.3 percent each year, harvest area in Sub-Saharan Africa accounted for 85 percent of food output growth due to almost stagnant crop yields. The very slow growth of output per hectare in that region was partly because a relatively large portion of food production is composed of noncereals for which significant technological advances have yet to be achieved. Except in a few countries, the levels of output per hectare of both cereals and noncereals in Sub-Saharan Africa had remained about unchanged or even declined during the past two decades (Paulino, 1983).

The low rates of increase in both harvest area and output per hectare of major food crops in the very slow-growth economies contributed about equal shares to the small production gain made by this country group during 1961–77. This was largely a reflection of the situation of the countries in Sub-Saharan Africa. For the slow-growth economies, more than 70 percent of food production increases could be attributed to output per hectare which rose at an average yearly rate of over 2 percent during the period. Crop yields also improved significantly in the medium-growth countries where output per hectare increased similarly by more than 2 percent a year and accounted for more than two-thirds of food output growth; the rest of production increases in this country group came from a one percent annual expansion in area. The rapid-growth economies had relied more on area expansion in increasing their output, with the harvest area of major food crops in this group rising by 1.9 percent a year and contributing 70 percent of production growth.

A comparison of output trends between decades shows that the average annual growth rate of food crop production in Third World countries slowed by 0.2 percent from the 1960s to the 1970s as a considerable decline in the growth of crop area more than offset the gains achieved by the improvement in crop yields (Table 1.7). Area expansion accounted for more than half of the 2.6 percent annual growth of food production in 1961–69 but increases in output per hectare contributed more than 60 per-

cent of production growth during 1970–77. Among the developing regions, growth in food output between these two periods accelerated in Asia and North Africa/Middle East but significantly declined in Sub-Saharan Africa and Latin America.

Table 1.7. Average annual growth rates of production, area harvested, and output per hectare among developing regions during 1961–69 and 1970–77 [a]

Country Group	Period	Average Annual Growth Rate			Relative Contribution to Production Growth	
Group		Production	Area Harvested	Output per Hectare	Area Harvested	Output per Hectare
			(percent)		(percent)	
Total	1961–69	2.6	1.4	1.2	53	47
	1970–77	2.4	0.9	1.5	37	63
By region						
Asia	1961–69	2.2	0.8	1.3	38	62
	1970–77	2.7	0.8	1.8	31	69
North Africa/ Middle East	1961–69	2.9	1.1	1.9	36	64
	1970–77	3.4	1.3	2.1	37	63
Sub-Saharan Africa	1961–69	2.0	2.2	−0.1	104	−4
	1970–77	1.3	0.6	0.7	48	52
Latin America	1961–69	4.1	3.0	1.1	74	26
	1970–77	2.1	1.2	0.9	56	44
By GNP/capita growth rate [b]						
Less than 1.0%						
	1961–69	1.9	1.3	0.6	68	32
	1970–77	1.7	0.4	1.3	24	76
1.0% - 2.9%	1961–69	2.5	1.0	1.4	42	58
	1970–71	2.3	0.7	1.6	31	69
3.0% – 4.9%	1961–69	3.3	0.9	2.3	29	71
	1970–77	3.3	1.7	1.6	52	48
5.0% and over	1961–69	3.1	2.9	0.2	93	7
	1970–77	2.6	1.2	1.4	47	53

a Excluding bananas and plantains.
b During the 1966–77 period.

Source of data: "FAO Production Yearbook Tapes, 1975 and 1978."

Increases in output per hectare were the major source of production growth in Asia in both the 1960s and the 1970s, indicative of the gains from the seed-fertilizer technology in the region during the second half of the earlier period. With a constant rate of increase in area expansion, growth of food output in Asia rose by half a percent from 1961–69 to 1970–77. During both periods, the growth of output per hectare among the regions was most rapid in North Africa/Middle East and hence, like in Asia, was consistently the major contributor to food production growth. Nearly pro-

portionate increases in the growth rates of harvest area and crop yields kept their relative contributions to production growth in North Africa/Middle East almost unchanged from the 1960s to the 1970s.

The rapid growth of food production in Latin America during 1961-69 was due mainly to the 3 percent annual growth of harvest area under food crops, which contributed nearly three-fourths of production growth in the region. However, the sharp decline in the rate of expansion of harvest area in the 1970s, coupled with a slight decrease in the growth of crop yields, slowed food production growth in Latin America to about half the 1961-69 rate during the later period. Sub-Saharan Africa had the slowest growth in food output among the developing regions during both the 1960s and the 1970s. Area expansion was the sole source of production increase in this region during 1961-69 as a result of the decline in crop yields. Like in Latin America, the rate of area expansion in Sub-Saharan Africa decelerated considerably during 1970-77 and, despite a significant improvement in the growth of output per hectare, the annual rate of growth of food production declined sharply from 2.0 percent in the 1960s to only 1.3 percent in the 1970s.

When grouped by income growth, the four categories of Third World countries show declines in the production growth of major food crops between the 1960s and the 1970s, except the medium-growth group whose rate of increase in food output remained constant at a high 3.3 percent a year. Growth of food production in the very slow-growth countries was below 2 percent annually during both periods, with expansion in harvest area providing more than two-thirds of output growth in 1961-69 and improvements in crop yield accounting for about three-fourths of production increases in 1970-77. The reversal of roles in sustaining food production growth in these countries resulted from the drastic decline in area expansion and more than a doubling of the rate of growth in output per hectare from the 1960s to the 1970s. The slow-growth economies also relied on increases of crop yields in almost maintaining their 1961-69 growth rate of food output during the later period; accelerated growth of output per hectare in 1970-77 nearly offset the decline in the growth of harvest area under food crops in this country group. The contribution of increases in output per hectare to food production growth in the slow-growth countries rose from 58 percent in the 1960s to nearly 70 percent in the 1970s.

In marked contrast with the above trends shown by the other country groups, the rate of growth of food production of the medium-growth economies stayed about unchanged from the 1960s to the 1970s as a result of a significant decline in the growth of output per hectare that was balanced by increases in harvest area. The rate of area expansion nearly doubled from 1961-69 to 1970-77 while the growth rate of crop yields decreased by nearly a third. The growth contribution of harvest area to food production in these countries increased from about 30 percent during the 1960s to over 50 percent in the 1970s. The rapid-growth countries experienced a rapid deceleration in food output growth between these periods due to a major decline in the rate of growth of harvest area under food crops. Increases in food production of this group in the 1960s exceeded 3 percent a year, more than 90 percent of which came from the rapid rate of area expansion. However, annual growth of harvest area drastically declined from nearly 3 percent during 1961-1969 to only 1.2 percent in 1970-77; this

was partly offset by a significant acceleration of the growth of crop yields. More than half of the 2.6-percent growth rate of food output in the rapid-growth countries during the 1970s came from increases in output per hectare.

It should be emphasized that the poorer performance of Third World countries in food production during the more recent period was due to a decline in area expansion that could not be outweighed by increased yields per hectare. Since area expansion is not likely to accelerate in the future, it follows that the rates of increase in crop yield hold the key to the future record of food production in the developing countries and that depends on the pace and pattern of technology improvement.

FOOD PROJECTIONS TO THE YEAR 2000*

Production

If the 1961–77 output trends will continue in the future, the production of major food crops in Third World countries is projected to reach 940 million metric tons by the year 2000 (Table 1.8). This is nearly twice the estimated output of these basic food staples during 1977. More than half of the projected production would come from Asia and about one-fourth from Latin America; the remaining 25 percent would be about equally shared by North Africa/Middle East and Sub-Saharan Africa. Slight changes are projected in the shares of total food output that these developing regions had during 1977. A 2½ percent increase in relative contribution would be made by Latin America where food production has been growing rapidly while a 2 percent decline is projected for Sub-Saharan Africa where food output performance has been poor. Asia's contribution to the projected food output would be one percent less than in 1977. The relative share of the North African/Middle East region may slightly increase.

The very slow-growth developing countries would account for about one-tenth of the projected Third World production of major food crops, which share represents a significant decline of more than three percentage points from the relative contribution of the group in 1977. About half of the projected food output would be produced by the slow-growth countries while one-sixth would come from the medium-growth economies and nearly 25 percent from the rapid-growth countries; these three groups would have slight increases in relative shares compared to those in 1977.

Consumption

On the demand side, about 865 million metric tons of the basic food staples would be required by the expanded population of Third World countries if the 1977 average per capita consumption levels are held unchanged (i.e., assuming no income growth). However, an additional 155 million metric tons of these commodities will

* Also exclude those of China

Table 1.8. Estimates and projections of food production and consumption in developing countries, 1977 and 2000 [a]

(in million metric tons)

Country Group	1977 Estimates			Projections to 2000				
	Production	Consumption	Surplus/ Deficit	Production	Zero Income Growth Consumption	Surplus/ Deficit	Trend Income Growth [b] Consumption	Surplus/ Deficit
Total	483.0	501.7	−18.7	940	865	+75	1,020	−80
By region								
Asia	252.1	247.2	+4.9	480	410	+70	463	+18
North Africa/Middle East	59.8	78.5	−18.7	120	133	−14	177	−57
Sub-Saharan Africa	67.7	72.9	−5.1	113	135	−22	148	−36
Latin America	103.5	103.2	+0.2	227	186	+41	232	−5
By GNP/capita growth rate [c]								
Less than 1.0%	63.4	72.4	−9.0	92	128	−36	132	−39
1.0%–2.9%	236.5	221.1	+15.4	467	380	+87	418	+48
3.0%–4.9%	73.2	81.2	−8.0	158	137	+22	182	−24
5.0% and over	109.8	127.0	−17.2	223	221	+2	288	−65

a Excluding China.
b 1966–77 average annual growth rate of GNP/capita in each country with lower and upper limits set at 0.5 percent and 6.0 percent, respectively.
c During 1966 to 1977.

Note: Parts may not add up to totals due to rounding.

Sources of basic data: "FAO Production Yearbook Tapes, 1975 and 1978," "FAO Global Programming System Supply Utilization Accounts Tape," *World Population Trends and Prospects, 1950–2000*, and "Gross National Product, 1960–78 Times Series Data by Country."

be needed to meet the increased food demand of the developing economies due to income growth, assuming that the 1966–77 trends of per capita incomes in these countries will continue.* Of course, one may expect a larger increment of the income-induced food demand in the Third World if future growth in incomes would accelerate and a smaller increment if income growth would be slower than these trends.

Projected food demand for Asia at trend income growth is 463 million metric tons, nearly 90 percent of which would be required by the increased population from 1977 to 2000 with no growth in per capita incomes. North Africa/Middle East would need 133 million metric tons of the basic food staples in 2000 for population growth alone and about 44 million metric tons more for increases in food demand based on the region's rapid income-growth trends. Sub-Saharan Africa has a projected food requirement for population growth that about equals that of North Africa/Middle East, but would need only 13 million metric tons more for income-induced demand. The consumption of major food crops in Latin America is projected to reach 232 million metric tons of which about one-fifth or 46 million metric tons represents the increased consumption due to income growth.

The very slow-growth economies would account for 13 percent of the projected Third World demand for basic food staples at trend income growth. With their low rate of growth in incomes, only about 4 million metric tons will represent the added demand for food due to increases in income; about 97 percent of consumption requirements of the group will be needed for population growth. More than 40 percent of total food demand in 2000 will come from the slow-growth developing countries, about 9 percent of which would be needed for the increased requirements due to income growth. The medium-growth group of Third World countries would require 137 million tons of basic food staples for expanded population and an additional 45 million metric tons, or one-fourth of their food needs, for income-induced demand. Projected requirements of basic food staples for the rapid-growth economies would represent nearly 30 percent of the total for developing countries and, like in the medium-growth group, about 25 percent of projected food demand would result from increases in per capita incomes.

Food Gaps**

If the 1977 per capita income levels in developing countries are held unchanged, the projected production of basic food staples in the Third World in the year 2000 would exceed the projected demand for these commodities by about 75 million metric tons. But income-induced demand for food, assuming that the 1966–77 trends in the growth of per capita incomes will continue, would require more than twice this amount. Thus food output is projected to fall short of demand at trend income growth by about 80 million metric tons which is more than four times their estimated 1977 net deficit of basic food staples.***

Based on trend income growth, the projected food output in Asia would more than meet the projected food needs of its large population. Demand projections show that

* Trend income growth rates are based on the estimates of real GNP/capita in each country for the years 1966- 1977, with minimum and maximum levels set at 0.5 percent per year and 6.0 percent a year, respectively.

** These projections are in net terms and thus assume exportable food surpluses in a number of developing economies can be used to fill the deficits of food-short countries.

*** The projected net deficit of 80 million metric tons of basic food staples under the trend income growth assumption results from an aggregate shortfall of about 180 million metric tons and an aggregate surplus of about 100 million metric tons.

Asia would have a net surplus in basic food staples in 2000 of about 18 million metric tons which is more than three times the estimated surplus of this region ion 1977. Unlike Asia, however, the other developing regions are projected to face net deficits by the end of the century. North Africa/Middle East is projected to have a large food gap due largely to rapid growth in incomes; its net deficit of nearly 60 million metric tons in 2000 would be three times the 1977 level. The projected production of basic food staples in that region would fall short of projected demand by 14 million metric tons even if the average levels of per capita food consumption in 1977 are held constant.

With its very slow growth of food production, Sub-Saharan Africa is projected to face a shortfall of more than 20 million metric tons of basic food staples just to meet the requirements of increases in population. The projected net deficit at trend income growth of 36 million metric tons in Sub-Saharan Africa is seven times the 1977 food gap of the region. Despite the fast growth of food production in Latin America, the region's food situation is projected to shift from a slight surplus in 1977 to a deficit of 5 million metric tons by the year 2000 because of the faster expansion of food demand. As shown earlier, the use of basic food staples for animal feed has been the dynamic component of food consumption in this region. The projected food deficit for Latin America can be expected to increase if the region is unable to maintain its 3.2-percent annual production growth.

Food output and demand projections show that among the income-growth categories of Third World countries, the slow-growth economies would be the only food-surplus group by the year 2000. Projected production of basic food staples in these countries would exceed projected demand at trend income growth by nearly 50 million metric tons or three times their net food surplus in 1977. The very slow-growth economies represent the only group whose projected food output would fall short of projected food needs for population growth alone. Demand for basic food staples in 2000 based on 1977 average per capita consumption levels would exceed production by 36 million metric tons; this gap would widen to almost 40 million metric tons if per capita incomes expand on the basis of 1966–77 trends. Projections for the medium-growth countries indicate a net food surplus of 22 million tons if per capita income is held constant but a net food deficit of 25 million metric tons if demand would increase at trend income growth. The largest food gap in 2000 among the income-growth groups is indicated for the rapid-growth economies whose projected production of basic food staples is below projected demand at trend income growth by 65 million metric tons or nearly four times their net food deficit in 1977. Food output in these countries would slightly exceed the projected requirements for population growth.

It should be emphasized that the levels of food production and consumption for the year 2000 discussed above are projections based on a continuation of past trends in output and per capita incomes. These projections are likely to miss important dynamic elements. Firstly, developing economics may sharply accelerate their growth rates when their long period of foundation-laying begins to pay off. The pattern of economic development has been a succession of take-offs. One would expect the above projections to understate these changes. Projections also miss dynamic elements hidden in the aggregates. For consumption projections, in particular, the utili-

zation of basic food staples for animal feed in many developing countries has increased rapidly although still on a low base. As that base expands, the overall consumption growth rate will be further accelerated. Between these two interacting forces it seems likely that the projected food gap is on the conservative side.

PROSPECTS OF FILLING THE FOOD GAP

The potential food deficit of Third World countries, as reflected by the cited projections of their production and consumption of basic food staples, serves as an indicator of the general magnitude of the world food problem in the next two decades. As shown in the preceding section. its true measure would differ to the extent that the assumptions used in these projections deviate from reality. This food gap will ultimately close by some combination of acceleration of production growth in developing countries, food transfers from the developed economies, and reduced consumption. These means of filling the projected deficit will come about depending on the output and import capacities of particular Third World countries and on developments in the world's economic and political scene in the years ahead.

A significant share of the food deficit in developing countries may have to be filled by increases in domestic production. In countries with potentials for increased output, faster growth rates in food production would require the wider use of yield-increasing technology and/or the expansion of harvest area. Data suggest that possibilities for raising output per hectare exist in Sub-Saharan Africa where crop yields are still low and growth had been very slow. Additions to the area under food crops may be also possible in both Sub-Saharan Africa and Latin America where the land constraint is less than the other two regions and area expansion had been the principal contributor to past growth in production. Recent trends, however, indicate that a number of developing countries would have to increase both crop yields and harvest area in order to maintain their long-term growth rates of food output. Further public investments are required in irrigation and such support services as agricultural credit, extension and research, especially where these investments are needed to sustain the momentum of past rates of growth.

The magnitude of the potential food gap also points to increased reliance of Third World countries on food imports from the developed economies. How likely are the projected food gaps to be filled by trade? Although long-term projections of food production and consumption for the developed countries may show ample exportable surpluses to fill the deficit, availability of such supplies is uncertain. Production in the major food exporting countries is highly responsive to changes in their trade policies that are, in turn, dependent on shorter-term prospects in the world market. Mellor and Johnston suggest that food exports from the developed countries will meet developing country demand with at most modest increases in real food prices (Mellor and Johnston, 1984). Filling the food gap through trade also depends on the

course of national development in Third World countries and on international relations. Gaps generated through growth are likely to be met by commercial trade with the developed economies. For the slow-growth countries, the situation is more problematical depending substantially on foreign assistance flows.

Declines in Third World food consumption can result from depressed incomes due to price increases and/or growth deceleration. In the event of shortage in food supplies, the consequent rise in food prices would adversely affect consumption in many developing countries where food represents the bulk of expenditures. Food consumption may decrease also in a number of Third World countries which are unable to sustain their past rates of income increases. As shown early in the paper, many Third World countries have entered the development stage when food demand is increasing rapidly at rates difficult to match by growth in food output. Growth of per capita incomes in these countries from the 1960s to the 1970s, trends of which form the basis of consumption projections in the preceding section, had been the dynamic element in the growth of their food consumption during that period. However, the more recent developments in the world economy likely affected these trends. With the interrelationship of developing and developed countries, the recent deceleration of growth in industrial economies may be passed on to Third World countries. If the growth of developing countries is closely linked to the growth of developed countries and growth in the latter group slows, one can expect a slower growth in developing countries and, hence, in their imports of staple foods (Mellor and Johnston, 1984). Decreases in food consumption would disadvantage especially the low income countries where significant portions of the population face serious nutritional problems. Of course, a more optimistic view would see present day developing countries accelerating their growth and thereby stimulating the developed countries much as Europe in the late 1950s did to North America.

CONCLUSION

Five points are clear from the foregoing. First, developing country net food imports will increase substantially over the next few decades. Second, the imports will occur principally in the fast-growth countries under their rapidly growing capacity to finance commercial imports and in the lowest income countries, particularly in Africa, depending substantially on foreign aid. Third, even maintaining past growth rates in production will depend increasingly on yield increases. The burden of further acceleration in output growth rates will demand unprecedented rates of yield increase. Fourth, African countries face an immense problem and a lengthy process of turning around a very poor past performance in production. Fifth, the food situation will be more difficult over the next two decades than in the past two with consequent added privation to low income people not participating in income increases.

The extent to which malnutrition and hunger in the world is diminished in the next

two decades depends on the rate of production growth and its distribution. At past rates of growth there will undoubtedly be more malnourished people in the year 2000 than now, although the proportion will have declined. It seems probable, however, that if agricultural production growth rates can be stepped up to the levels achieved in the high growth developing countries, malnourishment can be largely removed by the year 2000. A study by Kumar calculates for Africa a close relation between aggregate food availability and malnutrition (Kumar, 1981). The analysis of fast growth agricultural countries shows that the average per capita supply of the country group in 1975 exceeded the FAO-WHO recommended level (Bachman and Paulino, 1979). Finally, the conceptual framework for a growth strategy based on agriculture confirms this relation (Mellor, 1976). The burden thus falls on the agricultural scientists to give us the correct technology and on the policymakers to provide the appropriate environment for both application of that technology and for its benefits to spread to the poor and undernourished.

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CHAPTER 2
Quantitative Dimensions of the Nutrition Problem

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INTRODUCTION

ABOUT HALF THE population of the developing countries cannot afford a diet that meets their minimum energy needs for a healthy active life. This is how the global dimensions of the nutrition problem were described in the 1960s and 1970s, and they remain much the same today, with little prospect of reduction in the course of the present level of development in the foreseeable future – before the year 2000 (FAO, 1952, 1963, 1977; Reutlinger and Sellowsky, 1976; Sukhatme, 1961).

It was believed in the 1960s that as GNP increased, gains in income would find their way to the poor and would result in increasing their levels of food consumption. However, this was too slow a process. Later, emphasis came to be placed on agriculture in the expectation that this would increase food supply and simultaneously lead to the increase in the purchasing capacity of the landless and the small farmer who formed the bulk of the poor and malnourished. While food supply increased, purchasing capacity of the poor remained inadequate. The persistent nature of malnutrition became all too apparent: poverty leading to low food intake, low food intake leading to reduced body weight and low level of activity, low level of activity leading to decreased productivity and decreased productivity leading to still greater poverty. Direct intervention programmes to ensure minimum nutrition for health were thought to be the answer. However, it is generally believed that even these have failed to make an impact. The explanation offered is that the nutrition supplement has served as replacement, partly or wholly, due to a corresponding decrease in dietary intake at home. This is understandable when a child is so poor that the diets of other members of the family are also inadequate. It is, therefore, argued that unless the programmes are extended to cover the entire family, it is unlikely that intervention programmes will succeed (Gopalan and Vijayaraghvan, 1971). But this requires larger funds than are available today, and if larger allocations are to be made for the intervention programmes, it may affect economic growth even more adversely than at present. This is the dilemma the developing countries face today.

However, the inference that nutrition supplements have primarily served as replacement can also mean that the incidence of malnutrition may not be as large as assessed or that people may be malnourished but with little or no consequence for their health and work performance. It can also mean that nutrition supplements were ineffective in the absence of adequate support of health and sanitary inputs, calling for an altogether different policy of intervention. The studies cited above are largely silent on these issues. Besides they give the impression that the world's nutrition problem principally arose from the poverty of the people in the developing countries. Actually, affluence is equally responsible for the world's nutrition ills, especially in the context of the global aspect of production. In general, not only have the studies not paid enough attention to the policy issues of the need for a correct statement of the problem in terms of magnitude, location, type, effect and socio-economic components but they have also not attempted to examine the validity of the methodology used in their assessment. The result is that the dimensions of the nutrition problem have got unduly exaggerated and the nature of the problem also misrepresented. This chapter reassesses the size and nature of the problem but in doing so particular attention will be paid to examining the scientific basis of the nutrition concepts used in the evaluation. We shall refer to both the developed and developing countries but we shall primarily concentrate on the latter. We shall first consider the problem in terms of macro availability of food in relation to requirements for health and then pass on to the micro approach of assessing the number of malnourished and the prospects for the year 2000.

FOOD AVAILABILITY COMPARED WITH REQUIREMENTS

Table 2.1 shows for the developed and developing countries and for the world as a whole the per caput availability of energy compared with requirements for healthy individuals engaged in moderate level of activity as assessed by FAO/WHO Expert Committee on Protein and Energy Requirements (1973). The world food supplies can provide everyone with an adequate diet but the supplies per caput are unequally distributed.

The energy available per caput in the developed countries is 25 to 33% above the requirements and in the developing countries 5 to 10% below the respective requirements. People in the developed countries evidently eat enough and more and those in the developing countries only what they can afford. To understand the table further we need to know the meaning of requirements. As is known, energy requirements are based on measurements of intake in healthy active subjects of the 'reference' type and are defined as average per caput for each age–sex–activity group. One would, therefore, expect that if a population is healthy and active, food availability per caput will be about equal to per caput requirement. That this is not so but that food availability is 25 to 30% above the requirements must mean that a proportion

Table 2.1. Per capita energy supply compared with requirements

	Energy (kcal)		Supply as % of requirement	
	1961–1963	1972–1974	1961–1963	1972–1974
Developed countries	3170	3380	124	132
Developing countries	2060	2210	89	96
World	2410	2540	101	107

of the population continues to overeat above the needs of health. By contrast, the problem in the developing countries with only about 5 to 10% deficit must be considered less acute. A proportion of their people will undoubtedly be undernourished with adverse consequences for their stature, health and work output but this proportion is likely to be much smaller than the proportion of overnutrition in the developed countries.

The point that requirements represent the average and not the minimum intake for health and prescribed level of activity needs to be emphasised here. Unfortunately, it is ignored in most studies. Thus, when Reutlinger and Sellowsky (1976) report that 44% of the population in Brazil cannot afford a diet which meets the average needs for health and are, therefore, malnourished they in effect use the average for the minimum. Dandekar and Rath (1972) commit the same error. If as these authors find that some 50% of the population live below the level of expenditure corresponding to respective energy requirements, it is more an indication that the population under study is for the most part healthy and active than undernourished. If 44% eating below the average requirements of 2435 Cal in Brazil are to be considered to suffer from energy deficit then it would imply that the remaining 56% of the population suffer from excess energy intake and are, therefore, exposed to the risk of obesity. Likewise, if 40% of the population of rural India, eating below the average requirement of 2250 Cal are to be considered as undernourished, then the remaining 60% eating above 2250 Cal in rural India must be considered to suffer from over-nutrition. If the dividing line between the undernourished and overnourished is the average requirement, then one cannot but conclude that the more serious problem for these developing countries is overnutrition, not undernutrition! One is bound to reach such absurd conclusion if one does not put correct interpretation on the meaning of requirement.

The difficulty in the case of developing countries stems from the fact that small as the difference is between levels of consumption and needs of health, their efforts rarely go beyond keeping barely ahead of the population growth. To put it differently they are not able to hold securely to the improved levels of consumption whenever these occur with the result that the poor and malnourished remain as they were over the years. Consequently, if widespread droughts should intervene to bring about

abrupt decreases in the accustomed levels of consumption, as often happens in some area or the other once every few years, they become an object of world wide sympathy. Combined with the unacceptable quality of life in the tribal areas where people are known to live on inadequate diet for generations, it is hardly surprising if the developed countries with their levels of consumption far above those in the developing ones come to believe that people in the developing countries live on the brink of starvation levels and do not have work capacity to improve their lot and levels of consumption.

Table 2.2 shows the per caput availability of total dietary protein and the part of it available as animal protein. Current standards for protein show that the per caput allowance (recommended intake) in the developed and developing countries is less than 40 gms in terms of total proteins. It will, therefore, be seen that the protein availability exceeds even the upper level for the needs very considerably both in the developed and developing countries. The excess availability is so large that it is most unlikely that more than a very small fraction of their population would be unable to meet their protein needs. This is not to say that protein malnutrition does not occur; it certainly does. But as is well known, it is for the most part the indirect result of inadequate energy in the diet.

An important point to note here is the contrasting situation in respect of the availability of proteins and its consumption in the developed and developing countries. As the table shows, the per caput availability of dietary protein is twice as high in the developed countries as in the developing countries and that most of this difference arises from the difference in the levels of consumption of animal protein. Strictly speaking, there are no requirements for animal protein as such. So long as the requirements for essential amino acids are met, it is immaterial whether the dietary protein came from vegetable or animal sources. The dietary protein from foodgrains and legumes is almost as good in quality as egg or milk protein. Consequently, almost any diet if it is based on varied sources of food and is eaten in sufficient quantity to meet the energy needs, will meet man's needs for protein.

Table 2.2. Per capita supply of total and animal protein

	Total protein (gms)		Animal protein (gms)	
	1961–1963	1972–1974	1961–1963	1972–1974
Developed countries	91	98	45	54
Developing countries	53	57	11	12
World	65	69	22	24

If then the developed countries consume large quantities of animal food and hence animal protein, it must be because it is difficult to resist the temptation of eating animal products when one can afford to do so. This disparity between the levels of consumption of animal protein in the developed and developing countries has obvious implications for the global aspects of food production. Animal products make a demand on land which is several times larger than plant products. This means that the developed countries constituting about a quarter of the total population of the world put pressure on world resources which is twice as large as that from three-fourths of the world's population from the developing countries. We can state the same thing by expressing consumption per caput either in terms of primary calories or food grain equivalents. Expressed in either term, it means that the per caput consumption in the developed countries relative to the need for health is 4 to 5 times as large compared to that in the developing countries. What is disconcerting is that the proportion of animal foods in the diet of the developed countries is increasing as can be seen from table 2.3, which shows the share of cereals as feed in the consumption of the developed and developing countries. It would be seen that the share has increased from 62% in 1961–63 to 72% in 1972–74. In absolute terms, it means that foodgrains fed to animals in the developed countries amount to almost as much as the total cereals consumed as food by the ¾th of the world's population in the developing countries. Advocates of doomsday professing concern for the world's poor and undernourished conveniently ignore this point when they blame the runaway population growth in the developing countries for the increasing pressure on world's resources.

Table 2.3. Use of cereals as food and feed

	Food (in million tons)		Feed (in million tons)		%share of food in consumption (food and feed	
	1961 – 1963	1972 – 1974	1961 – 1963	1972 – 1974	1961 – 1963	1972 – 1974
Developed countries	159.0	160.0	257.3	416.1	62	72
Developing	358.2	498.5	47.3	74.8	12	13

The position in respect of per capita availability of fats is not much different from that of proteins, with the developed countries consuming 3 to 4 times as large a quantity per caput as the developing countries. Requirements for fats have not yet been worked out; they are, however, believed to be small and more than adequately met from the diet as eaten both in the developed and developing countries.

The assessment in respect of food availability and requirements will be incomplete without a reference to micro-nutrients. Individuals are known to suffer from specific mineral and vitamin deficiencies even while eating enough to meet their needs for total energy and macro-nutrients. For this reason, it is a common practice in the developed countries to fortify bread and other foods with vitamins and minerals to

minimise the risk of specific nutrient deficiencies. It needs to be remembered, however, that conditions differ widely in the developed and developing countries. In the former, nearly 50% of the calories in the diet are almost empty calories from fats and sugar. The corresponding figure for the developing countries is in the order of 25%. Furthermore, in the developing countries, particularly in the rural areas, diet is based mostly on naturally occurring foods (Table 2.4). Consequently when the diet is varied and the energy needs are met, the risk of deficiency is likely to be small. Our present knowledge of requirements for vitamins and minerals and their interaction with macro-nutrients is too meagre to elaborate further.

Table 2.4. % contribution of vegetables and animal foods to daily energy supply

	Developing countries		Developed countries	
	1961–1963	1972–1974	1961–1963	1972–1974
Veg. Foods	*90*	*90*	*68*	*67*
Cereals	51	51	31	26
Sugar	10	10	12	13
Animal Foods	*10*	*10*	*32*	*33*

UNDERNUTRITION: SIZE AND NATURE OF THE PROBLEM

If as explained above, every individual with intake below the average energy requirement for his age-sex category is not undernourished or everyone with intake above the same requirement is not overnourished then how does one define undernutrition and overnutrition? Is it not true that on current theory individuals of the same age, sex and body weight living the same mode of life and engaged in similar activities have the same or similar energy requirements? This is perfectly true but it does not follow that energy requirement of an individual is constant or near constant as implied in this definition. Available data critically examined show that energy intake in man engaged in fixed tasks and maintaining body weight varies from day to day indicating that the daily variation is non-random and that this variation persists even when the intake is averaged over a week. Further, the successive values are found to be correlated in an autoregressive process (AR), showing that the variance of the daily intake is constant and the intake is self-regulated – (Sukhatme and Margen, 1982). This means that there is no absolute energy requirement for any day or period but that the individual is in homeostasis or strictly in homeorhetically channeled homeostasis and that his requirement is controlled by a regulated system. This also

explains the paradox implied in the observations on nutritional variability made by Widdowson as early as 1947 that one can be sure of finding two individuals in every twenty of the same age-sex group, one of whom has an intake twice as large as the other and yet all are healthy and active individuals doing similar work. In effect, the variation observed by Widdowson can now be understood as partly an intra-individual variation which remains a fundamental source of variation even after intake is averaged over a week and determines the capacity of an individual to adapt.

Table 2.5. Analysis of variance of daily energy intake/kg of body weight in different groups of depot centres, period Monday to Friday

	Energy Intake/kg					
	A+B+C*			D+E		
	d.f.	M.S.	Estimates of true variance	d.f.	M.S.	Estimates of true variance
Between Subjects within Centres	14	462	10	7	578	23
Between periods within Subjects	28	336	42	18	240	27
Between days within periods	180	124	124	108	106	106
o^2_w		166			133	
% C.V.		22			20	
Variance of daily mean over 5 days		67			48	
% S.E.		14			12	

** Data relates to first two weeks only. The third week was excluded as it commenced on Thursday instead of on Monday.*

Widdowson's observations referred to intake only, not energy expenditure. Further, there was no means of knowing how far the variations reported by her arose from variation in body weight and in level of activity. One had, therefore, to wait for results of longitudinal studies of energy intake and expenditure on subjects engaged in fixed tasks before knowing more about the size, nature and source of intra-individual variation. The study carried out by Edholm and his associates (1970) was the first longitudinal study to throw light on these questions. The study was carried out on army recruits engaged in similar activities using the most sophisticated methods yet developed, viz. Integrated Motor Pneumotachograph (IMP) to measure energy expenditure and 'weight as you eat method' to record intake. The finding was that there was a wide intra-individual variation in daily observations and that even when the measurements were averaged over five days period and adjusted for differences in body weights, the differences over time remained large. Relevant analysis is given in Table 2.5. It will be seen that the coefficient of variation of daily intake was

of the order of 20 per cent and that of daily mean intake over 5 days was 12 to 14 per cent. This latter value is much larger than can be explained on the basis of measurement errors and leaves little doubt that the variation between successive value is non-random.

Unlike intake, the variation in the case of expenditure was small. This was expected. Lack of space does not permit us to reproduce the expenditure data.
Now, in the hierarchical model of analysing variance, the three mean squares shown in Table 2.5 represent estimates of $np\sigma_b^2 + p\sigma_p^2 + \sigma_d^2$, $p\sigma_p^2 + \sigma_d^2$, and σ_d^2, respectively, where σ_b^2 is the true variance between subjects, σ_p^2 is the true variance between periods within subjects, σ_d^2 is the true variance between days within periods, p is the length of the period in days, d is days, and σ_w^2 is the variation within individuals.

It follows that the variance σ_w^2 of the daily observations for any subject is given by $\sigma_p^2 + \sigma_d^2$ and that of the variance of mean daily intake over p days is given by

$$\sigma_p^2 + \frac{\sigma_d^2}{p} \qquad (1)$$

Clearly the reason why the mean daily intake decreases with p more slowly than if the variation is random must be traced to the presence of the component σ_p^2 in E.q. (1). We cannot, therefore, regard energy requirement to be fixed in an individual.

A glance at Edholm's data is adequate to confirm that the variation in daily intake, expenditure and balance is non-random and implies regulation. The cumulative energy balance over 5 days periods is not only seen to vary considerably from one week (period) to another (period) but is of the order of several thousand kcals. If the control system in the body were to tolerate energy balance of this order and yet maintain body weight within narrow limits as most recruits have done, it means that the real control of body weight is exercised by means of some homeostatic mechanism working for the good of the whole body. If it had been otherwise most of the recruits would have gained or lost up to five kilograms during nine week period in this study. It follows that the real controlling variable of the homeostatic process is not intake or expenditure but co-factors like dissipated heat which is known to increase as intake increases above the threshold limit, thereby conferring on man a wide, though strictly limited lower range of energy intake in regulating body weight. This is equivalent to saying that an individual ceases to be the same individual as he advances in time, which of course is true. The specialised environment in which he is brought up apparently interacts with the genetic component to keep the intra-individual variation a fundamental source of variation. It must be concluded that man adapts his requirement to intake over range of intra-individual variation and that he does so by varying the efficiency of utilising his energy intake for maintenance. (Sukhatme, 1982b). The conclusion is consistent with the known evidence that humans possess a physiological regulatory mechanism for controlling appetite and expenditure.

That adult children can adapt themselves to energy intakes which differ from the mean energy requirements for their age group by as much as 500 calories or more and yet have the same weight as that of the reference median for their group can be seen from Table 2.6.

Table 2.6. Observed energy intake and body weight in different rounds of surveys on school children at Urali Kanchan

Round No.	Intake in KCal	Age Group 13–15 Body weight in kg	Intake in Kcal	16–19 Body weight in kg.
2	1990	34.6	2040	41.5
3	1920	35.4	2130	41.6
4	2000	35.8	2170	43.2
5	2070	36.3	2140	43.9
6	1970	37.5	2030	43.0
Required Median body wt (ICMR)	2500	36.0	3000	45.0

The table is based on data from longitudinal surveys on school children in rural areas at UraliKanchan near Pune (Tilve, 1979). The children were healthy, active and engaged in a similar mode of living and activity. Clinical examination did not reveal any symptoms of malnutrition. They were also examined for haemoglobin.

The series reported by Edholm *et al.* is limited to three noncontinuous weeks. It does not, therefore, permit a direct study of autocorrelations to verify the inference that energy requirement is self-regulated over a range of intakes. We can, however, examine simple autoregressive models by the indirect method of computing variance of the mean intake expenditure and balance when daily observations are averaged over 2, 3 or more successive days. The results of such exercise are given in Table 2.7.

Table 2.7. Variance of an individuals mean energy intake expenditure and balance based on p successive days as proportion of unit variance for p = 1 depot centre D

Period in days	Observed intake	Values for expenditure	Balance	Calculated =0.00	=.30
1	1.00	1.00	1.00	1.00	1.00
3	0.43	0.63	0.55	0.33	0.49
4	0.27	0.37	0.31	0.25	0.39
5	0.28	0.29	0.29	0.20	0.32

It will be seen that the variance of the daily mean intake does not decrease inversely as the length of the period but that it decreases slowly according to the variance postulated on the hypothesis that the daily observation is distributed in a stochastic stationary distribution of the Markovian type (Sukhatme and Margen, 1982). In algebraic notation the variance can be approximately written as (where p denotes the serial correlation of order one between successive values).

$$\frac{\sigma_w^2}{p} \quad \frac{1+p}{1-p} \qquad (2)$$

The best example of the evidence that energy intake in man engaged in defined tasks is used with variable efficiency is provided by Edmundson (1979) in his recent study of farmers in Java. He determined the basal metabolic rate (BMR) and energy costs of standard tasks in farmers with low and high energy intakes by measuring subjects, gaseous exchange with a calorimeter and analysing the respiratory gases with a microscoholander analyser. The results are summarised in Table 2.8.

Table 2.8. Comparison of energy costs of specified activities in high and low energy intake subjects

Intake in observed	Height (cm)	Mass (kg)	Energy intake (kcal per diem. 6 day average)	Basal metabolic (kcal rate per min 12 hours fasting)	Light work output (kcal per min 300 kpm/50W)	Medium work output (kcal per min. 600 kpm/100W)
High	162.0	52.1	2754	1.32	4.28	9.41
Low	161.6	52.8	1770	0.68	3.53	6.63

It will be seen that the high energy intake group had a BMR twice as large as the low intake group. Further the energy cost of activity was 50% higher in the high intake group compared to that in the low intake group. Clearly, the increase in metabolic efficiencies enabled the individuals on low energy intake groups to perform on par with those on high energy intake.

Equally instructive is the study of data from Indira Community Kitchen, Table 2.9. This table shows the distribution of energy intake of adult young women in the kitchen preparing 500 to 600 chapaties per day. It will be seen that relative efficiency of output is 60 per cent higher for women with the lowest energy intake. The same result can also be expressed in terms of the relationship of body weight and work output. The data show that there is hardly any correlation between the two (Sukhatme, 1982a).

The above example is important for another reason because it was generally taken for granted that since women were drawn from the poorest of the poor and were assured of getting enough to eat for themselves and their families, they would increase both their intake and body weight while engaged in the heavy muscular work that is reflected in the level of productivity described above. One has to visit and see for oneself the sight to appreciate the intensity of work involved. Measurements of body weight, however, show that there was hardly any difference in the body weight that was reported on joining the kitchen and one year later. What is instructive is the relatively wide range of intake and body weight over which the same output was obtained. Before joining the kitchen, these subjects were poor hutment dwellers at best. Their poverty arose from the fact that they hardly lived as human beings.

We find much the same experience in the data reported from Kerala (Soman, 1982) where a healthy active woman there has a level of intake of only about 1,300 to 1,400 kilo calories a day which is about 35 per cent less than the prescribed allowance and

Table 2.9. Distribution of energy intake of adult young women preparing 500 to 600 chapaties in 8 hours shift a day

Sr.No.	Calories/Day	No. of workers
1	1500–1600	2
2	1601–1700	2
3	1701–1800	5
4	1801–1900	4
5	1901–2000	2
6	2001–2100	8
7	2101–2200	-
8	2201–2300	3
9	2301–2400	-
10	2401–2500	1
Total		27

yet this woman has a level of health and activity on par with a northern woman eating much more. Lack of space does not allow us to elaborate.

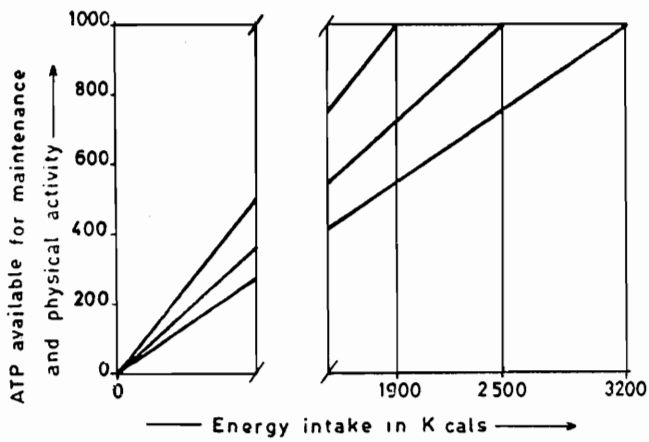
The conclusion we reach is that the expenditure per unit of time on well defined activities is not fixed as assumed in current nutrition literature but varies from person to person and over time in the same person. This happens because energy is used with variable efficiency which decreases as intake increases over the homeostatic range. Consequently, intake ceases to be the main determinant of body weight and work performance within a homeostatic range. However, a host of questions arise. How can an individual engaged in fixed tasks and maintaining body weight can do so on a range of intakes? Again, how can we accept the interpretation that the genetic entities in man interact with the environment to slow down or speed up metabolism when the germplasm with which he is born is fixed?

It is known that of total energy in the food consumed, by far the larger part is dissipated as heat, a part is spent on maintaining body functions such as self-regulation, synthesis of enzymes, protein etc., and the residual is spent on physical activity. It is also known that only that part of energy which is mediated through ATP or other high energy bonds is spent on maintenance of body weight and physical activity. When total energy intake is less, the body wastes less, thus using intake with greater efficiency. As intake increases wastage also increases and energy is used with decreased efficiency. However, a point is reached in the intake of food below which BMR gets depressed and the body is forced into parting with its fat in favour of vital need to maintain body heat. That is the point of clinical undernutrition. Likewise, in a state of excess energy intake a point is reached above which the body overheats and is forced into storing the excess energy as fat. This is the point of clinical overnutrition. Below and above these points, the body is under stress, auto-regulation ceases to work and the pattern of oscillations in the daily energy balance is more like that in ECG of man suffering from tachycardia.

Experimental observations confirm that low intake is followed by low intake and high intake is followed by high intake, but always in a manner that restricts the move-

ment within limits of homeostasis. This is a sort of a negative feedback, a restraining action, which ensures that internal process, or balance between the intake of energy and dissipation of heat and energy mediated by limits on the production of enzymes and the size of body compartments for protein, fats and glycogen, does not get out of control. It is apparently the self-regulated mechanism of varying the metabolic efficiency which enables man to adapt his requriement to intake as depicted in Figure 2.1. At the lower threshold value of 1900 kcal an individual functions with about 50 per cent efficiency. This is the maximum amount of energy which metabolic pathways for glucose and fat can convert to ATP. The rest is wasted as heat. For protein, the maximum yield is smaller. At 2550 kcal, which is the average requirement for adult males (FAO/WHO 1973), the efficiency of utilization is 37 per cent and at 3200 kcal it drops to 30 per cent. This means that of the energy released from a given amount of food, only about 35 per cent is available for essential anabolic processes and physical activity, the rest is lost as heat. Eventually of course, even the energy used in essential processes appears as heat since 'no energy can be lost without a trace'. The fact that only about a third of total energy in the food consumed is used for anabolic purposes including physical activity and that this is the maximum, explains why a man engaged in similar work can be in energy balance on a wide range of intakes without change of body weight.

Figure 2.1. Efficiency of utilization



It is true that there is no known way in biology which can enable man to change the genetic blue-print with which he is born but it appears that he can change its development under the impact of specialised environment (Sukhatme and Narain, 1982). Used to analyzing data in terms of the hierarchical additive model, one is apt to forget that the two components of phenotype, viz. nature (g) and nurture (e) need not necessarily be independent but interact, giving for the variance of the phenotypic value the expression:

$$V(g) + V(e) + 2\,Cov\,(g,e) \quad (3)$$

The fact that observations of energy intake within different weeks (periods) of the same individual resemble each other show that we have a data situation which precisely contributes to the covariance component. We can, therefore, interpret data in the same individual by the method of intra-class correlation and state that for a given total observed variance, higher the association $\bar{r}$ between the different values within the same period, smaller would be σ_d^2 and greater would be σ_p^2. In other words, the ratio of σ_p^2 to the total variation σ_w^2 can be said to represent the fraction of the phenotypic variability which is due to genetic causes. This ratio is known as repeatability of the character and sets an upper limit to the heritable portion of an individual's variance. Since the observations refer to the same individual, the heritable portion must be interpreted as arising from interaction between genetic entities in individual and the environment in which he is brought up. It can be shown that on substituting $\sigma_p^2 = \bar{r}\sigma_w^2$ in Eq. (1), we obtain for the variance of the mean intake, the expression

$$\sigma_w^2\left(\bar{r} + \frac{1-\bar{r}}{p}\right) \quad (4)$$

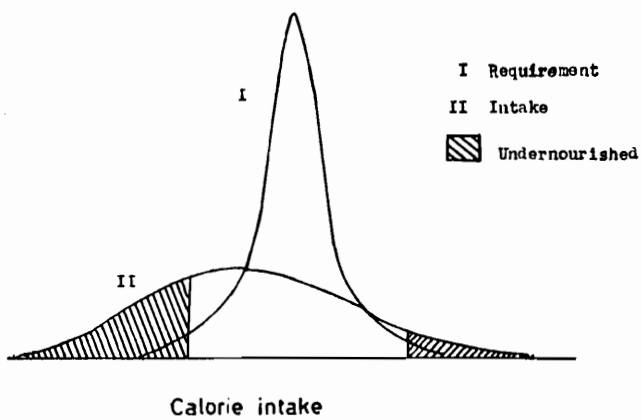
Table 2.5 shows the estimated values for σ_b^2, σ_p^2, and σ_w^2. It will be seen that σ_p^2 is small relative to total variance, but is far from negligible relative to total heritable variance.

The enhanced variability that we observe in mean daily intake in the same individual can thus be explained in two ways (a) in terms of auto-correlation of order 1, with its implications for regulation and (b) in terms of intra-class correlation $\bar{r}$ with its implications for genetic significance. The capacity to adapt within threshold limits is heritable and implies adaptive regulation, arising from interaction between genetic entities in man and the environment (Sukhatme and Narain, 1982). Apparently living organisms have devices for sensing the external environment and internal metabolic changes for adapting to them and for regulating their internal machinery as a result of these signals. Recent experiments support this inference. The basic mechanisms of control are found to be mediated by induced changes of proteins which either turn on or turn off the processing system. In this way signals can feed back to inhibit synthesis of a product that is in excess or can feed forward to activiate a pathway that must be mobilised for a particular function (Koshland, Goldbetar and Stock, 1982).

Requirement is thus a dynamic variable because in a healthy active individual engaged in specified tasks, balance is found to vary as a matter of course around zero with stationary variance without implying under or overnutrition. It follows that it is only when the intake exceeds the homeostatic mechanism that man is under stress from inadequate or excessive intake. The application of this criterion for assessing the incidence of undernutrition in the population is illustrated in Figure 2.2. Curve II in this figure shows the distribution of intake adjusted for body weight and level of activity of the reference man, while Curve I shows the distribution of requirement for normal healthy adults of the 'reference' type, the shaded area to the left shows the proportion of individuals with mean daily intake less than the estimated lower limit

of homeostasis ($m-2s_w$), where m stands for the average requirement and s_w stands for standard error of daily mean intake and represents the estimate of the incidence of undernutrition. The shaded area to the right shows the proportion of overnourished with intake exceeding $m+2s_w$. The unshaded area in the middle represents normal healthy individuals with intake varying within limits of homeostasis. The value of s_w depends upon the length of the period to which the mean daily intake refers. This means if the period is 1 day s_w will be 20 per cent of the average requirement, s_w decreases as the period increases and stabilises at approximately 12 percent for periods of 5 days and beyond when available evidence is examined using the above methodology it shows that the incidence of undernutrition in developing countries can be placed at 15 to 20 percent. Space does not permit elaboration.

Figure 2.2. Distribution of calorie intake compared with requirement



PROTEIN MALNUTRITION: SIZE AND NATURE

A man may not be undernourished judged by the level of his energy intake and yet he may not meet his needs for nutrients, proteins, fats, minerals and vitamins. Inadequacy in one or more of these, if allowed to continue, results in malnutrition of one kind or another. The most widespread and serious of these is protein malnutrition. Others are anaemia due to deficiencies of iron and folate, goitre due to dietary shortage of iodine and xerophthalmia due to shortage of vitamin. Here we confine ourselves to protein malnutrition, its size and nature. For, as already stated there is sufficient evidence to show that if the diet is varied and meets energy needs, malnutrition due to deficiencies of vitamins and minerals will be taken care of.

Ten years ago it was asserted that protein deficiency lay at the heart of the problem of malnutrition. So serious was believed to be the deficiency of protein in the food-

grain diets normally eaten in the developing countries that the U.N. Committee on Science and Technology warned that if people continued taking the diet as it is, without enriching it with good quality protein, then economic, social and physical development would be completely arrested. The Committee further observed that the gap was so big that the developing countries would not be able to fill it in the normal course of economic development. Even if they produced the needed animal products most people would not be able to afford them. The only feasible solution in the Committee's view was technological. Modern technology, the Committee observed, had fortunately made it possible to produce new protein products which can be had at little extra cost. All that was needed was capital from the developed countries to back the effort and co-operation of the poor countries in distributing the protein so produced.

It is now common knowledge that this effort of the United Nations to combat malnutrition was, to quote McLaren (1974),'a total fiasco'. The reason was that its assessment of the problem was wrong. Contrary to what it said, the concentration and quality of protein in the cereal-pulse diet that people normally eat is more than adequate to meet man's needs, provided he eats enough to meet his energy needs. For children, milk is a desirable addition, but not so much because the diet does not meet his protein needs but because it provides them in proper composition along with vitamins and minerals, especially calcium; and further milk helps the transition from breast milk to solid food. Even mother's milk contains no more than 5 to 6% of its calories in the form of protein and yet it is an ideal food for infants. It is of course true that a food grain diet is not adequate for a satisfactory growth of laboratory animals like rat, but man is not a rat. There are no known benefits from excess consumption of protein either. On the contrary, at very high doses of nitrogen an adult organism is found to be under stress; protein metabolism is altered becoming more rapid in an effort to eliminate excess nitrogen as quickly as possible (Sukhatme and Margen, 1978). If, as we stated before, people in the rich countries eat more protein than what is needed for health, it must be because it is difficult to resist the temptation to eat more of tasty animal foods when one can afford to do so.

And yet despite the fact that a food grain diet provides all the protein that one needs, protein deficiency does occur. This is confirmed by the data of numerous clinical and nutrition surveys which show that an appreciable proportion of children suffer from states of protein malnutrition, ranging from retarded growth to the signs of severe protein deficiency, such as nutritional oedema and reduced serum albumin. If protein malnutrition does occur and is widespread, it must then be due either to abnormal losses such as occur during infections or to low energy intake. Protein synthesis is known to be expensive in terms of calories. Unless a diet provides the energy cost of re-synthesizing and retaining protein, a person must lose protein. Only a bivariate analysis of energy and protein intake can show the extent and nature of protein malnutrition.

We have summarized in Figure 2.3 the findings of this analysis. Protein intakes are shown along the horizontal axis and energy intakes along the vertical axis. The intersecting lines in the middle of the figure are drawn at $m\text{-}2^{b}{}_{w}$ corresponding to the lower critical limits of homeostasis for energy and protein in reference adult. The jus-

tification for this is that N balance on any given intake in a man maintaining body weight is found to be regulated much in the same way as energy balance and is distributed around zero with stationary variance. These lines thus help to classify the diets according to whether they are protein deficient (PD) or not protein deficient (NPD) and energy deficient (ED) or not energy deficient (NED). The marginal totals show the incidence of PD and ED diets.

Figure 2.3. Extent and nature of protein malnutrition

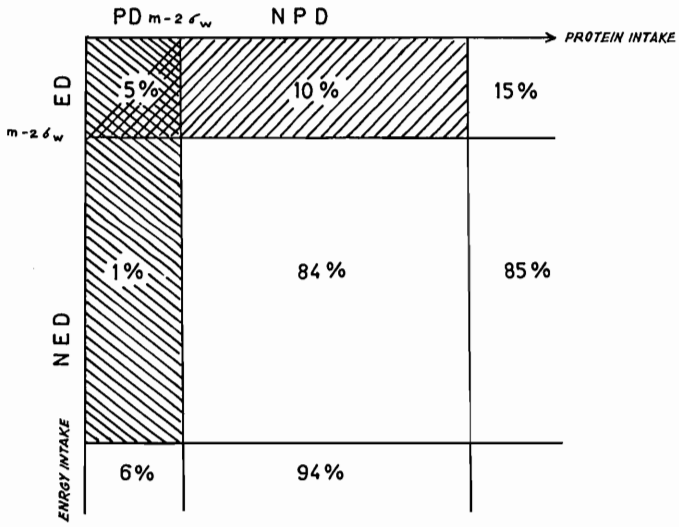


Fig. 2 : Extent & Nature of Protein Malnutrition

PD : Protein Deficient

NPD : Not Protein Deficient

ED : Energy Deficient

NED : Not Energy Deficient

It will be seen that only about 6% of the diets are deficient in protein. By comparison the incidence of ED diets is large, being 15%. Clearly, energy is the more limiting factor in our diets. It will be further observed that PD diets are also ED diets. Simple protein deficiency is thus the direct result of inadequate diet.

PD set shown in the vertical column on the left of the figure is made up of two subsets; in one the diets are deficient in energy, in the other they are not. However, as the figure shows, the latter is almost an empty set. In other words, there are hardly any diets which, although adequate in energy, lack protein. To put it differently, if an individual eats enough to meet his energy needs, he will also meet his needs for protein.

The energy deficient diets set shown in the horizontal column on the top is also made up of two sub-sets; the first consisting of (ED, PD) which are deficient in both energy and protein and the second consisting of (ED, NPD) diets which are deficient in energy, but are adequate in protein. At first glance, it will be thought that individuals taking such (ED, NPD) diets will not show any signs of protein deficiency. This is, however, not true. The fact that diets are deficient in energy means that the individuals cannot maintain their normal body weight and stores. Experimental results show that when the energy intake falls short of the energy needs for maintenance, protein in the diet is partially diverted to meeting energy needs, thus, causing negative N balance. Calculations show that the lower critical limit for energy needed for maintenance also represents the cost of synthesising and retaining protein. As Figure 3.2. shows, some two-thirds of the PD diets fall under this category, showing that protein malnutrition for this sub-set is the indirect result of inadequate energy in the diet. An undernourished individual is thus also exposed to protein malnutrition. It means that as long as the diet is adequate in energy, adding protein to the diet will not help alleviate protein malnutrition.

The fourth sub-set consists of individuals who are neither deficient in calories nor in protein. They are seen to account for some 85% of the individuals in the country. Some of these individuals will of course be eating in excess of energy needs. However, with this aspect we shall not concern ourselves here.

It is now quite some years since these findings are known. They have received general acceptance.

IMPLICATIONS

With over half the population thought to be malnourished, with the population growth showing little signs of perceptible decline, with levels of consumption already low and with the increasing encroachment on land to produce food, the problem of the developing countries appears formidable. In reality, their problem need not appear formidable as has been made out because the magnitude of their food problem has been grossly overestimated. There seems little realisation that policies and programs based on cut-off point for income corresponding to the average energy requirement can be self-defeating. By including twice as many individuals as poor and undernourished, when only the lower half or third among them are so, the developing countries have in effect provided opportunities to the relatively better offs among the poor to capture the benefits of official programs, leaving the really poor as they were or even worse off. Failure to hold securely to the improved level of energy supply is partly the result of this policy in as much as the countries are not able to generate effective demand among the poor and the malnourished to buy the needed foods. The food either gets stored, as at present in India, or gets increasingly restructured to create dietary variety to meet the demands of the well-to-do sections

of the population, leaving the poor to live under stress as before.

The analysis reveals that there are two kinds of problems the developing countries are confronted with. The first is the problem of those who are under stress because of lack of purchasing capacity or a manipulated price rise, of developing energy deficiency and its adverse consequences for health; some of these, particularly children are even functionally malnourished. These people, amounting to roughly 15 to 20 per cent of the total mostly come from: (a) drought prone areas, (b) tribal areas, and (c) slums.

Among them, the sectors of the population who are poorly nourished are most likely those who do not do heavy physical work, but either do light work or subsist on charity or both and include old people, widows and those who are chronically ill with insufficient strength to do heavy work. These people need an assured supply of income and wages from employment, besides needing health and medical services to look after the functionally malnourished members of their households. Food for work, together with the primary health agencies in the different areas, would appear to be an ideal instrument to deal with their problem. The community kitchen offers another example to show how the poor can help the poor to be self-reliant and altruistic at the same time (Sukhatme, 1982a).

The second problem which the developing countries are confronted with is the problem of poverty as distinct from that of malnutrition linked with poverty. Small stature in children thought to be the result of malnutrition is the indirect result of this poverty which expresses itself in miserable conditions of living. These people need help in developing an alternative model for living built around village well, community latrines and bio-gas as a means to develop a more efficient use of human, animal and agricultural waste which in fact is the primary cause of their poverty. Intervention to deal with their problem need not be focussed on food and medical help nor addressed at the individual level. Its purpose is to involve the community into social measures of improving environment on the lines being attempted in the 8 village project funded by the Department of Science and Technology, Government of India, using school as an instrument of effecting change in the life style of the village. These measures are based on the concept that education, like nutrition and health, is also a process and that as the community moves in time under sustained stimulus, a transition takes place. Necessarily, this realisation takes time. However, once the change is integrated into the life style, the community begins to see a cause-effect relationship resulting from interaction between community and environment to establish a viable self-sustained change which can satisfy basic need, though not greed. The time required in practice is often larger than one would wish because some of us, influenced by the materialistic philosophy, tend to belittle the change so brought about, as poor substitute for the change that can be accomplished from use of modern technology, forgetting that a lasting change must be value and culture based. Only such change can ensure use of appropriate technology within resources which developing countries can afford.

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Appendix A

Grouping of Developing Countries by Geographical Region and by the 1966 to 1977 growth rate of GNP/capita

Asia

a. Very slow growth (less than 1.0 percent)
Bangladesh, Bhutan, Kampuchea, Laos, Vietnam

b. Slow growth (1.0 percent to 2.9 percent)
Burma, India, Mongolia, Nepal, Pakistan, Sri Lanka
c. Medium growth (3.0 percent to 4.9 percent)
China (removed from the analysis of trends for reasons noted in the text), *Fiji, Malaysia, Papua New Guinea, Philippines, Thailand*
d. Rapid growth (5.0 percent and over)
Hong Kong, Indonesia, Korea DPR, Korea Rep., Singapore

North Africa and Middle East

a. Very slow growth (less than 1.0 percent)
Afghanistan, Kuwait, Libya, Yemen AR
b. Slow growth (1.0 percent to 2.9 percent)
Sudan
c. Medium growth (3.0 percent to 4.9 percent)
Algeria, Cyprus, Egypt, Iraq, Lebanon, Morocco, Turkey, Yemen, PDR
d. Rapid growth (5.0 percent and over)
Iran, Jordan, Oman, Saudi Arabia, Syria, Tunisia

Sub-Saharan Africa

a. Very slow growth (less than 1.0 percent)
Angola, Benin, Burkina Faso, Chad, Ethiopia, Ghana, Guinea-Bissau, Madagascar, Mauritania, Mozambique, Namibia, Niger, Senegal, Sierra Leone, Somalia, Uganda, Zaire, Zambia
b. Slow growth (1.0 percent to 2.9 percent)
Burundi, Cameroon, Central African Rep., Congo, Gambia, Guinea, Ivory Coast, Kenya, Liberia, Malawi, Mali, reunion, Rwanda, Tanzania, Zimbabwe
c. Medium growth (3.0 percent to 4.9 percent)
Mauritius, Togo
d. Rapid growth (5.0 percent and over)
Botswana, Gabon, Lesotho, Nigeria, Swaziland

Latin America

a. Very slow growth (less than 1.0 percent)
Chile, Cuba, Honduras
b. Slow growth (1.0 percent to 2.9 percent)
Argentina, Bolivia, El Salvador, Guatemala, Guyana, Haiti, Jamaica, Mexico, Nicaragua, Panama, Peru, Trinidad/Tobago, Uruguay, Venezuela
c. Medium growth (3.0 percent to 4.9 percent)
Colombia, Costa Rica, Ecuador, Paraguay, Surinam
d. Rapid growth (5.0 percent and over)
Brazil, Dominican Republic

Appendix B

Assumptions used and data sources

The analysis here of trends in food production, consumption and trade in Third world countries and of a trend-based scenario of their future food supply and demand situation draw mainly from the results of the research work on food trends in IFPRI which focuses on the basic food staples in 105 developing countries. Basic food staples here include cereals and the major noncereal food crops consisting of roots and tubers, pulses, groundnuts, bananas and plantains. The analysis of past trends of these commodities in each country examines the 1961–77 annual estimates on production and the 1961–65 and 1973–77 data averages on consumption and trade. In projecting future food output and requirements, a number of assumptions are used: (a) past country production trends will continue in the future, except in countries with negative production trends for which no further declines in food output is assumed;* (b) trend increases in food production are logarithmic, (c) increases in food demand arising from growing population assume the U.N. -projected medium-variant population growth rates, (d) changes in food demand arising from increases in income are based on the trend growth rate of per capita gross national product (GNP) during the 1966–77 period and on the available quinquennial estimates of income elasticities for 1975–2000, and (e) price relationships remain unchanged.

Most of the data used in the analysis are from the Food and Agriculture Organization of the United Nations (FAO) which developed a major statistical base for their more comprehensive global effort, "Agriculture: Towards 2000." The population and income statistics used in the study came from the U.N. Department of International Economic and Social Affairs and the World Bank. Estimates on population and on the production of major food crops for the People's Republic of China are from Tang and Stone. (Tang and Stone, 1980).

1/ This assumption further implies that on the average, the past long-run behavior of weather, the critical determinant of annual food output in many developing countries, will continue into the future.

CHAPTER 3
Energy Balance in Agriculture: the Developed World

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INTRODUCTION

HAD IT NOT been for synthetic fertilisers, Thomas Malthus would already have been proved right, for even with well-managed land, many developed countries are already too densely populated to feed themselves from their land resources. However with artificial fertilisers, land productivity has soared, and as new thresholds have been reached, new genetic varieties have come along to take advantage of the potential of intensive fertilisation. When one looks back to the halcyon sixties of this century, when the price of everything was steadily dropping in real money terms, it seemed that the world's potential to grow and grow was unlimited. Writers like Clark (1967) were amiably toying with a world population of 30 billion. Producing enough food really seemed no problem, and though one was aware of an awful gap between rich and poor nations, and the paradox of famine and plenty side by side, the problem was considered a political or even an economic problem. It was not considered a resource problem. It was certainly not considered a problem beyond the wit of man to solve. The future, if full of difficulties, seemed to pose no great problems, so far as food supply was concerned. And, of course, for the developed world easily able to purchase energy and furnish capital, food was seen as no problem at all. There were a few pessimists, such as Borgstrom (1969) and Goldsmith (1971). The latter argued that the long term UK solution to survival was to plan emigration on a large scale and reduce her population from 55 to 35 million.

In the 1960s not only was energy not considered a problem but the link between energy and food production had not been revealed. Energy policy was restricted to considering which source of energy had the least marginal cost, then going for that source. In real terms oil and coal were becoming cheaper. If one thought of energy at all, it was in terms of price. It was rare to find anyone thinking of it in terms of what energy did in the economy, or of the energy requirements of many of the inputs one took for granted, such as synthetic fertilisers. Yet some people's minds were turning to these problems even before OPEC raised the price of oil by a factor of three in

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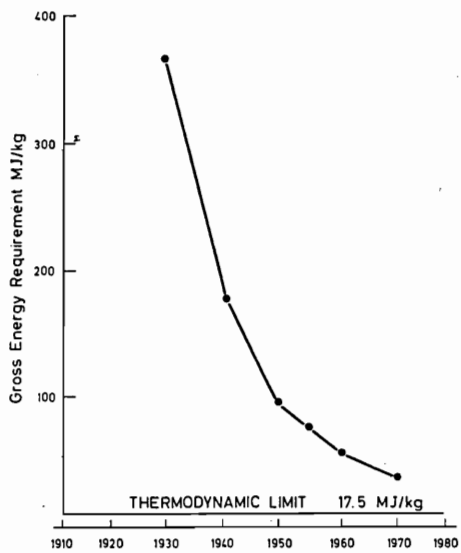
1973. These were people accustomed by their professional training to looking at mass and energy balances of industrial processes, and who, out of curiosity, applied the same methodology to the interaction of the three elements of modern agriculture – land, photosynthetic energy and man-made inputs. Fleming (1943), in a fine piece of work, analysed the energy required to actually produce nitrogen fertilisers year by year from 1910. He found that through technological progress, man had made immense strides. Figure 3.1 gives Fleming's original data, side by side with a plot of nitrogen fertiliser prices. To the unwary it looked as if technological progress would continue indefinitely. But to the thermodynamician, the outlook was quite different, for, from thermodynamic principles, he could calculate the minimum energy needed to create nitrogen fertiliser. It was plain that technological progress had almost reached the limit of its potential for by 1975 energy requirement had fallen to only *twice* the theoretical minimum.* The most economic process was the methane-air one (using natural gas). Economies of scale had driven design to huge plants of 300,000 tonnes/year output. Further advances would require huge trade-offs between capital (for better energy use) and rate of output, and they were not forthcoming.

Figure 3.1. Improvement in gross energy requirement of ammonia production

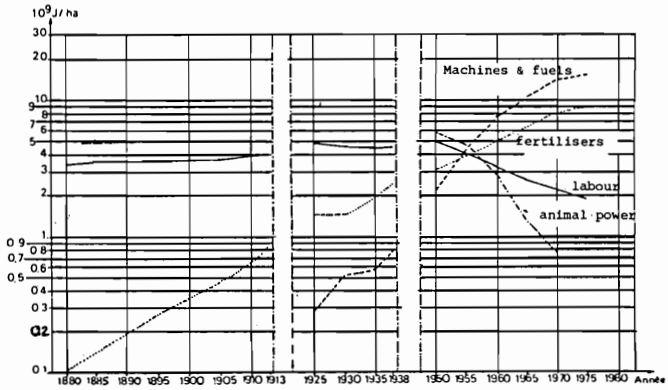


* The thermodynamic minimum exists when the rate of production is zero. One needs substantially more energy to create a finite rate of production.

ENERGY REQUIREMENT IN AGRICULTURE

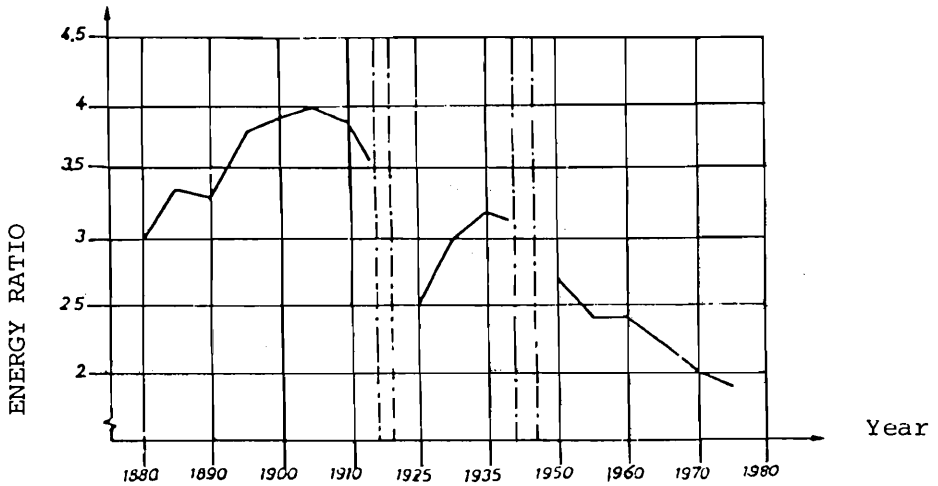
A logical step from looking at the energy requirement of nitrogen fertiliser was to look at all the energy inputs to agriculture, for by now it was apparent that all of them were made possible only the application of energy. Every activity, and every input, whether it was the supplanting of animal traction by tractors, or the preparation and delivery to the farmer of lime, phosphate or nitrogen fertilisers required the dissipation of energy. Figure 3.2, due to Weber (1979) depicts the change in German agriculture from 1880 to 1975. It is typical of developed agriculture everywhere. One sees a steady rise in the use of synthetic fertilisers, till by 1976 they represented the equivalent of 9 GJ/ha that is to say, the energy required to manufacture those inputs and deliver them to the farmer was 9 GJ/ha or some 1.4 barrels of oil equivalent per hectare per year. Following the second world war there took place a swift substitution of traction animals for machines, so that by 1976 traction animals had virtually vanished and fuel for machine farming had risen to an average of 16 GJ/ha, the same period man-power needs on the farm had slumped. The farm worker had been supplanted by the 'energy slave', who instead of requiring board and lodging, food and entertainment, required only fuel and the occasional attention of a mechanic.

Figure 3.2. Consumption of energy in German agriculture, 1880–1976



The price paid for these advances in outputs and in economics of farm operation are revealed in Figure 3.3. Weber (1979) calculated that for every unit of fossil energy expended on the inputs to the farming operation, four units of metabolisable energy were delivered to the customer. By 1976 this had fallen less than two. In other developed countries the figure fell even lower. In the UK it was close to unity, while in France it fell to around 1.2.

Figure 3.3. Energy ratio (metabolizable energy out/fossil energy in) in German agriculture, 1880–1976



This number is called the energy ratio (ER) and is defined as the ratio of the metabolisable energy in the food produced divided by the total amount of primary energy in the ground that had to be extracted in order to manufacture all the inputs to the farming process. It is an extremely interesting computation, giving one a feel for the intensification of farming in energy terms. Unfortunately many analysts and commentators have attributed to the energy ratio a value judgement, implying that a low energy ratio is bad, and while a high one is good. But life is not that simple. In the first place, one cannot eat fossil fuel, but one can eat food. Without this expenditure of energy there would be less food around, and certainly much less meat. Provided the energy supply is sustainable, what's wrong with using energy to get food? If, however, if energy supply is not sustainable an agricultural system based on fossil energy may lead a society to the brink of disaster or beyond.

Table 3.1 lists energy ratios for many foods produced in many parts of the world. In the table data is also given in terms of the energy required to produce one kilogram of the various foods. This latter number is called the Gross Energy Requirement (GER) and is usually expressed as GJ/tonne or MJ/kg. The GER and ER are then compared with output intensity, kg/ha.

The reader should bear in mind that the numbers in table 3.1 apply to systems of various intensities on varying soils, in varying climates at various times. No one figure can be applied to another situation without further analysis.

In 1976 a group studying the energetics of food production at Strathclyde University assembled the data from 350 systems, comparing the output intensity of the farming system with the energy requirement of these systems, expressed as fossil energy inputs per hectare*. The result was a surprising correlation over eight orders of magnitude of intensity of inputs, Figure 3.4 (Edwardson *et al.* 1977). In other words there

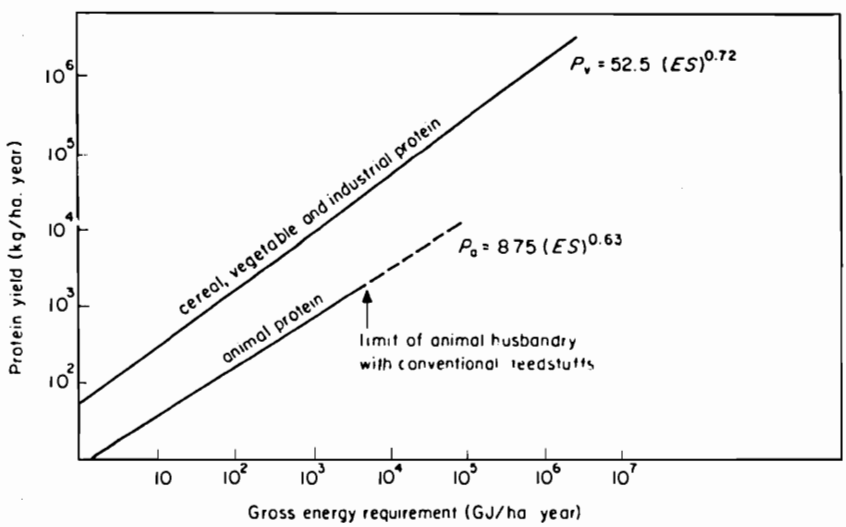
* Fossil or fissile. The meaning here is of use of the earth's fuel stocks.

exists a quantifiable relation between the energy expended on the land and the resulting food produced. This energy, in the form of tractors, fertilisers, insecticides and so forth, effectively enhanced the capture of the incident solar radiation. The sum of these energies have been (Slesser, 1973) called the energy subsidy to food production. This generalized plot can be reduced to an equation of the form

$$P = P_o + ES^{\beta}$$

where P_o is the protein productivity (kg per hectare per year) of a natural system (on average). ES is the energy subsidy (GJ/ha·Y) and $\propto$ and ß are constants. For vegetable, cereal and synthetic protein production (e.g., SCP from paraffins) $\propto = 52.5$ and $\beta = 0.72$. For animal and fish farmed protein the figures were $\propto = 8.75$ and $\beta = .63$ that is, each increment input produces steadily less as intensification is increased.

Figure 3.4. Global realtion between gross energy requirement for protein production versus intensity of protein production



Though the correlation coefficient over eight orders of magnitude are good (0.91) it would be a mistake to imagine that such a plot gave a unique answer to the productivity of any piece of the earth's surface. Firstly, the analysis supposes good husbandry, secondly (and this implies the former) one assumes that the crop or animal is appropriate to the soil, climate, genotype and so forth. In fact, figure 3.4, though shown as a log–log plot with a straight line, can be considered a vast collection intensification plots of an infinite variety of plant types, as depicted in figure 3.5. Thus, as one particular crop responds to inputs and peaks out, agricultural science and good husbandry dictate moving onto a more developed genotype better able to utilize inputs.

ENERGY INPUT-OUTPUT IN DEVELOPED COUNTRIES

One finds, on analysis, that the energy input–output ratio (that is, the energy ratios) of food producing systems do not significantly vary from country to country for a given level of ouput intensity. The energy ratios themselves may vary enormously but then so will the intensity of husbandry. This much may be seen from table 3.1. Thus, from a policy point of view, we are faced with the ineluctable truth that as man chooses to intensify the output of land, there is price to pay in energy terms. There is, in fact, no limit to the amount of food that can be produced if the energy is there.

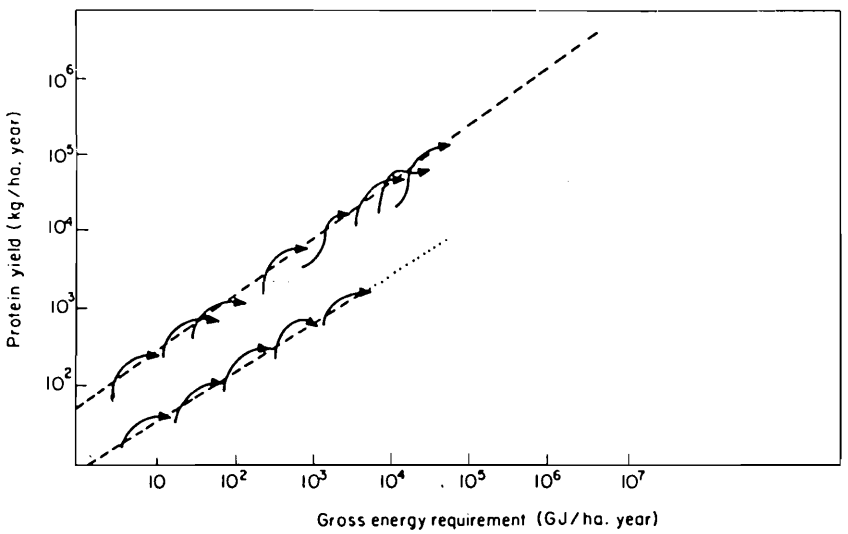
Table 3.1. Gross energy requirement of various food products as a function of intensity of production

Product	Country	Intensity (kg/ha)	Energy ratio[a]	GER (GJ/t)
Beef (low intensity grazing)	New Zealand	840	2.4	5.7
Corn (manpower only)	Nigeria	1004	6.41	2.3
Beef	Puerto Rico	1010	0.36	38
Corn (using an ox)	Guatemala	1066	3.1	4.7
Peanuts	N E Thailand	1280	2.6	6.3
Wheat	Saskatchewan, Canada	1514	8.7	1.6
Potatoes (edible yield)	UK	1790	1.6	2.02
Corn (manpower only)	Mexico	1944	10.7	1.4
Wheat	USA	2060	2.4	5.7
Maize	Tanzania	2060	5.4	6.3
Barley	UK	3410	2.4	4.6
Sugar-beet	UK	3550	4.2	0.77
Peanuts	Georgia, USA	3724	1.4	12.3
Fresh Peas	UK	3890	0.94	2.8
Barley	Denmark	4300	3.2	4.5
Maize	UK	5020	2.3	5.3
Milk	USA	5360	0.66	4.1
Rice (intensive)	USA	5581	1.3	11.7
Rice	India	9066	6.9 9	2.1
Apples	USA	17920	0.53	4.2
Potatoes	Denmark	28000	2.6	1.2
Sweet Potatoes	Taiwan	40000	18.5	2.6
Tomatoes	California, USA	49616	0.6	1.4

$$\text{Energy ratio} = \frac{\text{output of metabolisable energy}}{\text{input of fossil/fissile energy}}$$

In principle, one could produce all food by hydroponic means, where the energy ratios are far below unity. The interesting question is simply whether one can furnish enough energy to the food producing systems to meet man's needs. This is an energy supply question, not an agricultural problem. But as an energy supply problem it is also an economic problem, for the cost of energy determines the degree to which third world countries can lay their hands on enough energy for their food producing needs. If instead of looking at individual developed countries, one looks at the global food producing system, one quickly finds (as may be seen in table 3.1) that in some parts of the world energy ratios are much lower than in others. This suggests that the least energy intensive way to grow food globally would be to first intensify those parts of the world still comparatively unintensive, such as Brazil, Argentina, India, Thailand, China and many other countries, rather than further intensify the USA, Canada, Japan, and Europe. But this is the philosophy of idealism. For both strategic and environmental reasons, it pays countries to support their indigenous food producing systems. Moreover, for the developed countries the energy required for food production, direct and indirect, while large, is less than 5% of total national energy consumption, though up to three times as much energy is expended on food processing, delivery and cooking (Leach, 1977).

Figure 3.5. Interpretation of figure 3.4.



ENERGY REQUIREMENTS FOR AGRICULTURE IN THE YEAR 2000

To determine the energy requirements for agriculture in the year 2000 AD is at once an easy and an impossible question. Impossible, because we cannot know the affluence of the people of that future time, their numbers or their eating habits. But, given

assumptions about each of these, one can easily compute the energy required to feed the global multitude of the year 2000. If we assume the UN's median projections (6.2 billion), a basic diet of adequate nutrition for all (30 kg protein/person/year) and the same proclivity as today to eat meat and other energy intensive food products, one finds that the fraction of world's energy dissipation that must go to agriculture in 2000 will remain much the same as today, and will amount to about 364 million tonnes oil equivalent, that is a 270% rise on 1975 energy to produce food up to the farm gate. This rise comes essentially from two factors, increasing population, and increasing intensification of the land, leading to more energy input per unit of food output. The basis for this computation cannot be given here, but is embodied in the world energy supply model, PIE-EM (Slesser, 1980).

If the question is addressed to individual countries, then the calculation may be more precise, and the answers more varied. If one makes some assumptions about eating styles (balance between animal and fish as opposed to vegetable or cereal diets) one can readily show how changing population alters the energy needs for food production within individual countries, which are largely, or seek to be largely, self-sufficient (Figure 3.6). Another interesting way to look at the problem is to work out the fraction of the national energy consumption that has to be spent on food. Figure 3.7 shows such a display for Kenya (Hounam and Slesser, 1980).

Prospects for improved energy use in developed agriculture

There are two main avenues for improvement: The first is to take a close look at the trade-offs between energy use and labour. The second is to examine the factors pushing farmers towards higher economic efficiency. Let us take the first.

Steinhart and Steinhart (1974) have looked at energy–labour trade off in U.S. agriculture. From their data one can compute that the marginal energy requirement to replace an hour of man-power has steadily risen till by 1975 it had reached 0.73 GJ/man-hour (about 19 litres of fuel). As the relative price of labour and energy change, the economic optimum will change. Till recently the cost of labour was rising faster than energy. Now that trend has been reversed. It may be that normal economic forces will improve the energy-labour trade-off in favour of reduced energy use and enhanced labour use, though the amount of the change is likely to be fairly small.

But one cannot look at labour without looking at the other factors that have pushed farmers towards greater economic efficiency. Principally these have been the pressure on land prices on the one side, and government determination to control food prices for purely popular political reasons. Every farmer has been faced with the task of getting more out of the same land or of going out of business. It often pays to leave land fallow (as in the USA) and concentrate on a smaller area, or to put land under trees or sell for property development, and then grow more intensively on what remains. Economic efficiency in a market orientated society, tends to push farmers towards an industrial type of agriculture. It is now not at all unusual to have capital investment in farming enterprises at the level of £5000 a hectare for a unit of 400 hectares. With that level of investment it is not easy, perhaps even impossible, to

Figure 3.6. Minimum energy requirement for two food patterns related to agricultural land availability

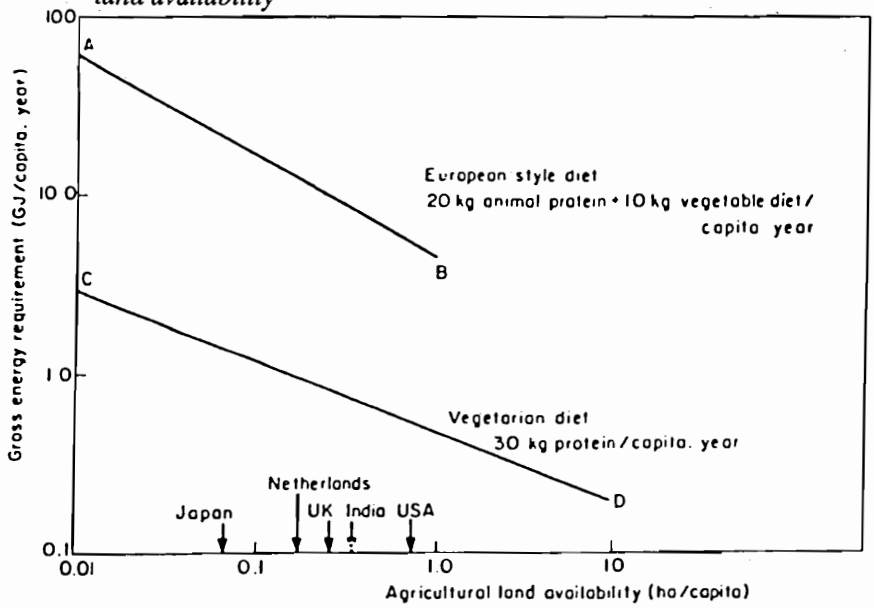
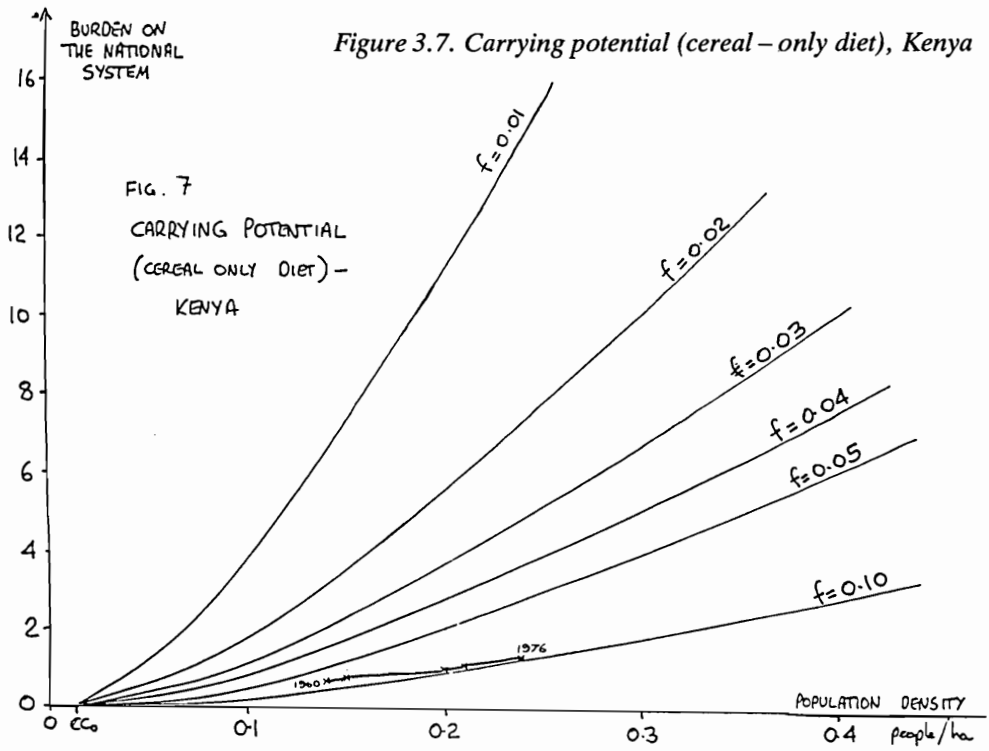


Figure 3.7. Carrying potential (cereal – only diet), Kenya



embark on any sort of deenergization of the farming activity. In the EEC, the European Commission has actually paid farmers to go out of business, thus intensifying the remaining farmers. In an extreme case of destructive economics, hot house tomato growers were only compensated if they broke or dismantled the glass houses! What however, may be possible is for the farmer to utilize the biomass output of his farm. Grain is often no more than 40% of his output. The balance, such as straw may be burnt, or used as green manure or other wastes, digested in a biogas digester, to yield methane. One might call this approach the better use of solar energy. So far there has been a piecemeal attack on these approaches, with little attempt to explore the consequences of a fully integrated farm in which wastes and maximal use of solar energy form the basis of the inputs.

Indeed efforts to interest development planners in the developed countries have, to the certain knowledge of the author, been spurned. One must turn to studies in the less developed countries to see what can be achieved by these methods. A study made by Seshadri *et al.* (1981) of a simple agricultural system in India showed that output would be raised three fold, with a reduction of energy ratio of food products from a very poor one to one ratio today to a potential 10:1 fifteen years hence. This would be entirely achievable by integrating various bio-and solar technologies within the agricultural process in such a way as to partially complete the biological cycle. In the developed world this is not entirely possible because the farmer sells most of his food for consumption off-site, to the people of the cities. Yet if the sewage of those cities could be treated, to yield energy and fertiliser inputs to the farming process, the energy ratio (with the system taken as a whole) could be much improved. This point is well developed by Ward and Sutherland (1980).

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CHAPTER 4

Energy Balance in Agriculture: the Developing World

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INTRODUCTION

IN EVERY SPHERE of human endeavour energy requirements have become a major consideration. Until the beginning of the 1970s no one cared about the relationship between energy and agriculture; otherwise Paddock and Paddock (1967) would have found an additional reason to forecast doom for the developing countries. However, the realities of life have unfolded in recent years, and it is now very clear that the Western model of agriculture adopted by all developed countries and to some extent by some developing countries, is energy intensive. In fact, replacement of human and animal energy by commercial energy has been a major achievement in the United States, the Federal Republic of Germany, the U.K. and other developed countries. This led de Wit (1975) to suggest a new definition of agriculture stating "agriculture should be redefined as the human activity that converts fossil fuel into food by means of solar energy, plants and animals." Indeed this definition is appropriate for the developed countries. Many authors defend this achievement by stating that after all growing eatables require energy and no one could think of eating fossil fuel which must be utilized to produce food (Slesser, 1986). On the other hand, the time spent by a population on food collection or production may be taken as an index of the advancement of a society or nation. The people spending less time on food, would have more time for other creative work, which in turn would improve other aspects of the society. However, there does come a time when an innovation tends to become a liability if it were based on a factor which is likely to become limiting and is beyond the human control. The use of fossil fuel in agriculture seems to be such an innovation. The basic concept of the Western model of agriculture is that it requires heavy investment of commercial energy. Since the sources of commercial energy are exhausting, it leads to the following alternatives:

1. That the source of energy in agriculture should be changed from non-renewable to renewable forms.
2. To improve the energy use efficiency in the present system of agriculture.

Both the alternatives mentioned above require a detailed energy analysis of the agricultural system so that certain options could be identified. Several such analyses have been made in recent years (Leach, 1976; Pimentel and Pimentel, 1979). All these studies consider energy balance in the production of an individual crop. Using some unrepresentative data base, Pimentel & Pimentel (1979), Pimentel & Trehune (1978), and others have analysed energy balance in agriculture of the developing countries. The analyses presented by Leach (1976) and Pimentel & Pimentel (1979) tend to suggest the following:

1. High productivity and modern agriculture are synonymous.
2. Modern agriculture is highly mechanized. Therefore, high productivity can be achieved through mechanization.
3. Developing countries should modernize their agriculture to increase food production to enable them to meet their future needs. This means that the developing countries will have to make substantial investments in developing energy resources.
4. Slesser (1986) admits that use of fossil fuel is essential and inevitable for food production.

Almost all energy analysis results are based on the conventions agreed to by energy analysts of the developed world. Therefore, it is relevant to restate these aims and conventions to enable us to develop suitable conventions for the developing countries.

ENERGY ANALYSIS

Conventions and methods

In a workshop held at the International Federation of Institutes for Advanced Study, certain conventions were agreed to by the participants (IFIAS, 1974). Following this Leach (1976) stated "a major aim of energy analysis is to estimate the total quantity of energy required directly or indirectly to provide a good or service to a final user. By agreed convention this is called a Gross Energy Requirement (GER), or briefly as 'energy input'." Leach (1976) further stated "In estimating a GER or 'energy input', one is trying to evaluate a quantity similar in conception but complementary in kind to the economist's notion of a 'cost'. A cost measures a certain sum of actually or potentially 'useful' physical resources (labour, material, fuels, land, etc), evaluated to the present time as x that are required to produce a given good or service. A fundamental assumption underlying this concept is that there are other com-

peting uses for the resources. If there were no such alternative uses (now or in the foreseeable future) then the concept of a cost has no meaning".

The above concepts have led to the following conventions:

1. Solar energy is not to be treated as an input since it has no cost.
2. Fossil fuels such as coal, oil and natural gas used directly or indirectly have to be included as input. The same would apply to hydro-electric power.
3. Human and animal work: For industrialized countries, the input of human energy varies from 0.2 to 0.5% of the total input. Therefore, it is ignored. According to the agreed convention, no charge is made for the energy required to support the personal or domestic life of the farmer or farm workers since these are of no relevance to the business of producing food.
4. However, in the case of low energy systems, such as those prevalent in developing countries, human or animal labour must be counted since they are often the only energy input (apart from the sun).

There are obvious difficulties in calculating the input of human and animal energy. Three different alternatives have been described by Leach (1976) apparently based on the agreed convention. According to him, the amount of food energy taken by a man proportionate to the amount of time spent on agriculture should be counted as energy input. In case this is not done, the energy output: input ratio would become infinite, which will be inappropriate.

As against this Makhijani and Poole (1975) considered 5% efficiency of energy generation in animals. Thus, a work equivalent to 5 h.p. by cattle was taken as an input of 100 h.p. energy. The same standard was applied to human labour. Strangely Makhijani & Poole (1975) did not consider crop residues as energy output which constitute a major portion of animal feeds. Further, they did recognise that cattle dung accounts for 40-60% of animal feed, but surprisingly the use of cattle still appeared as energy input with 5% efficiency.

All the above energy inputs were then used to show an output of 850 kg ha^{-1} of wheat which is about 60% of the national average of 1450 kg ha^{-1}. Unfortunately, these calculations have become the basis to show that energy balance in agriculture in India, representing the developing countries, is not only poor but negative.

The above discussion highlights the need for a rational basis of energy analysis studies wherever, human and animal power is a major component of energy input.

Human energy

Let us consider a simple question of transport of fertilizer from the market to home and then to the field of a farmer. Energy is needed to load, unload and transport fertilizer. Thus, the movement of 1 tonne of fertilizer would require a certain amount of energy to transport it to a kilometer. If a vehicle is used in the transport, we consider the amount of energy spent on the production of the vehicle. Should we give the same consideration to a man and animal? A man once born has to be fed whether he works or not. Therefore, the total food energy spent on the maintenance could not be logically used as energy input, with whatever efficiency one might like to include.

Indeed, the energy spent in transport of fertilizer by man equivalent to any other unit should be used as energy input in the system. Thus, man-hours in different agricultural operations could be converted into energy units, but not the total food energy required to maintain a healthy man.

Animal energy

Animal energy input should also be used as the duration of work by animals in energy units. Thus, an hour work by a bullock is equal to 0.5 horse power or 8.0 MJ. However, the question of energy to maintain an animal is different than of a man.

Odend'hal (1972) observed 17% energy efficiency of cattle population in West Bengal in India. Thus, one might like to multiply the animal energy by a factor of six, to calculate energy input in agricultural operations. And yet, this would not provide a satisfactory alternative, because such a large amount of energy *per se* is not utilized in a particular operation. However, one must consider crop residue as a component of energy output in agriculture because crop residue constitutes a major part of animal feed in developing countries. For the purpose of estimating energy inputs in the production of a crop, the time spent in terms of energy units should be used.

Energy output

Leach (1976), Pimentel and Pimentel (1979), Slesser (1986) and others consider the edible food for humans as the only output because it is the primary purpose of producing food. Outputs are normally given in the form of (a) a weight or volume of whole food (e.g. kg or l. of milk), (b) a nutritive energy content (MJ) and (c) a quality of crude protein. Thus, from the point of view of developed countries, crop residues such as wheat straw, sorghum stem sticks, sugarcane tops, leaves of pulses, etc. have no output value. Accordingly they are not either mentioned or included in calculations for energy output. Unfortunately, while calculating energy balance in agriculture of developing countries, the animal energy is used as energy input but crop residues are ignored (Pimentel *et al.*, 1975; Leach, 1976; Pimentel & Pimentel, 1979). This is a gross misrepresentation of data from the developing countries and could be due to insufficient understanding of agricultural systems of the third world. However, representation of data by Makhijani & Poole (1975) by ignoring such basic aspects of agriculture in the Third world displays their bias towards the Third world.

OBJECTIVES OF ENERGY BALANCE STUDIES IN DEVELOPING COUNTRIES

Energy analysis studies in developed countries are aimed to determine the absolute energy requirement in the production of an edible product by human beings. This indeed would be a broad objective of any study, but in developing countries we must know the importance and contribution of commercial energy in crop production. We have to examine the requirements of commercial energy in the year 2000, in mechanized, semi-mechanized and animal based farming. Therefore, we should have the following objectives:

1. What is the minimum requirement of commercial energy to practice modern agriculture?
2. Which commercial energy requiring inputs have poor efficiency? How could they be improved?
3. What is the importance of animal based agriculture? Can it be replaced in near future and at what cost?
4. The possibility of energy farming using conventional crops.

MODERN TECHNOLOGY OF GRAIN PRODUCTION

The modern technology is necessary to improve crop production in different parts of the world, if the food needs of the people are to be met even at the present level of consumption by 2000AD. The modern technology has developed over the years in developed countries but has become universally available. The major components of this technology are the high yielding variety, inorganic fertilizers, pest and weed control measures, irrigation, timely field operations and adequate post-harvest technology. In developed countries almost all operations are mechanical and hence energy intensive. For example, once a high yielding variety is identified, the seed production, processing, storage and transport could change the energy value of 1 kg paddy from 15MJ to 3OMJ. Thus, the energy cost of crop production increases substantially in developed countries. As against this, in developing countries land preparation, planting, weed control, pest and disease control, harvesting, threshing, transport of grains and their storage are carried out by human or animal energy. Thus, with the exception of fertilizers, pesticides and irrigation, all other operations are almost without the use of commercial energy. However, in many countries such as India, Pakistan, Bangladesh, etc., a large part of irrigation is through canal or surface irrigation involving no use of energy.

The following questions become relevant from the point of view of developing countries:

1. Is it possible to get the same grain yield by using human and animal energy as by mechanized farming?
2. What is the response of crops in respect of grain yield as well as energy output to such input which require commercial energy i.e. inorganic fertilizer, irrigation, pesticides, etc.
3. Which commercial energy inputs could be replaced by renewable sources of energy?

Answers to the above questions can help the developing countries to decide the needs of commercial energy in future. They may also have to consider the possibility of making liquid fuel through the use of agriculture, or install biogas plants to meet the energy needs.

Comparison of agriculture systems in the developed and developing countries

The modern agriculture in the developed countries such as the United States, Canada, Australia, etc. is almost completely mechanized. The landholding are usually 100 hectares or more because only a small population, approximately 5%, is engaged in agriculture. In the developing countries, the land holdings are small (Table 4.1). In the early sixties 71, 51, and 39% farm sizes were less than one hectare in Indonesia, Bangladesh and India, respectively. By 1970–71, 50.6% of the farms were smaller than 1 hectare in India (Table 4.2). Thus, the trend towards smaller farm size has been increasing in densely populated countries. As against this, in many western countries, the farm size has been increasing because many farmers have left their farms to start other occupations. This trend is clearly evident from the decreasing percentage of the population engaged in agriculture in USA (Heady, 1976).

If we consider the situation in India as representative of most of the developing countries, it is then apparent that the percentage of farms with land holdings of smaller than 1 hectare, 2 hectare and 3 hectare is 50.6, 69.6 and 79.1, respectively (Table 4.2). The number of farms above 20 hectares were only 0.9% in 1970–71. This number has further decreased in the subsequent years. The farmers having holdings of 1 to 3 hectares cannot be expected to have mechanized farming using tractor or power tillers. It is difficult, if not impossible, to persuade farmers to have community tractors because of uncertainty of its availability due to shortage of liquid fuel, repairs or services. Therefore, the use of animal power becomes an inevitable consequence. In fact, as has been argued in the later section of this chapter, the animal power cannot be replaced in near future. As against this, the increasing farm size in developed countries makes mechanization inevitable. However, in India, Philippines and many other developing countries, one has the opportunity of comparing different farming systems, such as mostly mechanized, mixed and bullock (animal) operated. The mechanized farming in India would still have some manual operations, such as weeding, hoeing and harvesting.

Table 4.1. Distribution of farm size in Indonesia, Bangladesh and India

Area (Hectare)	Percentage of different holdings		
	Indonesia (1963)	Bangladesh (1960)	India (1961)
Less than 0.4	45	24	-
0.4–1.0	26	27	39*
1.0–2.0	18	26	23
2.0–3.0	5	12	13
3.0–5.0	3	7	15
5.0–10.0	2**	3	6
Over 10	-	-	-

* All holdings under 1 hectare
** Including over 10 hectare
After Wortman and Cummings, 1978

Table 4.2. Number of operational holdings of different size categories in India (1971)

Size Class in ha.	Number x 10^6	Percentage
0.5	23.2	32.9
0.5 - 1.0	12.5	17.7
1.0 - 2.0	13.4	19.0
2.0 - 3.0	6.7	9.5
3.0 - 4.0	4.0	5.7
4.0 - 5.0	2.7	3.8
5.0 - 10.0	5.3	7.5
10.0 - 20.0	2.1	3.0
20.0 - 30.0	0.4	0.6
30.0 - 40.0	0.1	0.1
40.0 - 50.0	0.05	0.1
Over 50.0	0.05	0.1
Total	70.5	100.0

Anonymous 1975: Agricultural Census of India (1970–71)

Studies on farm size, cropping intensity and energy balance have been attempted in Punjab, which is one of the agriculturally most progressive and advanced states in India. Three categories of farms, low, medium and high on the basis of productivity were chosen. Irrespective of the productivity group, the average size of holding was 10.12, 4.95 and 3.27 hectares for tractor, mixed and bullock operated farms respectively (Table 4.3). For these groups of farms i.e. tractor, mixed and bullock operated, the cropping intensity was 174, 182 and 190, respectively (Table 4.4). Even in low productivity bullock operated farms the cropping intensity was 195 as against 171 and 177 in tractor and mixed farms. We can draw two important conclusions from these studies:

1. With the increasing farm size, mechanization increases. Smaller farms are mostly or exclusively bullock operated.
2. With the increasing mechanization, there is a decrease in cropping intensity.

Of the two conclusions, the second is rather surprising and affirms that mechanization need not necessarily lead to improvement in agricultural production if the latter is through multiple cropping in the developing countries.

Table 4.3. Average size of holding (ha) of different categories of farms in Punjab (1978–79)

Level of Productivity	Categories		
	Tractor	Mixed	Bullock
	Low	8.86	4.49
2.95			
Medium	10.77	4.85	3.54
High	10.73	5.51	3.32
Average	10.12	4.95	3.27

Source: Annual Report Energy Requirements (1978–79), Punjab Agricultural University, Ludhiana, India.

Table 4.4. Intensity of cropping on various categories of farms in Punjab (1978–79)

Level of Productivity	Farm Categories		
	Tractor	Mixed	Bullock
Low	171	177	195
Medium	160	175	180
High	197	194	190
Average	174	182	190

Source: Same as Table 4.3.

Grain yield in farms of different categories

An important consideration for determining utility and efficiency of different categories of farms is the level of their productivity. In Punjab, a comparison of productivity in tractor, mixed, bullock operated farms showed that there was no significant difference in the productivity of wheat, paddy (rice), maize and cotton (Table 4.5). In fact, the yield of maize and cotton in bullock operated farms was better than mixed or tractor operated farms. Recent investigations at the International Rice Research Institute, Manila, Philippines by Kuether and Duff (1981) also demonstrated that the same yield of rice could be obtained in mechanical, transitional and traditional farms (Table 4.6). Thus, it is reasonable to conclude that mechanization is not associated with higher productivity.

Table 4.5. Yield kg ha^{-1} of various crops of different categories of farms in Punjab (1978–79)

Crop	Category		
	Tractor	Mixed	Bullock
Wheat	3040	3160	3130
Rice – Paddy	6280	6330	6330
Maize	810	740	870
Cotton	570	650	650

Source: Same as Table 4.3.

Table 4.6. Energy inputs (MJ ha^{-1}) for the various rice production systems in the Philippines

Operations	System of Production		
	Traditional	Transitional	Mechanical
Land Preparation	1567.0	1887.2	1470.7
Planting	729.8	729.8	729.8
Crop Care	3880.9	3880.9	3880.9
Harvesting	150.0	150.0	150.0
Threshing & Drying	249.1	249.1	2484.4
Total	6576.8	6897.0	8715.8
Energy Equivalent as diesel (1)	171.4	179.6	227.1
Grain yield kg.	3500	3500	3500

Comparisons of energy budget in different crops

Leach (1976) and Pimentel & Pimentel (1979) have calculated energy budgets for corn, wheat and rice for some countries having differences in the pattern of energy use. The yields of corn vary from 1000 to 5000 kg ha among different countries. Although with highly mechanized and energy intensive farming, the yield of corn in the U.K. and in the United States has reached five tons per hectare, but semi-mechanized and non-mechanized farming in India and Mexico could yield 2500 kg per hectare and 1934 kg per hectare respectively (Table 4.7). This gives an energy output: input ratio of 2.57 in U.S.A., 2.33 in U.K. and 5.02 and 30.6 in India and Mexico, respectively. It should be pointed out that energy ratio further improves for India and Mexico by considering the energy output of corn stalks or stem. In Philippines, even the introduction of partially mechanized farming did not improve grain yield. Thus, it would appear that mechanized farming does not necessarily enhance crop production, though it does lead to poor energy ratio.

If we consider energy output in relation to commercial energy input, obviously the output ratio might reach infinite which is not realistic but emphasizes the fact that up to 2 tons yield could be obtained without using commercial energy. Undoubtedly, the grain output could be substantially increased by introducing such inputs as inorganic fertilizer and irrigation.

Table 4.7. Energy budgets in corn production in different countries GJ/ha/yr

	Countries						
Inputs	Mexico	Guatemala	Nigeria	Philippines	India	U.K.	U.S.A.
Labour	0.915	0.561	0.496	0.237	0.119	-	0.018
Animal	-	2.488	-	1.168	0.224	-	-
Machinery	0.045	1.013	0.045	1.013	0.050	2.84	4.343
Fuel	-	-	-	-	0.346	3.82	8.92
Fertilizer	-	-	-	-	-	-	-
Organic	-	-	-	-	3.000	-	-
Inorganic	-	-	0.90	0.375	3.820	5.51	11.12
Others	-	-	-	-	-	14.2	5.45
Total	0.96	4.062	1.44	2.79	7.56	26.37	29.85
Output							
Grain (kg)	1934	1056	994	931	2500	5002	5060
Grain Energy	29.4	16.05	15.1	14.15	37.9	61.7	76.91
Crop Res. (kg)	3868	2112	1988	1862	4500	-	-
Crop Res. (Eng)	51.1	29.6	27.8	26.0	63.0	-	-
Output (Grain) Input ratio	30.6	3.95	10.48	5.06	5.02	2.33	2.57
Output (Biomass) Input ratio	80.8	11.2	29.8	14.3	13.3	-	-

Table 4.8. Energy balance in paddy-rice production in different states of India (GJ ha^{-1})

Inputs	States						
	Punjab	Tamilnadu	Maharashtra	West Bengal	Bihar	U.P	U.P.
Field Operations and crop care	0.77	1.45	0.62	0.72	1.41	0.66	1.52
Irrigation	9.35	-	-	-	-	0.43	-
Organic Fertilizer	7.20	1.50	-	0.36	0.60	1.20	1.20
Inorganic Fertilizer	9.88	1.29	0.80	-	-	2.20	2.85
Total input (GJ)	27.20	4.24	1.42	1.08	2.01	4.49	5.57
Grain yield (Kg.)	7200	1800	400	1000	600	1000	1600
GJ	106.56	26.6	5.92	14.80	8.88	14.80	23.68
Output: Input ratio (Grain)	3.91	5.14	4.17	13.70	4.40	13.29	4.25
Total biomass Energy	297.74	74.48	16.57	41.44	24.86	41.44	66.30
Output: Input ratio (Biomass)	10.94	17.56	11.67	38.37	12.36	9.22	11.90

Table 4.9 Energy balance in wheat production in different states of India (GJ ha^{-1})

Inputs in Operations/items	States			
	Punjab	West Bengal	U.P.	Himachal Pradesh
Field operations and crop care	2.22	1.19	2.89	2.90
Irrigation (Diesel)	4.76	-	-	-
Organic manure	-	-	-	11.49
Inorganic fertilizer	2.97	-	1.00	2.40
Total	9.95	1.19	3.89	6.74
Grain yield (Kg)	4200	2800	2500	1000
GJ	62.1	41.4	37.0	14.80
Energy Output: Input ratio (Grains only)	6.24	34.78	9.51	2.19
Total biomass energy	179.8	115.9	103.6	41.44
Energy Output: Input ratio (Biomass)	18.07	97.41	26.63	6.14

Although it is common to use a single value for grain yield and inputs in preparing energy budgets for a country (Makhijani & Poole, 1975; Leach, 1976; Pimentel and Pimentel, 1979), there could be a considerable variation within a large country, such as India (Table 4.8). Both the level of input and output varies depending upon the availability of water, fertilizers, pesticides and above all the attitude towards agriculture. Thus, paddy rice production per hectare is now highest in Punjab though the highest output: input ratio was observed in West Bengal. A similar situation was obtained for wheat cultivation in different states of India (Table 4.9). It was claimed

by some farmers in West Bengal that they could obtain 1200 kg wheat grain yield without any fertilizer application or irrigation. During the rainy season, this area is often flooded and receives new soil and is characterized by high water table. As against this, in Himachal Pradesh, a hilly region, the productivity was 1000 kg despite application of fertilizers. Nevertheless, the output: input ratio varied from 2.04 to 35.6. Thus, it appears that the energy output: input ratio depends on several factors which could be location specific.

FACTORS AFFECTING CROP YIELD AND ENERGY RATIO

Single values for energy output: input ratio for wheat and rice were estimated for farming systems in India by Leach (1975), Pimentel & Pimentel (1979) and also others. The output values were based on grain yield lower than the national averages of wheat and rice. However, an average grain yield of 1450 kg ha^{-1} of wheat is indicative that there would be areas which produce more while others which produce less than the average yield. The average grain yield of wheat in Punjab is well above 2500 kg ha^{-1} whereas in Madhya Pradesh, it is much lower than 1000 kg ha^{-1} (Sinha and Aggarwal, 1980). However, the inputs and crop management differ widely in these two states. This can be observed from the variation in inputs and grain output of maize in several countries (Table 4.7). An analysis of crop production in India indicates that the energy input varies considerably from one region to another (Table 4.8). The difference can be observed in the use of commercial energy, which is not necessarily proportionate to energy output. Therefore, it is important to identify factors which with very little energy investment can contribute in increasing the output, to improve energy balance or energy ratio. This could happen due to either of the following:

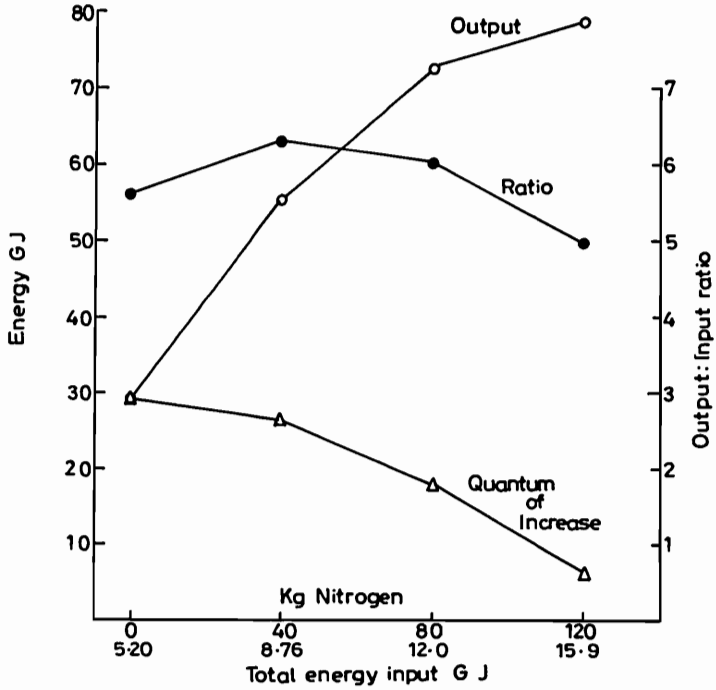
1. Reducing energy input, particularly the commercial energy in developing countries.
2. Increasing production without a significant change in energy input.
3. A combination of the above.

Firstly, the major items of energy input are fertilizer, irrigation and organic manure. Therefore, management of these inputs would possibly have a significant effect on energy balance.

Fertilizer use

In last two decades, there has been a sharp rise in the use of inorganic fertilizers in developing countries. Amongst the various fertilizers, nitrogen application constitutes a major component. In most of the tropical regions, the losses of nitrogen are very high, particularly in crops such as rice (Prasad, 1985). Since rice is the most

Figure 4.1. Effect of nitrogen application on energy output and input ratio in wheat



important crop in many developing countries which are located in the tropical region, any improvement in nitrogen use efficiency could be an important objective for obtaining better energy output: input ratio. Several techniques such as split application of nitrogen or use of sulphur or neem-cake coated urea have been suggested. Unfortunately, they have not yet gained popularity with the farmers. Furthermore, the effectiveness of these techniques is much more obvious in winter crops such as wheat. In wheat also the results show that a dose of 40 kg N ha^{-1} gives reasonable return in energy output. Enhanced levels of nitrogen application gave a poor quantum increase (Figure 4.1). Therefore, much more efforts are needed for summer or rainy season crops if the nitrogen use efficiency is to be improved.

Availability of fertilizer nitrogen will always be dependent upon energy input. The cost of energy, particularly the fossil fuel, will continue to rise in future. Therefore, dependence on fertilizer will become a more and more difficult proposition for the developing countries in view of their increasing needs of food. Biological nitrogen fixation is by far a cheaper source of nitrogen. In developing countries mixed cropping involving a cereal and a legume is an age-old practice. In recent years, it has been demonstrated that leguminous crops contribute nitrogen to cereal crops in such combinations. In addition, in a multiple cropping system, short duration legumes such as cowpeas, mungbean and others enrich the soil in nitrogen which can be utilized by the succeeding crop. This effect could be equivalent to 25 to 30 kg N ha^{-1} (Giri & De, 1981). A saving of 25–30 kg N ha^{-1} could be enormous in a country where per hectare consumption of nitrogen is only around 30 kg N ha^{-1}.

A long-term objective in developing countries should be based on promotion of biological nitrogen fixation by cereals either through rhizosphere association or development of symbiotic relationship with nitrogen fixing organisms. In this respect, studies with old varieties could be useful because these were largely grown without any inorganic fertilizers. They possibly harbour some mechanism(s) which facilitates association with rhizospheric nitrogen fixing organisms.

Efficient use of irrigation

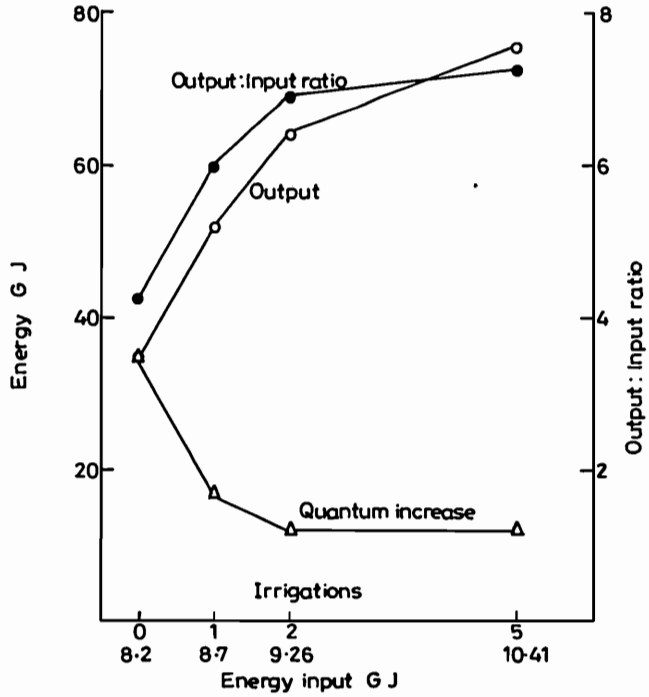
Water is a major constraint in crop production in tropical countries. In the rainy season, there are long periods of dry days or premature termination of rains thus causing conditions of water deficit at the time of grain development. This has a serious adverse influence on grain yield. A single irrigation on such occasions can have a profound effect on grain yield (Table 4.10) and hence on energy balance. Depending upon the source of irrigation the energy cost differs widely. In those areas where harvesting of rain waters is practiced, the energy cost is insignificant. For an input of 0.15 to 0.45 GJ, there could be a return of 10 to 14 GJ in the form of grains under the above adverse conditions. If the irrigation source is a canal, then the cost of irrigation is only 16 man hours or 12.8 MJ. However, the energy cost of tubewell water could be 165 MJ ha^{-1}. Thus, whatever be the source of irrigation, a single irrigation when provided during the periods of water deficit aids in achieving high returns of energy output. This situation may not be applicable in temperate regions because of the mild temperatures the crop does not often experience severe stress during grain development. In areas predominantly irrigated, increasing the number of irrigations does not necessarily increase yield very significantly. In fact the quantum increase decreases after one irrigation (Figure 4.2).

Table 4.10. Effect of a single irrigation on the yield of various crops

Region	Crop	Season's average	Yield Q ha^{-1}	
			Without Irrigation	With one irrigation
Bijapur	Sorghum	5	16.5	23.6
Sholapur	Sorghum	5	9.8	18.2
Delhi	Sorghum	4	31.2	42.5
Rewa	Upland rice	4	16.2	27.8
	Wheat	4	15.7	18.8
Ludhiana	Wheat	4	19.2	41.1

Source: All-India Co-ordinated Project on dryland Agriculture, ICAR. "A corner stone for dryland agriculture" 1979, and Professor of Eminence Scheme, IARI, N.Delhi.

Figure 4.2. Effect of irrigation energy on energy output and energy ratio in wheat



The improvement in irrigation efficiency can be affected by several methods which would reduce losses of water in transport from the source to the field. Lining of the channels, underground or covered transport systems and proper methods of irrigation could improve irrigation efficiency by 25% or more. In tubewell operated irrigation systems, it is estimated that more than 50% of the wells are poor and require attention to supply adequate water. The pump sets usually have a poor efficiency. It was estimated by Pathak *et al.* (1981) that a 20% increase in efficiency of pump sets would save 7761 tonnes of diesel in Punjab alone. At the national level, this could help saving 5 TWH units of electricity and 1.84 million tons of diesel by 2000 A.D. by improving efficiency of pumpsets and tractors. Thus, improvement of pump sets and water transport system alone could improve output: input energy balance in the developing countries. In addition to the above some minor alterations in pumping systems could save energy to a considerable extent. Recently scientists at the U.P. Agricultural University, Pantnagar, have developed a footvalve for water lift systems, which can effect about 80% reduction in energy requirement of the present consumption with the other valves (Table 4.11). These are small devices but very significant for rural economy where most of the energy balance is decided.

Table 4.11. Power required to overcome head loss due to friction caused by commercial foot-valve and Pantnagar foot valve considering pump and motor efficiences 70 and 90 per cent, respectively

Type of Foot valve	Power required at maximum discharge rate			Power required at 21 lit/sec.		
	Head loss m	Power needed hp	Relative energy loss	Head loss m	Power needed hp	Relative energy loss
Commercial foot valve	3.18	1.83	4	2.31	1.03	8
Pantnagar foot valve	0.65	0.46	1	0.31	0.13	1

Source: S.Ram, H.C. Sharma and H.S. Chauhan (1982).

Use of organic manure

Organic manure is an important energy input in crop production during the rainy season in most parts of India. This is responsible for a relatively low energy output: input ratio in maize and paddy. It is estimated that annually 970 million tonnes of wet dung is available in India. This equals to 170 million tonnes of dry weight of dung. Most of this is either consumed as fuel or is used as manure. Both these objectives could be met if the use of dung is rationalized.

Biogas production from animal and agricultural waste is one of the notable achievements of Indian science since its inception in 1939 at the Indian Agricultural Research Institute, New Delhi. Biogas contains between 50–60% methane and 5–10% hydrogen both of which serve as fuel. One tonne of dung produces 66 cubic meters of biogas at Delhi but it could produce more wherever there is no cold season, for example, Central and South India. However, even with this average production, the presently available dung could provide 1.2×10^9 GJ as against the total of 5.2×10^9 GJ available at present through coal, petrol and hydroelectric (Sinha, 1980). Another advantage of biogas production would be the availability of 3.04 million tonnes of nitrogen, 2.85 million tonnes of P_2O_5 and 1.9 million tonnes of K_2O as by-products. Furthermore, the energy source would be available at the village level without investing in long distance transmission and transport. Accordingly, the biogas technology can have a profound effect in the Third World. Here it must be added that the age-old practice of supplying organic manure to the fields is for maintaining a reasonable level of organic matter in the soil and replenishment of micronutrients. The organic matter serves as chelate and rarely an occasion arises when micronutrient deficiency is observed. However, the modern agriculture technology has resulted in higher production with a concomittant removal of nutrients from the soil. In most developing countries, there is no crop residue left in the field to be ploughed back into the soil. Consequently, in the absence of any addition of organic matter, it

will not be surprising if the soil fertility is eroded. Therefore, it is necessary to determine the optimum number of cattle population in India, so that a part of the crop residue is returned back to the soil instead of being used as cattle feed.

Crop sanitation

In tropical countries, the crop yields suffer due to weeds, pests and diseases. The number of diseases and pests on major crops is severalfold in tropical regions as compared with the temperate regions (Swaminathan, 1980). In several pulse and oilseed crops plant protection alone can double the yields. Pradhan (1971) in a very eloquent article demonstrated that plant protection is more important in the tropics. As an example, it can be seen from Table 4.12 that the yield of Brassica increased 700kg and 1100 kg with plant protection alone and plant protection plus fertilizer application respectively. Since the grain yield is a measure of energy output, it is obvious that just by an input of 205 MJ an output of 1400 MJ could be enhanced. These examples can be multiplied to emphasize that a very small input energy in the form of pesticides

Table 4.12. Relative increase in yield of rai *(Brassica sp.) by two inputs separately and in combination*

Treatment	Year	Yield Q/ha. 1965–66	1966–67	1967–68	Average
1. Control		7.5	10.3	22.1	13.3
2. Plant protection measures (pest control only)		15.0	15.4	30.3	20.2
3. 100 kg N, 50 Kg P_2O_5 and 50 Kg K_2O ha^{-1}		14.6	9.7	29.1	17.8
4. Combination of 2 and 3		19.2	18.8	35.1	24.4

Based on Pradhan, 1971.

could considerably improve yield. This would be far more paying than mechanization of agriculture.

There are a large number of weeds in tropical countries which strongly compete with crops both in irrigated and unirrigated conditions. Chemical weed control is somewhat sophisticated and it has been difficult to induce an ordinary farmer to use such modern methods. However, the age-old labour intensive hand weeding method is generally practiced. Improvement in crop yield due to hand weeding in rainy season crops is shown in Table 4.13. Six to eight persons can do weeding in one hectare of land. Thus, an input of 40 to 200 MJ of human energy could enhance energy output by 11.8 to 30.8 GJ.

Table 4.13. Effect of weed control on crop yield in dryland agriculture

Region	Crop	Method of weed control	Seasons average	Yield Q ha^{-1}
Sholapur	Pearl millet (Bajra)	Hand weeding	5	9.5
		Control	-	1.8
Bangalore	Elusine (Ragi)	Hand weeding	3	27.2
		Control	-	15.0
Hyderabad	Sorghum	Hand weeding	2	37.4
		Control	-	15.0

Source: All-India Co-ordinated Project on Dryland Agriculture, ICAR. *In*. A Corner Stone for Dryland Agriculture, 1979.

ENERGY BALANCE IN A FARMING SYSTEM BASED ON MAIZE-WHEAT AND RICE-WHEAT CROPPING SEQUENCE

The conventions and methodologies adopted at the Stockholm Workshop considered energy balance in a single crop only. This was inevitable because in most of Europe and north America, usually only one crop is grown in a year. Therefore, they refer to energy balance as annual for a single crop (Leach, 1976; Pimentel & Pimentel, 1979).

Table 4.14. Energy input and output in production of maize and rice paddy as rainy season crop and wheat as winter crop following maize or rice paddy

Inputs ha^{-1}	Maize	*Energy in MJ* Rice Paddy	Wheat
Manual	497	1093	616
Bullock	824	1264	1600
Diesel	3031	10392	4763
FYM	10485	10485	-
Fertilizers	960	410	1600
Total	16157	30667	11550
Output ha^{-1}			
Grain yield (kg.)	38000	133200	66000
Crop Residue	70000	182000	98000
Total	108000	315200	164000
Output:input ratio			
Grain	2.35	4.34	5.71
Total Biomass	6.68	1027	14.20

This is not true of the tropical and sub-temperate regions of the world where there could be a reasonable possibility of growing two or more crops in a year (Sinha and Swaminathan, 1979). While calculating energy balance, all the inputs such as the preparation of land, crop care, crop harvesting, transportation and drying are taken into consideration. Since the machines such as tractor, thresher, etc. are used only for certain duration, the energy input is calculated for the duration they are actually used. However, in countries where animal power is commonly used either alone or in combination with partial mechanization, the consideration of total system becomes necessary. In a multiple farming system, often the rainy season crop receives organic fertilizer and other inputs which considerably enhance energy input cost (Table 4.14). A study of energy balance in crop production in a village farm of Ludhiana district showed that the output: input ratio was 2.35 and 4.34 for maize and rice, respectively for the rainy season (Table 4.14). Wheat was grown as a winter crop after both the crops and it gave an output: input ratio of 5.71. If we consider output: input ratio in respect of total biomass, it was 6.68, 10.27 and 14.20 for the individual crops of maize, rice and wheat, respectively. Thus, on the basis of such a study, it would be concluded that energy balance in wheat production is much more favourable than either maize or rice. The fact, however, remains that organic manure is usually added to the rainy season crop and almost none is provided to wheat. The latter crop derives the benefit of residual effect of the organic manure. Therefore, it would be much more realistic to consider energy balance in maize-wheat or rice-wheat cropping system. The energy output: input ratio for maize-wheat and rice-wheat was 3.75 and 4.71 respectively for grain yield and 9.81 and 11.35 for the total biomass (Table 4.14). It must be recognized that the input energy of manual and animal power is only for the duration they worked. If the manual labour is considered with a 5% efficiency on the basis of food consumption, one might show that energy balance in production of these crops is poor or negative. This is what has been done by Makhijani & Poole (1975).

Nevertheless, as mentioned earlier, we must give a due consideration to energy required for the maintenance of bullocks and other cattle. A farmer with 1 hectare holding usually has two bullocks, one buffalo and a cow. Energy balance for these are shown in Table 4.15. As against an energy input of 91.6 GJ per year their output is 36.00 GJ per year. Thus, the energy balance in a holding of one hectare can be worked out (Table 4.16). Considering all the inputs in rainy season and winter crop maintenance of four cattle, the total investment comes to 119.3 GJ. In comparison, all outputs including grains, crop residue, fodder, dung, animal power and milk gave a value of 370.6 GJ. Thus, an energy input: output ratio of 1: 3.10 is obtained. Thus, a positive ratio makes it possible that a family would have enough to eat as well as sell a small amount of grain or fodder to earn some cash. In case, this input: output ratio became negative as calculated by Makhijani & Poole (1975), Pimentel and Pimentel (1979), then it would be necessary that energy flows into the farming system from outside. Without any other source of monetary income, any additional energy input would be impossible. Therefore, such a population should vanish gradually. Obviously, this has not happened, and is, hence the evidence that many estimates of energy balance in agriculture of the developing countries have had no proper rationale.

Table 4.15. Energy balance for the maintenance of two bullocks, one buffalo and a cow

Energy Input for	MJ per day	GJ per year
Bullocks 2	125.6	45.8
Buffalo 1	62.8	22.9
Cow 1	62.8	22.9
Total 4	251.2	91.6
Energy output		
Bullocks (Power) 200 days 8 hr per day		6.99
Dung (All cattle)		21.39
Milk		7.62
Total		36.00

Table 4.16. Energy balance in a holding of one hectare in a village of Ludhiana district (Punjab) on a yearly basis

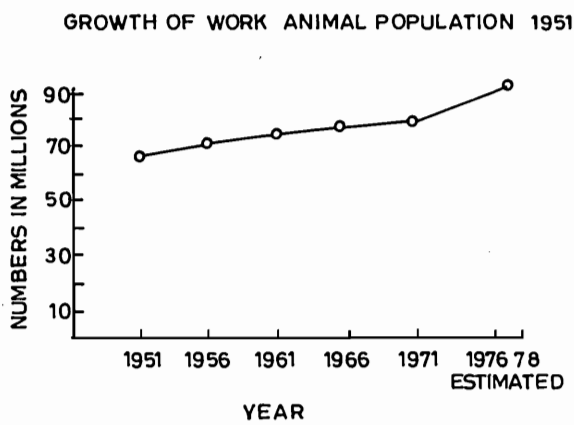
Energy input	GJ per year
1. Agricultural operations Kharif (rainy season)	16.1
2. Agricultural operations Rabi (Winter season)	11.6
3. Maintenance of Bullocks (2), buffalo (1) and Cow (1)	91.6
Total input	119.3
Energy output	
1. Grain & straw yield Kharif	108.0
2. Grain & straw yield Rabi	164.0
3. Forage (Green fodder)	62.0
4. Dung	22.0
5. Animal power	7.0
6. Milk	7.6
Total output	370.6
Energy Input: Output = 1:3.10	

ANIMAL POWER

Use of animal power, bullocks, buffalos and other animals is a common feature of agriculture in the Third world countries. The efficiency of such work animals has been variously estimated by many workers (Makhijani & Poole, 1975; Mitchell, 1979; Ward *et al.*, 1980). Sometimes it is argued that replacement of animal power might

improve agricultural production, because this has been the history of Europe and North America (Pimentel & Pimentel, 1979). The magnitude of the problem is often not very much appreciated. In India, there is a total population of approximately 236 million cattle including work animals, milch-cattle and calves (Ramaswamy, 1979). Although there has been no substantial change in total population, the work-animal population, particularly of buffalos has been increasing over the years (Figure 4.3). At present there are about 80 million work-animals in India. The working capacity of animals varies from 0.4 to 0.6 h.p. but some individuals could have higher capacity. Assuming that each work-animal would have an average 0.5 h.p. energy output, then 40,000 million h.p. energy is being obtained from work animals in India. According to Ramaswamy (1979) this is equal to 30,000 megawatts. It is significant that the total power generation at present in the country is less than 30,000 megawatts. Thus, the question of replacing animal power by commercial energy does not arise. A major advantage of animal power is its availability at the place of need, whereas considerable expenditure has to be incurred in transmission of electrical power or transport of fuel from one location to another.

Figure 4.3. Growth of work animal population in India. 1951–1978



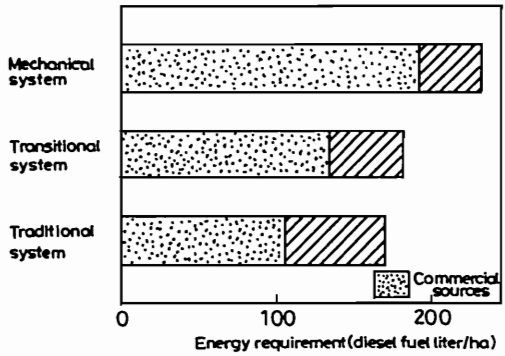
While the importance of animal power in developing countries including India cannot be under-estimated and denied, the animal population in India appears to be more than necessary. The straw of wheat, maize, sorghum and partly of rice constitutes the main cattle feed. It is partly supplemented by green fodder or sugarcane tops when they are available. Most work-animals do not get grains as cattle feed. A large number of animals stray around in 'pasturelands' which have remained out of cultivation because the soil is affected by alkalinity or salinity. If we calculate an annual requirement of 20 GJ per animal, then the straw including that of rice would hardly suffice for cattle feed in India. Therefore, it is not surprising that the health of most work-animal is poor and their work output is low. The same applies to milch cattle who have one of the lowest milk production rate in world. A large number of cows are neither capable as work-animals nor a source of milk. They just live and are let

live. However, they do share the feed with other productive animals who suffer from under-nourishment. A much smaller population could possibly accomplish the work requirement and milk production if they could be properly managed (Ramaswamy, 1979; Ward *et al.*, 1980). In fact, there is an urgent need to have a national policy on the work and milch cattle in most of the developing countries, eliminating several cruel practices as mentioned by Ramaswamy (1979) and improving the health and productivity of these animals. This is essential because most of the developing countries would not be able to replace animal power by commercial energy in the next 20 years. If there is no major breakthrough in the use of solar energy, the cost of fossil fuel and hydroelectric power will increase severalfold making mechanized field operation almost completely out of reach of small farmers. Therefore, the improvement of feed quality, health, sanitation and breed of the desirable animals should be a major effort in the developing countries.

USE OF COMMERCIAL ENERGY

In the primitive agriculture, as that of Mexico, Guatamala, Nigeria, India, and other countries mentioned by Pimentel and Pimentel (1979), there is no use of any commercial energy, because the main inputs are human and animal labour and seed. However, such an agriculture is now becoming rare and may be confined to some tribes, who have not yet been influenced by the modern necessities (amenities, depending who uses them) such as electricity, roads, railways, communication, etc. The Governments of the developing countries are making efforts to reach such people and influence their way of life. Thus, soon we may reach the situation when agriculture without any investment of commercial energy would be a thing of the past. However, before agriculture becomes modern in the sense of the western world, if it ever becomes, there would be several transitional steps. Initially fertilizers, pesticides and irrigation would become the inputs of agriculture. This would be followed by machines such as pump sets, threshers, power tillers, etc., along with the use of bullocks. Finally the mechanized farming as practiced in Japan, the Philippines, parts of India and other developing countries would have to make use of medium sized tractors, field implements, transportation units, threshing equipments, etc. in addition to heavier inputs in fertilizers, pesticides and irrigation. It is likely that all levels of agriculture, traditional, transitional and mechanical may be found within a village or a state. This indeed is happening. The examples of bullock and tractor operated farms using commercial energy inputs in the form of fertilizers, pesticides and irrigation coexist in Punjab, Haryana, Tamilnadu, Gujarat and other states in India. Since the same yields can be obtained and are being obtained in bullock and tractor operated farms, it is important to compare the use of commercial energy in such farms. Kuether and Duff (1981) made such a comparison in the Philippines and we made it in Punjab. The results clearly demonstrated that the consumption of commercial

Figure 4.4. Comparative level of commercial energy utilization for three alterntive rice production systems



energy increased from traditional, to transitional and mechanical farming in Philippines (Figure 4.4). A similar situation was obtained in the Punjab. Recently Pathak (1982) has shown that the consumption of commercial energy in Punjab increased thirteen-fold from 1965–66 to 1979–80. However, the production of major crops (grains) increased only 2.7 times in the same period. Therefore, there has been a sharp decline in energy output: energy input (commercial) ratio in the past 15 years. This trend can be seen in the national production also. In the last 20 years, the energy output: input ratio has declined from 89 to 5.7 (Figure 4.5). This ratio in Punjab has come down from 16.24 in 1965–66 to 3.36 in 1979–80. There was almost no use of fertilizers, pesticides and mechanized systems immediately after independence in India. Thus, a developing country like India is almost following the pattern of the developed countries between 1940 to 1970. If the same trend continues in India, then the requirement of commercial energy would increase very sharply in the next few years. With the limited indigenous fossil fuel resource, the dependence on imported fuel might increase. Alternatively, the technology to use coal may have to be developed faster. All these efforts would be capital intensive, which would make agricultural products very expensive.

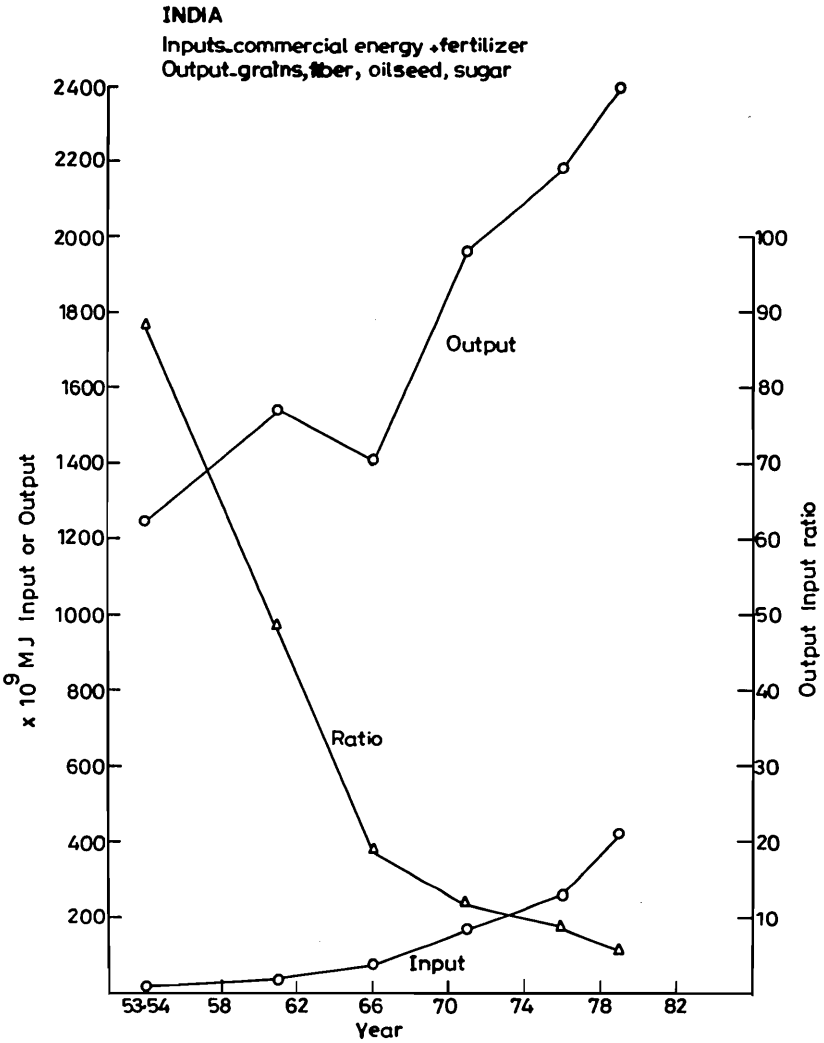
However, the present analysis very clearly shows that mixed farming involving the use of bullock power with modern agricultural inputs could be as productive as mechanized and commercial energy intensive farming. The developing countries need to follow the former. In the long run this would be not only economically but politically prudent.

ENERGY FARMING

There are several suggestions for producing liquid fuel from crop plants and other species to replace fossil fuels. This is indeed important for the developed countries

where less than 2% energy comes from biological sources. In the developing countries more than 50% energy comes from biological sources (Sinha, 1980). The problem of producing liquid fuel from crop plants requires practical energy analysis of the system. So far most exercises have been done on paper in this respect (Seshadri *et al.*, 1978; Ghosh, 1980). At some stage, it is likely that crops and energy plants may compete with each other for the same land (Brown, 1980). However, in the developing countries there is an urgent need for cooking fuel since there has been considerable deforestation. In recent years, some agroforestry systems have been identified in India. These systems could prove very helpful. Therefore, there is an urgent need to evaluate the potentialities of various crop and tree species as source of energy in tropical regions.

Figure 4.5. Energy balance in agriculture in India on the basis of commercial energy and grain production (energy)



WORLD FOOD PRODUCTION AND ENERGY DEMAND

There are now several studies which project the food demand for 2000 A.D. according to various population projections (OECD, 1979; Global 2000 Study). Most of the estimates vary within a range of 5%, therefore, anyone of them could be used for estimating energy requirements in terms of oil. The estimates of oil requirement for producing 2412.5 million tons of grains (OECD Projection) would be 264.4 million tons and 91.9 million tons of oil using US and Indian technology, respectively (Tables 4.17 and 4.18). If we consider the demand of developing countries alone, they would need 1015.9 tons of grains. The oil requirement to raise this much of grains would be 117.8 million tons and 42.7 million tons using U.S. and Indian technologies, respectively. This estimate should be viewed in relation to the present total annual requirement of 28 million tons of oil in India. Obviously, it would be difficult for the developing countries to buy such large quantities of oil. Furthermore, the cost of grains imported from the developed countries would be very high. It is, thus, essential that the developing countries produce their own food using Indian-type technology.

Table 4.17. Projected world grain requirement and the estimated oil needs for its production in 2000 A.D.

	Grain requirement (million tons)	Oil requirement (U.S. Technology) (million tons)	Oil requirement (Indian Technology) (million tons)
Wheat	601.3	51.1	10.5
Coarse grain	1186.6	123.6	44.5
Rice	633.6	89.7	36.9
Total	2412.5	264.4	91.9

Table 4.18. Projected grain requirement of developing countries and the estimated oil needs for its production in 2000 A.D.

	Grain requirement (million tons)	Oil requirement (U.S. Technology) (million tons)	Oil requirement (Indian Technology) (million tons)
Wheat	220.9	18.8	3.9
Coarse	361.9	37.7	13.5
Rice	433.1	61.3	25.3
Total	1015.9	117.8	42.7

CONCLUSIONS

In most of the developing countries, the land-holdings are small, and are becoming smaller because of increasing population density. In small farms, it would be difficult to adopt the western model of agriculture which is almost completely mechanical and commercial energy intensive. The results of energy analysis in India and Philippines show that modern agriculture can be practiced using animal power. This type of agriculture is transitional or mixed. It combines the modern inputs such as the high yielding seed, fertilizer, pesticides, irrigation, etc. with the animal power and human labour. The energy analysis at the country level shows that the developing countries such as India are reaching the stage in commercial energy use in agriculture comparable to the one between 1940–1970 in the United States. This would be difficult to sustain with the given indigenous fossil fuel resources. Therefore, the transitional model of agriculture would be most suitable for the developing countries. However, this model also requires the following improvements:

1. Improvement of the efficiency of inputs such as fertilizers, particularly nitrogen. Efforts should be made for a greater use of biologically fixed nitrogen through inter-cropping or multiple cropping. In addition, the research on biological nitrogen fixation should receive a higher priority.
2. Irrigation has a profound effect on crop yield, and could improve energy balance at a relatively low energy cost. Improvement in components of irrigation such as the lift devices, pump sets and irrigation could be very beneficial.
3. The management of animals require a national policy. Fewer animals could be as effective as a large population, provided that they get proper nutrition.
4. Although biogas technology has been known for more than forty years, yet it has not been fully utilized. This needs to be propagated.
5. Through mixed farms it should be possible to produce food at a lower cost of commercial energy. Adoption and improvement in this technology will be more useful.
6. Crop sanitation, pests and weed control, could increase yield almost the double at a very little energy cost. This aspect should receive a high priority in developing countries.
7. Energy farming using some plant species may be very desirable for firewood and even electricity generation. However, the growth rates of many *Euphorbia* sp. and other plants are too low to provide any suitable alternative. The utility of sweet sorghum as an energy source needs evaluation.

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CHAPTER 5

Research and Technology Needs for the Twenty-First Century*

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INTRODUCTION, BACKGROUND AND CHALLENGES

THE AIM OF agriculture in crop production is to adjust species to locations, planting designs, cropping systems and cultural practices to maximize the biological harvest of sunlight by green plants to produce useful products (food, feed, fibre and energy) for people. Many products of agriculture may be alternatively routed as food, feed, fibre or energy. Agricultural production which is renewable will become increasingly important in resource bargaining.

There are two general types of food production technologies for the future —

* The author in the preparation of this paper has drawn heavily from his previous reports. These include *BioScience* 24, 216–244, (1974); *Science* 188, 579–584, (1975); Chou, M., Harmon, D.P., Kahn H. and Wittwer, S.H.)1977). *In* "World Food Prospects and Agricultural Potential," pp. 66–135, Praeger Publishers, New York; J.S. Bethel, and M.A. Massengale, eds. (1978). *In* "Renewable Resource Management for Forestry and Agriculture," pp. 35–56, University of Washington Press, Seattle; U.S. Gupta, ed. (1978). *In* "Crop Physiology," pp. 334–373, Oxford and IBH Pub. Co., New Delhi; carlson, P. (1980). *In* "Biology of Crop Productivity," pp. 413–459, Academic Press, New York; D.G. Johnson, ed. (1979). Food Production Prospects: Technology and Resource Options, *in* "The Politics of Food," Chicago Council on Foreign Relations University of Chicago Press; "Priorities of U.S. Food Research and Management," Vol. III, (1980); "Agriculture for the 21st Century," the Coromandel Lecture, New Delhi, India, (1979); *in* "Long-Range Environmental Outlook," pp. 64–107, Washinton, D.C., (1980); *in* "Agriculture in the 21st Century," pp. 450–495, (1980); "The Role of Science in Future Food Production Increases," paper presented at the International Wheat and Maize Development Center (CIMMYT) Long Range Planning Conference, (1980); "Advances in Protected Environments for Plant Growth," Proceedings of an International Symposium on Advances in Food Producing Systems for Arid and Semi-Arid Lands, pp. 679–700, Kuwait, (1980); L.E. St. Pierre, and G.R. Brown, eds. (1980). *In* "Future Sources of Organic Raw Materials, Chemrann I," pp. 401–412, Pergamon Press, New York; *in* "Conference on Animal agriculture – Meeting Human Needs for the 21st Century," pp. 329–344, (1980); "United States Agriculture in the Context of the world Food Situation," *in* "American Association for the Advancement of Science Policy Outlook: Science, Technology and the Issues of the Eighties," a report prepared for the National Science Foundation in support of the Second Five-Year Outlook for Science and Technology, pp. 315–353, Washington, D.C. (1981); and "Productivity and Sources of Growth." A paper presented at an International Food Policy Conference – Food Security in a Hungry World," San Francisco, California, March 13–15 (1981).

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highly mechanized and land, water, and energy resource intensive on the one hand, and biologically based and land, water and energy resource sparing on the other hand. The future will show a worldwide shift from less of a resource-based to a more science - and biologically-based agriculture. The emphasis will be to raise output per unit natural resource input and release the constraints imposed by relatively inelastic supplies of land, water, fertilizer, pesticides, and energy and, in some nations, labor.

Ruttan (1977) and Hayami and Ruttan (1971) have pointed out that this has already occurred during the first part of the 20th century in Japan and certain European countries. Whereas the U.S. has followed a mechanical-resource intensive technology, Japan has followed a biological-chemical resource-sparing one. Incentives for increasing yield technologies in the U.S. have lagged until recently, compared to Japan and some European countries, because of the abundance and low cost resources. It is projected now, however, that almost all future increases in food production will be a result of increases in yield (output per unit land area per unit time) and from growing additional crops during a given year on the same land. There are really no other viable options. The technologies with which these increases can be achieved constitute the body of this paper.

The above also underscores in a dramatic way the importance of science and new technologies for meeting future national and world food needs. New high payoff agricultural technologies for the future will be those which result in more dependable production coupled with higher yields, and are more labor than capital intensive, are crop intensive, and are sparing of natural resources. They must be non-polluting. They will be the ones which offer solutions to global food problems (Table 5.1), increase the demand for under-utilized labor resources, and put people to work more days per year, and more productively.

Table 5.1. Global problems and agricultural productivity

Poverty	Population increase
Inflation	Shortage of firewood
Malnutrition	Water-logging and salinization
Underemployment	Uncertainties of energy supplies
Deforestation	Toxic chemicals in the environment
Soil erosion	Improving production and yield stability
Changing Climate	Grain-food/energy conflicts
Communication gap between agriculturists and policy makers	

Such technologies exist. Hybrid cotton production in India and hydrid rice in China are classical examples (Patel, 1979). With hydrid cotton thousands of extra farm workers are required for hand pollination of flowers with resultant 50 percent increases or a doubling of yields. Hybrid rice in China is highly labor intensive and represents a remarkable breakthrough in yields (Swaminathan, 1984). We have not, heretofore, addressed ourselves seriously to the development of such agricultural technologies.

The future will see an inevitable shift from highly mechanized, labor saving, single crop or livestock systems to more science and biological opportunities, and a more diversified resource conserving set of agricultural production technologies.

RESEARCH PRIORITIES

Key research efforts for the future should relate to the control of the biological process that limit the productivity of economical important food crops and food animals and the more effective use and management of resources and other productive inputs. Assessments of research priorities for the plant and animal sciences have been elaborated in an international conference on crop productivity (Brown *et al.*, 1976)

Basic biological processes that control food crop productivity

The need for additional research on photosynthesis and biological N_2 fixation, along with cellular and molecular approaches to plant breeding, has been consistently highlighted. In addition, opportunities have been outlined for genetic improvement through conventional means; hormonal mechanisms and plant development; improved efficiency in nutrient and water uptake; greater resistance and adaptation to competing biological systems, mineral nutritional stresses in problem soils, environmental and climatic stresses, and toxic chemicals. Such research priorities were identified in the World Food and Nutrition Study of the National Research Council of the U.S Academy of Sciences (1977b) and elsewhere as grossly underfunded research; where industrialized developed nations — including the USA with its vast human, financial, and natural resources — could make the greatest contributions to the agricultural development of third world nations. If the research efforts were directed toward economically important food crops as experimental materials, the productivity and stability of output could be greatly improved. These research initiatives have been designated as the next generation of agricultural research (Wittwer, 1978), and have been identified as essential in agriculturally developing countries as well as in the more developed.

Photosynthetic efficiency and yield enhancement

Green plants are the primary harvesters of free solar energy. Photosynthesis is the most important biochemical process on earth. It originally provided the plant materials for the formation of oil, natural gas and coal in addition to the food for the evolving animal life. Improved photosynthetic efficiency is the key to future adequacy of our food supplies. Each day plants store 17 times as much energy as is presently con-

sumed worldwide. They can be net producers of food and energy on a renewable basis. All farm practices toward increased productivity of food crops must ultimately relate to an increased appropriation of solar energy in the plant system. Yet, research on photosynthetic efficiency has been neglected world wide. This is in spite of its high priority in every major study which has identified new initiatives for agricultural research (Brown *et al.*, 1976; Lu, *et al.*,1979; National Academy of Science, 1977b).

Few research efforts on photosynthesis have focused on improving crop productivity. The capture of solar energy by green plants through the photosynthetic process averages less than 0.1 percent during the entire year for the major food crops. For most crops the efficiency of solar energy utilization during the growing season does not exceed 1%. Under the best conditions, it can be 2-3 percent for such crops as sugarcane and water hyacinths. Many environmental pressures affect yields and photosynthesis, and there is great diversity among plants (Bolten and Hall, 1979; Brady, 1980; Good and Bell, 1980; Kramer, 1980).

The most productive crops on earth in an appropriate environment (high temperatures, adequate sunlight, water) are C_4 plants (the first product of photosynthesis is a four-carbon molecule). These include sugarcane, maize, sorghum, millet, some tropical grasses and some of the most noxious weeds. Most food crops are C_3 plants and include small grains, legumes, root and tuber crops and almost all fruits and vegetable and forest crops. Anatomical, biochemical and environmental response differences reside in the two types.

There are opportunities for enhancement of photosynthesis through research. They include identification and possible control of the mechanisms that regulate and could reduce the wasteful processes of both light and dark induced (photo) respiration. Similar mechanisms are responsible for redistribution of photosynthates which, in turn, regulate yield and maximise the "Harvest Index." (The "Harvest Index" is that part of the plant which is harvested for its economic value).

Photorespiration is an energy wasting process that occurs in C_3 plants. Its control would represent a major contribution to increased crop productivity. The key to reducing photorespiration is to prevent the initial reaction, that is oxygenation by ribulose bisphosphate carboxylase. Mutants of *arabidopsis* have been identified that are missing an enzyme for photorespiration (Somerville and Ogren, 1980).

Other research imperatives for improved photosynthetic efficiency include resolution of the hormonal systems and identification of growth regulators and heritable components that control flowering and leaf senescence; improvements in plant architecture and anatomy, cropping systems, planting designs, and cultural practices for better light reception; and carbon dioxide enrichment of crop atmospheres. Plant breeding research has not generally been aimed at improving photosynthetic process. The relationship between photosynthesis and crop yield is complex. More photosynthetically active mutants should be sought. Any physiologic-genetic prolongation of the functionally active state of chloroplasts and/or delay in leaf senescence would be important for enhancement of photosynthetic productivity (Hardy *et al.*, 1978; Kock and Kennedy, 1980; McCashin and Canvin, 1979; Nasyrov, 1978; Nooden *et al.*, 1979).

One of the most immediate improvements in photosynthesis for a large number of

food crops species is to genetically alter the plant architecture. An example of a recent technological achievement is vertical positioning the flag leaves of the rice plant above the panicles of grain rather than drooping below. The better light receiving system dramatically improves yields.

Great concern is being expressed about the rising level of atmospheric carbon dioxide (approximately 1.5 to 2.0 parts per million per year) as a result of the combustion of fossil fuels, deforestation, and soil erosion. The possible climate change impacts on our energy resources, dislocations of agriculture, and possibly rising sea levels (5–6m) from melting of the Antarctica ice caps as a result of a projected warming of the atmosphere have captured the attention of scientists as well as the public (Kellogg and Schware, 1981; National Academy of Sciences, 1983). So far these projections have not been verified by any detectable climate change.

Conversely, elevated levels of atmospheric CO_2 may also produce biological effects, most of which appear to be positive. These include increased photosynthetic efficiency, higher yields, improved water use efficiency, and greater resilience to water stress, both high and low temperatures, low light intensities and damage from air pollutants (Lemon, 1983; Wittwer, 1985). The ability of C_3 and C_4 weed and crop plants to compete with each other may change (Patterson and Flint, 1980).

Finally, much of the basic research on photosynthesis now in progress should be directed toward economically important crops grown under field conditions, as well as in the laboratory. As one moves in research from the microscopic laboratory level to macroscopic field experiments, the advantages of the highly productive C_4 photosynthetic mechanism over the C_3 are progressively diminished. The more efficient C_4 crop or weed grows better at higher temperatures than the C_3 crop plants, because photorespiration in the C_3 plant rapidly increases at high temperatures.

Biological nitrogen fixation

Chemically fixed nitrogen is the largest single energy input into agriculture. The energy — mostly natural gas invested in the fixation process — is non-renewable. This energy is used to convert nitrogen from the air to a form which plants can use. Up to 35 percent of the total productivity of all crops on earth is ascribed to this single input. The return on this energy invested is thus large, in terms of both energy and protein, since it is the source of all food protein. The global use of chemically fixed nitrogen fertilizer for crop production has grown dramatically. In 1905, 400,000 metric tons were produced. This increased to 3,500,000 tons in 1950 and to an output of 40,000,000 tons in 1974. The estimate for 1982 exceeded 50,000,000 tons. Natural gas is the primary feedstock (95 percent) used to produce anhydrous ammonia. And because of its low regulated price, almost all anhydrous ammonia plants also use natural gas as a fuel. A nitrogen fertilizer factory consumes approximately one cubic meter of natural gas for each kilogram of nitrogen it produces as ammonia.

Biologically fixed nitrogen is an alternative to chemical fixation. Current (1984) publicly supported U.S. expenditures for research on biological nitrogen fixation scarcely exceed $10 million annually. Increases in funding for this high priority area

during the past five years have hardly kept pace with inflation. The first opportunity lies in the establishment of rhizobial technology centers. Work should continue on the efficient legume – *Rhizobium* symbiosis rather toward the tenuous target of engineering a N_2–fixing cereal (Brill, 1980; Hardy, 1980). There are also possibilities to develop trees that biologically fix nitrogen, since a major limitation on growth of forests is adequate nitrogen. Nitrogen fixing trees with promise include mesquite, thornless honey locust, and red alder (Felker and Bandurski, 1979). Secondly, a return to research on farming systems specifically relating to cropping systems, making more extensive use of legume green manure and winter cover crops, forage legumes, and intercropping of legumes with non-legumes, is suggested. The challenge is to develop farming systems which are predominantly based on biological nitrogen fixation, but are still high yielding. This relates to and is supportive of one aspect of the "organic farming" movement; namely, a system which to the maximum extent feasible relies upon crop rotations, crop residues, animal manures, legumes, green manures, and off-farm organic wastes to maintain soil productivity and tilth and supply the requisite soil nitrogen. A third initiative lies in genetic engineering for improvement of both host and microorganisms.

Symbiotic relationships now exist for legumes, the actinomycete – nodulated angiosperms, the *Anabaena-Azolla* combinations that enrich rice paddies, and the *Azotobacter* and *Spirillum* rhizosphere associations in the grasses, cereal grains, and non-legumes. The best plants are those that excrete carbon compounds to supply energy for nitrogen-fixing bacteria on their roots. Symbiotic nitrogen fixation is dependent on large amounts of photosynthetic energy. The energy efficiency of symbiotic nitrogen fixation can be improved.

The magnitude of biological nitrogen fixation with many crops is already at a high level. The blue-green algae-*Azolla* complex (the green scum on the surface of the water in rice paddies) can provide 75% of the nitrogen requirement for California rice. A total of 465 kg of nitrogen per hectare were harvested from 22 crops of *Azolla* at the International Rice Research Institute over a period of 335 days. Similar results have been achieved in California if appropriate mineral nutrients are added. This approaches that from some plantings of alfalfa and some clovers that yield up to 500 kilograms of biologically fixed nitrogen per hectare per year. Planting intensities and depth of rooting are important. Over 50 percent of the nitrogen requirement for wheat in the famous Broadbalk plots at Rothamsted in the United Kingdom have since 1943 come from nitrogen fixation by blue-green algae on the soil surface.

Laboratory and field approaches toward improving biological nitrogen fixation in legumes include improved inoculation technologies, improved strains of *Rhizobium*, improved plant cultivators, better matching of the *Rhizobium* strain to the legume cultivator, energy minimization, development of nitrogen fertilizer systems to which legumes respond, and decreasing photorespiration for the improvement of photosynthate production. These approaches may be as important for increasing biological N_2–fixation as improvement of the N_2-fixation itself. Such views have recently been emphasized (Phillips, 1980). Biological nitrogen-fixation research has been outstanding in producing sophisticated basic information during the past 20 years, as reflected by the volumes of literature generated, but there is little of significance for practical

application to increase food crop production under field conditions (Newton and Ormi-Johnson, 1977).

Further research breakthroughs in biological nitrogen fixation, which will be important for enhancement of agricultural productivity, will be hastened if links are created between scientists engaged in basic fundamental research in the laboratory and those in the mission-oriented applied and problem-solving areas under field conditions. Collaborative efforts between scientists in developed and less developed nations should be encouraged. This is a unique opportunity with research on biological nitrogen fixation to apply science to national and global problems and, at the same time, contribute greatly to the enhancement of food production and the alleviation of environmental pollution. The economic, resource, and environmental stakes are too high.

A unique approach toward nitrogen fertilizer fixation for developing countries would be an abiotic technology utilizing renewable energy resources — solar, wind, or water power. A scaled-down electric arc system for atmospheric nitrogen fixation that was displaced over 50 years ago by the Haber-Bosch process is now under review (Rein, *et al.*, 1980; Treharne, *et al.*, 1978). The farm size unit has the potential of making even the poor small farmer self-sufficient in nitrogen fertilizer. This unit could be inexpensive and easy to operate and maintain. It would utilize nitrogen from the air, and a modest electric current from a generator powered by wind, water, or sunlight freely available on a farm. It is now being tested on a farm in Sandpoint, Idaho, and in Nepal with its plentiful supply of fast flowing water and very little nitrogen. The People's Republic of China with its vast hydro-electric power potentials may also benefit from such technology.

Genetic improvement

The standard techniques of selection, based on phenotypic expression, controlled hybridization, and selection for better nutritional qualities, have given super yielding and disease resistant strains of rice, wheat, maize, sorghum, millet, some legumes, and many new fruits and vegetables (CIMMYT, 1979; Coulter, 1980; Sprague *et al.*, 1980). Much can yet be done through genetic improvement to increase food production. The extensive use of commercial hydrid varieties now exist only for corn, sorghum, millet, sugar beets and coconuts. There are now well established networks for testing and evaluation of "multiline" selections of wheat, rice, barley, triticale, maize, sorghum, and millet. They slow the build-up of disease epidemics. A multiline composite is a mechanical mixture of lines which in appearance resemble each other in height, maturity, grain type, and yield; but differ genetically in disease resistance. This is particularly important for rust resistance in wheat. In 1978 India became the first country to release multiline varieties of semi-dwarf wheats. The process is relatively simple for cereal grains, the seed legumes, forages, and many vegetables. Those that are vegetatively propagated (potatoes, sweet potatoes, cassava, fruit trees, yams, coco yams), however, pose a special problem (Shepard. *et al.*, 1980). Meristems may be frozen in liquid nitrogen for the preservation of genetic stocks of

vegetatively propagated food crops. The challenge is to initiate regrowth, utilizing appropriate metabolites, growth regulants, and culture media.

Much of the early work in genetic improvement was focused on pest resistance, and the stabilization of yield by reducing crop losses from insects, diseases and viruses. The long term effort should look at maximum genetic yield potential of future varieties, and greater resistance to environmental stresses. Corn yields have not reached a plateau and will continue to improve. With wheat there has been a dramatic reduction in the severity of periodic catastrophic losses caused by diseases and insects. The commercial value of hybrid wheat remains to be established. A series of genetic improvements by conventional means in wheat, along with the improved cultural practices and irrigation, resulted in a three-fold increase in production in India from 1966-67 to 1978-79. This is the most remarkable increase in food production of any country in all time. Similarly genetic improvements in rice have taken a leap forward in the People's Republic of China. There are now extensive plantings — up to one-third of the total acreage — of hybrid rice with resultant increases in yield ranging from 20–30 percent.

An exciting area for the future is genetic alteration of crops for greater climatic adaptability and higher yields from soils which are infertile, too acid, toxic, or saline (salty) for varieties now in use (Boyer, 1982). A concentrated effort should be mounted by plant physiologists, agronomists, geneticists, and plant breeders to create strains of food crops capable of performing well on nutrient-poor soils and those containing deleterious concentrations of toxic elements and salts. This dimension is missing from the field of genetics. No wheat varieties are yet available for the lowland tropics, and at least 100 million acres are not suited for present strains of rice. Corn grown in the tropics is somewhat tall and vegetative and has a low harvest index. Vast land areas of the earth either are not utilized or are under-utilized for economically important food crops. It may be that production is limited more by nutritional incompatibility of the plant with its environment than the inefficiency of the photosynthetic process (ASA, 1978; Mussell and Staples, 1979).

Genetic resources will continue to be utilized for improvement of the nutritional value of food crops. Cereals dominate the diets of most people. Rice, wheat, and barley selections have been identified with higher protein levels. Both the biological value and the level of the protein of maize have been enhanced using the opaque-2-recessive gene and, more recently, in maize of normal background. Similar genetically superior strains of barley and sorghum have been identified (Harpstead and Adams, 1976). Each of these genetic improvements for practical human nutrition have, thus far, been largely in vain – irrespective of early and continuing publicity campaigns. There are still the important issues of food acceptability. Food commodities that differ appreciably in color, taste, texture, or general appearance and keeping quality or where yield is compromised are not likely to be accepted. Nevertheless, there is no cheaper, better, or quicker way to solve the protein needs of people in most agriculturally developing nations than to improve the cereal that they eat. Combining the high productivity of certain "coarse" (maize, sorghum, millet) with the superior protein quality of "noble" grain characteristics of others (wheat, rice) still remains a major challenge. Additionally, agricultural crops that dif-

fer appreciably – in the perception of the farmer – in requiring more inputs with little or no visible increase in return, or where economic return is comprised, are unlikely to be accepted.

Genetic engineering – broadening the genetic base

This has emerged as a series of events to cover the techniques of growing cells isolated in protoplast culture, anther culture and haploid production, protoplast fusion, and plasmid modification and transfer. (Plasmids are DNA fragments capable of carrying genetic materials). The majority of these techniques have been developed during the past 15 years (Carlson, 1980; Cocking and Riley, 1979; Melchers, 1978; Office of Technology Assessment, 1982; Reinert and Bajaj, 1977). Some now have agronomic or food importance (Hu Huan and Shao Qiquan, 1981). Significant advances have occurred in defining techniques for isolating plant cells without walls, their fusion, and providing cultures, with appropriate growth regulants, for rapid regeneration into new plants. New freeze-storage techniques and the establishment of gene banks of plant cells, as well as for meristems, will be a means of preserving rare and useful genetic materials. Meristem and leaf cell tip cultures have now been successfully employed with some major food crops including the potato and banana (Shepard, 1982). These new cellular approaches to plant breeding, sometimes described as somatic cell genetics, could become a major avenue for broad crosses, new species building with greater yield, resistance to biological and environmental stresses and toxins, and for improved nutritional quality. So far, however, modern plant scientists have produced only one new food species. This is triticale. Protoplast fusion offers hope for tapping genetic material not now available because of otherwise sterility barriers between genera and species. A somatic hybrid of the tomato and potato is an example (Melchers, 1978). Transformations and regeneration of parasexual hybrids from fixed protoplasts could revolutionize agricultural crop productivity. The ability to produce genetic material, however, that can be readily introduced into established plant breeding programs remains a major challenge. Furthermore, the number of species in which protoplast isolation, regeneration to whole plants and fusion have been reported is very limited and primarily confined to the Solonaceae and Cruciferae. Also, no useful hybrids have yet been produced for any cereal grains or legumes, the basic food crops of the earth.

Nevertheless, we are now in the midst of the greatest biological revolution of all time (Waldrop, 1981). It is a renaissance for molecular biology brought on by the possibilities with recombinant DNA and the sequencing of genes. Most of the excitement thus far has occurred in pharmacology (Newmark, 1980) with the bacterial synthesis of mammalian and human proteins (insulin, interferons, growth hormone). These accomplishments in pharmacology and human physiology are providing a constant catalyst for work with food crops and food animals. For food crops, collabortive efforts between plant cell biologists and plant breeders will have to occur. Meristem and shoot tip cultures are being used now for rapid multiplication of large num-

bers of genetically identical and uniform cut flower and potted plants. Meristem culture has also been employed with the potato, the African oil palm and several other tropical crops for the production of disease-free cultivars. Tissue culture techniques now appear essential for the future introduction of hybrid asparagus which will provide a quantum leap in productivity. Another culture of rice in China permits the rapid production of haploid rice (Hu Huan and Shao Qiquan, 1981). This has enabled the production of several genetically homozygous and greatly improved hybrid rice varieties within a three to four year cycle. Some future applications for genetic engineering in food crops will be the transfer of nitrogen fixation from prokaryotic species, bacteria, and blue green algae to major cereal grains, the development of new hybrid plants, improvement of protein quality in the major food crops, the introduction of insect, disease, and herbicide resistance, and greater resilience to environmental stresses. Similarly with food animals, embryo transfer techniques (both surgical and nonsurgical) have been used successfully to introduce new gentic materials into specific pathogen-free swine herds. There are other exciting possibilities for the application of recombinant DNA techniques to infectious agents to characterise the means by which food animals develop protective immunity and disease resistance (Office of Technology Assessment, 1982).

Many large corporations along with seed companies and newly formed institutes are busily recruiting from academic institutions outstanding scientists with specialties in molecular biology, tissue culture, genetics, and plant and animal breeding. The rapid rise of the new biotechnology corporations has been referenced as "The Second Green Revolution." The future success of the new ventures in genetic engineering of plants and livestock will depend on active collaboration between plant and animal breeders and molecular biologists, and from both publicly and privately supported institutions. All the linkages that will be necessary to bridge the current efforts in molecular biology with those of food production have not been identified, but the process has begun.

Efficiency in nutrient uptake

This poses one of the major challenges for future research (Firestone, *et al.*, 1980; Hubner, *et al.*, 1977; Smith and Tiedje, 1979). It has been estimated that 50 percent or less of the nitrogen, and less than 35 percent of the phosphorus and potassium, applied as fertilizer in the U.S. are recovered by crops. The recovery of fertilizer nitrogen in the rice paddies of southeast Asia is an unacceptable 30 percent. It is 50 percent for the corn fields of the midwest U.S. Denitrification causes nitrogen to be lost to the atmosphere. Nitrification encourages losses in the soil from leaching and surface run-off. Nitrification is also a prerequisite to losses from denitrification. Nitrification is also desirable because it is a prerequisite for much of the nitrogen availability to plants. Control of the rate of nitrification could eliminate much of the loss. Food production could be greatly improved if these enormous losses, particularly in the warm soils of the tropics, could be even partially reduced. The single factor, recently identified as responsible for failure to increase rice yields from 1970 to 1976

on Asian farms, was the low level of nitrogen fertilizer available.

Denitrification is a process whereby nitrate is reduced to gaseous nitrogen, principally nitrous oxide (N_20) and nitrogen (N_2). These forms are no longer available for crop production. The process is carried out by diverse bacteria which are widely distributed in soils. While the potential exists for significant nitrate removal by denitrification, the process is inhibited by oxygen and can be minimized in well drained and aerated soils. Nitrous oxide can catalyze the destruction of stratospheric ozone. Hence, the amount of nitrous oxide produced during denitrification, as well as nitrification which pollutes ground water, can have environmental significance.

A worldwide annual loss of 12 to 15 million tons of nitrogen fertilizer can be ascribed to denitrification alone. A recent evaluation of all lysimeter studies indicates that 25 percent of fertilizer nitrogen is lost to denitrification under normal agricultural conditions. Losses from nitrification are equally as great. Assessments of the fate of soil applied nitrogen fertilizer suggest that 25 to 35 percent is lost both by nitrification and denitrification. There are many variables that affect these losses. Some can be controlled. Root zone placement of fertilizer helps reduce the losses. Nitrification inhibitors, both natural and synthetic, applied with ammonia or urea, are effective deterrents to leaching and atmospheric losses of nitrogen. Denitrifiction inhibitors are also available (McElkannon and Mills, 1981). Both nitrification and denitrification inhibitors should be vigorously sought. A research challenge for the future also resides in designing a nitrogen conserving pathway that can out compete denitrification. The result would be a significant reduction in fertilizer cost and usage. Non-renewable resources would be preserved. Food production would be increased, and a potential environmental hazard reduced.

Denitrification occurs only under anaerobic soil conditions. This may be alleviated by reducing nitrification, soil compaction, improved drainage, use of soil improving crops, and careful attention to irrigation procedures. Research emphasis on reduction of losses of nitrogen fertilizer applied to crops should hold priority equal to that for devising means of nitrogen fixation utilizing renewable, rather than non-renewable, resources.

Another technology of some significance in reducing losses of fertilizer nitrogen is that used by the International Fertilizer Development Center (IFDC). It relates to production technology. Sulfur coated urea, super granules of urea, granular and prilled urea, and deep placement of urea super granules have all reduced losses (IFDC Reports, 1979).

Mycorrhizae and soil microbiology

The facilitation of nutrient uptake by micro-organisms (fungi) in symbiotic associations with the roots of plants is emerging as one of the most exciting frontiers for the global enhancement of crop production (Cress *et al.*, 1979; Ruchle and Marx, 1979; Safir, 1980; Splittstoesser, 1982; Tansey, 1977). Efficiency of plant roots in absorption of nutrients from the soil can be greatly improved. Mycorrhizae, particularly the endomycorrhizae and the subgroup referred to as vesicular-arbuscular, may result in

large increases in the uptake of phosphorus and other poorly mobile nutrients. Almost all crops respond. Vesicular-arbuscular mycorrhizae can be viewed as fungal extension of roots. They help roots absorb fertilizer and can stimulate growth and nitrogen fixation by legumes, especially in phosphorus deficient soils. The mycorrhizal affect is not only from an increased number of absorbing sites, but there may be an increased site affinity for nutrient absorption. There are superior strains of mycorrhizae, and crops can be inoculated with them. Mycorrhizae fungi have been reported to increase significantly the yields of cereal grains and many vegetable and fruit crops. They facilitate nutrient uptake by changing the amounts, concentrations, and properties of minerals available to plants. The potential is not only for a substantial increase in conventional crop production with conservation of non-renewable resources, but to expand the land base so that plants can be grown in areas which now have an unfavorable climate and non-productive soils. A research challenge is to culture the mycorrhizal organisms, genetically improve them, and then manage them as *Rhizobia* are now used for inoculating soybeans and other legumes.

Bacterization has emerged as a new approach to promote plant growth and control pests (Suslov *et al.*, 1979). It involves application of growth-promoting rhizobacteria to the soil and plant parts. Seed is treated with liquid suspensions or the bacteria are applied as a powder after coating with certain gums or polysaccharides to prevent loss of viability. The work was pioneered many years ago by Academician E. N. Mishustin and associates in the Soviet Union. The results of the Soviets recently have been confirmed in California. Yield increases in the field ranged from 15 to 144 percent when seed or seed pieces of sugarbeets, radish, and potatoes were treated with selected bacterial strains.

Foliar applications of fertilizer have been declared the most efficient method of fertilizer placement (Wittwer and Bukovac, 1969). Losses from surface leaching and to the atmosphere should be reduced since the soil with its micro-organisms is circumvented. Barriers to increasing yields might also be reduced by utilizing the absorptive capacities of aerial plant parts as well as the subterranean, especially when applying nutrients at crucial stages of development. Nutrients sprayed on aerial plant parts are absorbed, but application technology is still lacking.

Great hope was expressed for foliar sprays of nitrogen, phosphorus, potassium and sulfur on soybeans in Iowa at the seed filling stage in 1975 (Garcia and Hanway, 1976). But extensive subsequent foliar spraying of nutrients in all major U.S. soybean-producing areas during 1976, 1977, and 1978 did not duplicate the outstanding results achieved in 1975. Nevertheless the rising costs of nitrogen fertilizer and the fossil fuel resource requirement should be a continuing stimulus for further investigations of this technology. There are also persistent reports from developing countries (India, China) that foliar applications, particularly of nitrogen at the flowering or seed filling stage of cereal grains and legumes are beneficial (National Academy of Sciences, 1977a). Root colonizing bacteria of the genus *Pseudomonas* may suppress many plant diseases caused by bacteria. This is a new frontier for increasing crop yields in the future (Scroth and Hancock, 1982).

Resistance to environmental stresses

These stresses constitute the primary limiting factor(s) to crop productivity (Hanson and Nelson, 1980; Le Ruduliez *et al.*, 1984; Mussell and Staples, 1979; Rosenberg, 1980). As such, they also provide the greatest opportunities for increasing and expanding the production of the world's crops. Those that limit crop productivity include drought, cold, heat, salt, toxic ions, and air pollutants. Plants, unlike people, livestock, and other animals, are immobile, i.e., they are fixed in one location. Environmental adaptability is, thus, essential.

Any means of increasing the resistance of plants to high and low temperatures, drought and water stress, or adverse soil conditions holds great promise for enhancement of both the amount and dependability of agricultural production. Through the use of short season, early planted, single-cross maize hybrids commercial production of corn in the U.S. has moved 500 miles further north during the past 50 years (Battelle Columbus Laboratories, 1973). Spring wheat in the USSR has moved further north by 200 miles. The winter wheat zone in the U.S. could be moved another 200 miles further north utilizing new genetic selections for winter hardiness that are now available. Hybrid sorghum and millets are moving into hot-dry areas, not heretofore adapted for cereal grain production. Triticale has resistance to aluminum toxicity. Until now, the Soviets have been the main triticale producers. Thus, millions of acres of heretofore non-productive land could be opened for food cropping. Characteristic of the new seeds (rice and wheat) of the "green revolution" are varieties that show no response to length of day and thus will produce grain at any latitude. There are also genetic strains of rice, wheat, and barley having greater resistance to both cold and alkalinity. Potato and tomato selections have been identified in the high Andes with modest frost resistance and cold hardiness.

Plants can be made more "climate-proof" by genetic improvement and by appropriate soil, water, and pest management. Combining high yield with drought resistance in crops would increase productivity, and serve as a drought/hazard/reduction measure. The use of climate information in the selection of crop varieties for a particular climatic setting, the strategic planning of the size, the type, and operation of an irrigation system, or alternative strategies in pest management can reduce the adverse effects of climate on crop productivity (National Academy of Sciences, 1976).

The earliest and most significant technology for environment control is irrigation. It is the most certain of strategies for weather-proofing crop production (Ritchie, 1983). It along with other means of protected cultivation will be discussed later with technology options for the 21st century.

Environmental stresses, especially temperatures, have a marked effect on the performance of food animals (Ames, 1980; Hahn, 1976). They change the rate at which animals grow, reproduce, or accomplish their desired functions of meat, milk or egg production. Temperatures not only impact directly on animal physiology, but indirectly on forage production, parasites, diseases, and soils. Research initiatives on alleviation of environmental stresses, through genetic improvements, hormonal regulation, feed intake, and controlled environments, encompasses an important part of

our food system, as well as the productivity of rangelands and wildlife, in temperate zones, the tropics, semi-arid tropics, and arid lands. For each animal there is an optimal thermal environment in which the species enjoys optimum health and maximum performance and productivity (Ames, 1980).

Atmospheric pollutants

The changing regional composition of the atmosphere, both as to gases and particulates, in the industrialized world is a source of environmental stresses (Carnahan *et al.*, 1978; Kellogg and Schware, 1981; Likens *et al.*, 1979; National Research Council and U.S. Department of Commerce, 1976). These changes in atmospheric composition may either enhance or detract from agricultural productivity. Atmospheric particulates and gases – natural or of human origin – can be absorbed by aerial plant parts and, if present in precipitation, may be taken up by roots. Acid rainfall is common over the U.S. east of the Mississippi River, and elsewhere in localized industrial areas. its full effects on agricultural productivity (crops, livestock, range) have not been assessed. Air quality standards, thus far, have been associated with the activities and welfare of people, with little attention given to agricultural productivity. Crop losses from the stress of air pollutants may be minimized by genetic selection of resistant cultivars, application of antioxidant chemicals, elevating the level of atmospheric carbon dioxide and modifying the nutrition of plants. The effects of the atmosphere on the biosphere and what we can do about them will have an important effect on future agricultural productivity and food supplies.

There are currently many warnings as to climatic changes that will occur as a result of the rising level of atmospheric carbon dioxide (National Academy of Sciences, 1983). These warnings project severe agricultural dislocations and call into question the integrity of our food supply for the future. Much of this fear and apprehension could be alleviated by a reasonable research investment now on means of reducing the impacts of environmental stresses on crops and livestock. The necessity of research to alleviate climatic stresses transcends any importance attached to the $C0_2$ issue. In anticipation of an ever increasing level of atmospheric $C0_2$ the U.S.A. has initiated through its Departments of Energy and Agriculture and other federal agencies a national research program on the direct biological effects of a rising atmospheric level of $C0_2$ on plants, and on the environmental and societal consequences of a possible $C0_2$ induced climate change on agriculture and other renewable resources (Lemon, 1983).

Greater resistance to competing biological systems

Annual field losses from pests (insects, diseases, weeds, nematodes, rodents) for the major food crops approximate 35 percent. All major crops suffer losses before harvest that exceed 20 percent. The greatest losses are in developing countries. Significant increases in food production could be achieved on the earth by reducing these

losses in the field and after harvest without bringing any new land into production. Other imputs into the food system could also be greatly reduced. Losses from insects and diseases are discussed in Chapters 12 & 13.

An additional complexity in pest management has recently occurred involving resistance to herbicidal chemicals particularly the triazines widely used for corn production. At least 36 different weeds have become resistant to herbicides.* The common aspect of all resistant weeds is that they are found in areas of agricultural production where herbicides were used repeatedly with little or no rotation with other herbicides. Applications of active ingredients necessary to control the newly developed weeds were far beyond the concentration range that is commercially feasible or environmentally acceptable. The triazines are photosynthesis-inhibiting herbicides, and the site of action is very specific being in the chloroplast where electron transport is inhibited. Chloroplasts isolated from resistant plants are unaffected. Resistance of weeds to triazine herbicides has serious implications because they are the herbicides most commonly used for corn and soybeans. Precautions will need to be taken in the future to rotate herbicides, as well as crops, and to utilize combinations of herbicides from different chemical families. Considerable progress has recently been made in understanding the nature of herbicide resistance in plants (Chaleff and Ray, 1984; Hirschberg and McIntosh, 1983; National Academy of Sciences, 1984).

A novel approach to the future control of weeds and an alternative to the use of synthetic chemical herbicides is allelopathy (Rice, 1974). Many desert plants produce substances toxic to other plants which eliminate competition for limited water resources, and enables their survival under extremely hostile conditions. Also, certain crops and their residues, including the cucumber, rye, sorghum, asparagus and sunflowers have been identified as allelopathic. it is known that mulches of certain grasses and cereal grains have herbicidal effects. These have been identified both in developing countries and the U.S. Their use would greatly reduce or eliminate the present dependence on chemical herbicides, especially for conservation tillage programs (Drost and Doll, 1980; Lockerman and Putnam, 1979; Putnam and Duke, 1974; Putnam, 1983. Wejewardene, 1979).

Allelopathy deserves continued attention and research. The challenge will be for weed scientists, agronomists, engineers and biochemists to integrate the use of allelopathic crops, crop and weed residues, use of toxins from allelopathic plants as "natural" herbicides, and conservation tillage systems for simultaneously reducing resource inputs and for the enhancement of food crop productivity.

* The work of C.J. Arntzen (formerly of the United States Department of Agriculture/University of Illinois at Urbana, and now Director of the Plant Research Laboratory at Michigan State University in East Lansing, Michigan) and associates is particularly noteworthy relating to resistance of weeds to triazine herbicides. The following publications are critical. Arntzen, C.J., Watson, J.I. and Steinback, K.E. (1979). Analysis of Physiological Changes in Newly-Discovered Herbicide-Resistant Weed Biotypes. Proc. N.C. Weed Control Conference, December; Pfister, K. and Arntzen, C.J. (1979). The Mode of Action of Photosystem 11-Specific Inhibitors in Herbicide-Resistant Weed Biotypes. *Z.* Naturforsch 34c, 996–1009; Arntzen, C.J., Ditto, C.L. and Brewer, P.E. (1979). Proc. Nat. Acad. Sci. 76(10), 278–282; Pfister, K., Radosevich, S.R. and Arntzen, C.J. (1979). Modification of Herbicide Binding to Photosystem II in Two Biotypes of *Senecio*; Arntzen, C.J. (1980). *Arch. Biochem. and Biophysics* 200, 303–308; and several articles in *Weed Science* 26(4), 318–322; 27(2), 216–218; 27(3), 300–308; 27(6), 684–688. (1979).

*Hormonal mechanisms and plant development**

There are many chemicals, endogenous and exogenous, that offer control of biological processes that limit crop productivity (Nickel, 1982). The use of sugarcane ripeners for enhancement of sugar production in Hawaiian sugar plantations is now standard practice. Sugar yields are increased 10 percent. An equal increase is achieved with gibberellins to promote growth during the "winter" months. Lodging is prevented and yields of wheat in western Europe have been enhanced by treatment with a chemical now designated as "Chloromequat." The latest is Triacontanol, which in milligram quantities per hectare may significantly increase the yields of several major food, as well as vegetable, crops in some parts of the U.S. Currently, there are 40 major chemical companies, most of them in the U.S., that are engaged in chemical growth regulator research. The use of chemical growth regulants for crop production in the tropics needs exploration.

There has been little effort to focus chemical growth regulator studies on significant food crop species or on whole plants of economic importance. Most of the locally financed agricultural research in developing countries has been on plantation and export crops. Food crops for domestic consumption have been largely ignored. What is needed in the chemical growth regulator field is for scientists, especially in developing countries, to participate personally in field research to solve food production problems, rather than to contribute to the ever burgeoning growth of scientific journals. Much of the information from growth regulator research in the plant species, both at home and abroad, has not been brought to bear on the practical problems of crop productivity (Scott, 1979). Cytokinins and abscisic acid are examples. Under laboratory conditions the one (cytokinins) delays senescence, the other (abscisic acid) hastens senescence, inhibits growth, and reduces water requirements.

Animal agriculture and world food systems

There is a sound basis for efficient animal production in every nation in the world. Two-thirds of the world's agricultural land is in the form of permanent pasture, range, or meadow. Sixty percent of this land is not suitable for growing cultivated crops. Ruminant animals can harvest this vast food resource – otherwise of little value – and convert it to milk and meat and other useful products. They are natural protein factories and a living storehouse of mobile food. They can also utilize by-products, residuals, and waste materials that otherwise would be of little worth.

*** Numerous papers, summaries, reviews, and documentaries have recently been prepared on this topic. These include proceedings of the first six annual meetings (1973 through 1979) of the Plant Growth Regulator Working Group; the entire issue of Outlook on Agriculture 9(2), (1976); Wittwer, S.H. (1971). *Outlook on Agriculture* 6(5), 206–217; Nickell, L.G. (1978). Plant Growth Regulators C and EN, Oct. 9; Phytohormones and Related Compounds. 1978. A Comprehensive Treatise, Vols. I and II; D.S. Letham, P.B. Goodwin, and T.J.V. Higgins, eds., Elsevier Press, New York; Scott, T.K., ed. (1979). "Plant Regulation and World Agriculture." Plenum Press, New York; Ries, S.K., Wert, V., C. Sweeley, C.C. and Leavitt, R.A. (1977). *Science* 195, 1339–1341; and Moore, P.H. (1980). *Plant. Physiol.* 49, 271–276.

The rapid increase in the sales to developed countries of animal feeds, particularly of soybeans and their products, and a variety of feed grains is probably the single most important aspect of recent U.S. agricultural exports which was over $40 billion in 1981. There is an increasing demand for meat, milk, and eggs. There are in animal agriculture important economic, health and safety, environmental, socio-political, resource inputs, and productivity and biological research areas that need exploration.

A national conference on "Animal Agriculture – Meeting Human Needs for the 21st Century" was held at Boyne Mountain, Michigan, USA, May 4-9, 1980. The intent was to review research needs and set priorities (McGilliard *et al.*, 1980). To date, research in animal agriculture has been confined primarily to the enhancement of productivity through genetic improvement, better feeding, disease control, improved management and control of the environment (Salisbury and Hart, 1979). This conference focused on resource inputs, health and nutrition, economics, environmental issues, public policy, food safety and acceptability, socio-political considerations and biological efficiencies. Opportunities in research for greater reproductive efficiencies, improved animal health, resource conservations and reductions in carcass fat emerged as high priority.

Research in animal health must include control of major epidemic infectious diseases, minimizing losses from many other epidemic diseases, control of endemic diseases, studies of the economic impact of animal diseases, and fundamental studies on the biological factors relating to host resistance and parasite infections. World mortality losses from disease and parasites annually exceed 50 million cattle and buffalo, and 100 million sheep and goats. Reduction in losses through research from epidemic and infectious diseases of up to 50 percent is a possible and realistic goal.

Most current production inefficiencies resulting from impaired animal health can be eliminated if present knowledge is applied, if animal health delivery systems are improved and new technology is developed through basic and applied research. Major breakthroughs for improved animal health projected for the next decade could have wide implications for the 21st century. There is a great need for integrated food animal health systems, genetic engineering for greater disease resistance and immunity, a reduction in hazards to food animals from chemical agents, and elimination of human health hazards associated with the use of food animals and their products.

The model of success in disease control was the introduction of the vaccine for control of Marek's disease in poultry. This was one of the most significant scientific achievements in food production during the decade of the 1970's. The vaccine was accepted so rapidly that within months much of the world was using it (Purchase, 1977). Never before in the history of agricultural research had there been a parallel achievement. We should seek to identify the elements of acceptance.

Substantial gains in the utilization of feeds, genetic improvement, and increased fertility can come from developing genetically superior animals that would respond to low quality diets. Other opportunities would be to increase the availability of lignin and cellulose which are the major feedstuffs in many developing countries, improving the use of non-protein nitrogen (urea-ammonia) for conversion by rumi-

nants into protein, improved feeding and management at critical times in the life cycle, and development of the rumen bypass for increased protein utilization and appetite stimulation. "Rumensin" or "monensin" (Isichei and Bergen, 1980) added to the ration of dairy and beef cattle greatly increases nutrient utilization from forages. The full nature of the response or the mode of action is not known. This is a challenge for future research.

Improved fertility will come from estrus synchronization or control of the reproductive cycle, semen preservation, improved pregnancy detection, multiple births, superovulation, and non-surgical embryo transfer and implantation (Seidel, 1980;) All these can be maximized to increase the number of offspring per breeding unit. Low reproductive efficiency of livestock now results in 50 percent of potential animals lost. Twinning in dairy and beef cattle can become a reality through hormone treatment for superovulation, controlled breeding, non-surgical recovery of fertilized eggs, and non-surgical embryo transfer to recipient females (surrogates) of lesser breeding value.

Non-surgical embryo collection is now aided by extremely sensitive microscopic techniques for embryo sexing, freezing, and implantation. This could revolutionize genetic improvement and productivity in dairy and beef cattle. Embryo banks of sexed and frozen embryos may soon be available for cattle breeders to use with either surgical or non-surgical implantation techniques. This could mean twin males for meat animals and twin females for each superior milk producing diary cow. An inventory of the development of embryo transfer in the U.S. in 1980 revealed a $25 million industry that has developed in less than a decade. Twenty thousand calves were produced at a cost of $2,000/calf, with one super cow producing 50 calves a year. The major use of the technique is to increase the reproductive rate of valuable cows.

All of the above – improved production and utilization of feeds, animal disease control, and genetic improvement – are of equal priority. Little progress in better utilization of feeds can be achieved without timely inputs for disease control, genetic improvement, and increased reproductive efficiency. Similarly, research on animal disease control would be of little value, unless accompanied by better feeding. In fact, improvement of the breeding stock of animals may be impossible in some agriculturally developing countries until certain diseases are controlled and some nutritional disorders alleviated.

Controlled environments constitute a realm of technology scarcely tapped for livestock production. They are widely used now for poultry and swine (Pond, 1983), and are under test for sheep and goats. Programmed lighting (photoperiod) and temperature regulation should be vigorously pursued relative to their effects on dairy cattle productivity, feeding efficiency, rates of gain, hormonal relationships, and reproductive behavior. A photoperiod extended to sixteen hours in mid-winter in Michigan has resulted in a 10 percent increase in milk prodction with high producing dairy cattle (Peters *et al.*, 1978; Tucker, 1979; Tucker and Ringer, 1982). This was achieved with no additional feed inputs. The technique also works with horses.

Results in animal agriculture can be phenomenal when modern ("western") livestock production technology and improved forage programs are introduced in a developing country and combined with local scientific inputs. Such is the "White

Revolution" which is emerging in the Punjab and Gujarat states of India. Over a million farmers using the water buffalo as a milk animal have formed co-operatives for marketing and distribution of milk to the almost unlimited markets in Bombay, New Delhi, and other large cities. The program is known as "Operation Flood." Milk production at the farm level is enhanced by genetic improvement through artificial insemination, better feeding, utilizing the highly productive hybrid Napier grass and disease control. The results are a dependable daily cash income, better utilization of wastes and by-products, improvement of the nutritional status of poor people, an opportunity for landless laborers, and an enterprise which is labor intensive at the production level. The whole system is owned by the primary producers of milk and in practice as well as theory operates for the producer's benefit. The success of the Anand Milk Union Limited (AMUL) co-operative model raises the question of its value for other commodities and locations (Brumley, 1980). Considerable progress has also been made with improving animal agriculture in the People's Republic of China (National Academy of Sciences, 1980).

Improved forage production

Forages provide a feed supply for approximately 2.5 billion ruminant animals useful to man. They are the primary feed for livestock in developing countries. Because forages may reduce soil erosion, provide biomass and enrich the soil, their production is an essential component of appropriate, long-term land use (Burton, 1977; Hodgson, 1977; McGilliard *et al.*, 1980).

There are many opportunities to enhance the productivity of range and pasture resources. In temperate zones, a co-ordinated program of improved plant species (both legumes and grasses), controlled vegetation, mechanical soil treatments, fertilization, water control, and livestock and wildlife management would dramatically increase food and feed productivity. The land and water resources for forage production in the tropics and developing countries are enormous. In tropical developing countries, there are 1.5 billion hectares with little utility for cultivated cropping that could be devoted to forages. Livestock grazing in many areas is possible throughout the year. Many mixtures of legumes and grains provide the balance between energy and protein. Improved nutrition for ruminant animal production must come largely from improvements in the production and management of forages.

The potential genetic improvements for forages are exciting. Coastal Bermuda grass F_1 hybrids in the southeastern U.S. yield twice as much forage as the Common Bermuda grass. Hybrid Napier grass is highly productive, and provides an excellent feed for dairy cows in the tropics. The transpiration rate and resultant water requirements in hybrid pearl millet may be genetically reduced by 26 percent.

Forages as feed for ruminant livestock offer unique options in the use of energy and land resources in both agriculturally developed and developing countries. Efficient utilization of grazing animals in specific integrated farming systems can increase yields of high grade food products and byproducts from the renewable energy of biomass. Animal agricultural systems can be self-sustaining, productive, and require

only small inputs of fossil energy. Use of pasture and grazed forage range may reduce energy inputs by 60% and land resources by 8%, but animal protein production is also reduced by one half (Pimentel *et al.*, 1980; Ward *et al.*, 1980).

The most important feed constituent in forages is cellulose. It is the world's most abundant organic compound. Worldwide production of cellulose is estimated at over 100 billion tons (dry weight) per year. This is equivalent to approximately 150 pounds of cellulose produced daily for each of the earth's more than 4.8 billion inhabitants. Its conversion into food on an economic basis is accomplished only by ruminants.

TECHNOLOGY NEEDS AND OPPORTUNITIES

The role of science for future food production increases will focus on biology. Early in this century the western world went through an industrial revolution. We are now witnessing a global agricultural revolution. Fifteen international agricultural research centers and several commodity networks now exist. All are of recent origin. The next revolution will be a biological one. The 21st century can be projected as a biological opportunity century with renewed emphasis during the eighties and nineties in not only production of, but the use of renewable resources. Emphasis will be on biologically based production technologies that consume fewer resources. Conversely, it can be expected that the resource base will change and may improve with time and technology.

NEW CROPS AND CROPPING SYSTEMS

New crops

There is a continuing search for new crops and super selections of the old (Giri and De, 1978; Meyers, 1983; National Academy of Sciences. 1975b; Walton, 1980; Watson, 1980). Their potential wealth as resources continues to be emphasized as sources of food, feed, and energy. For the United States the sunflower is the latest excitement (Beard, 1981). It is the most rapidly expanding crop in North America. Much of the dwarf hybrid material has been derived from the Soviet scientists who lead the world in sunflower genetic improvement. There is a healthy export market for oil used for human consumption, grain producers can rotate their crops, the work load is leveled out. Sunflowers are productive and easy to grow. A groundswell of excitement has emerged in that the oil appears to be a substitute for fuel in diesel engines. The sunflower can be grown successfully in the United States from the Mexican to the

Canadian borders. Another oil crop is the Jojoba, a desert shrub with remarkable resistance to drought, high salinity, and temperatures lethal to most other plants. It is native to the Sonoran Desert which covers parts of Mexico and the southwestern United States. Jojoba nuts contain an oily liquid (50% by weight) that makes a lubricant base superior to that derived from sperm oil, a product that is strategically important.

Glandless cotton, with essentially zero gossypol, was first identified in 1959. After more than two decades, varieties have now been developed that are superior to referenced glanded varieties in fiber yield and quality. This places the American cotton industry, if coupled with the new high yielding varieties of India on a threshold for the development of new cottonseed flour high in protein and acceptable as human food.

The coconut sometimes referred to in Southeast Asia as the "tree of the Gods" is par excellence for small farms and for intercropping with legumes, cereals, tuber crops, banana and pineapple. Both dwarf and hybrid early fruiting types now exist.

Other "new" crops of great potential include the mangosteen, the world's best tasting fruit. A National Academy of Sciences report (1975 b) from the U.S.A. provides an inventory with a description of 36 underexploited tropical food crops with promising economic value. Included are 4 cereals, 3 roots and tuber crops, 4 vegetables, 7 fruits, 5 oil crops, 5 forages, and 8 having industrial or other uses.

On the list is the winged bean of the tropics. All plant parts are edible. The green pods, leaves, and seeds are rich in protein and vitamins. The tuberous roots, unlike cassava, sweet potato and taro are uniquely rich in protein. The seeds are a source of edible oil.

Another crop, widely adapted, is Amaranth. Both the grain (seed) and the leaves may be eaten. Amaranth is a highly productive C_4 plant and responds luxuriantly to added nitrogen.

Leucaena is a promising forage legume for livestock. It thrives as a small plant, shrub, or tree in the tropics and the Islands of the Pacific. Being a legume it supplies its own nitrogen. It may be particularly valuable for marginal land and low income farmers. It suppresses soil erosion on slopes and hillsides.

Other "new" crops of significance mentioned elsewhere in this report are triticale and Hybrid Napier grass. Triticale is an exclusive creation of science. Its value as a cereal grain for bread making in the 21st century resides in its potential productivity, adaptability and superior nutritive value. Hybrid Napier grass belongs to the tropics. Being a C_4 plant, it is one of the most productive forage crops on earth, and its use in the tropics could be greatly expanded as a forage for livestock.

Cropping systems

Central for increased food production in the future is the intensification of agriculture. A production strategy or technology that is being used increasingly where there is little or no new land available for cultivation is multiple cropping, relay cropping or intercropping. This depends in many instances on irrigation. The precipitous increase in tubewell irrigation in India has had the greatest impact of any type of

water management or any other technology for increasing yields during the last 15 years. Tubewell irrigation can significantly increase multiple cropping capabilities and thus agricultural productivity. Irrigation has had a great impact on multiple cropping in the People's Republic of China where up to four full crops of vegetables may be harvested from the the same land in one year (National Academy of Sciences, 1975a, 1979). Two rice crops per year and an upland crop are feasible on rainfed rice land of the Iloilo Province of the Philippines (Nicolas *et al.*, 1980).

Two or more useful food crops may also be grown together simultaneously with increased total productivity over that which would be realized if each were grown separately. Farmers with limited land resources in the tropics and subtropics have long used this technology for increasing food production and cash incomes. Legume-cereal grain combinations are most common. When yields of the two crops are added together the increases in total production can be very significant. More materials are recovered in the biomass produced. Water use is more efficient. The potentials for polycropping (two or more crops grown together) systems research, the combinations possible, the unknowns of root interactions, and the special constraints of the semi-arid tropics need review. Tree crop intercropping possibilities and agri-forestry (growing tree crops and food crops on the same land) alternatives have been outlined. "Alley Cropping," an improved bush fallow system, is an innovation suggested by the International Institute of Tropical Agriculture at Ibadan, Nigeria. It involves the use of nitrogen fixing trees or shrubs such as Leucaena planted in rows and intercropped with maize. Research with cropping systems for vegetables in the tropics and subtropics is particularly weak. It is known that beans, peas, cucumbers and tomatoes grown on poles or trellis can produce more per unit land area than bush types without support. This is an example of labor intensive high production agriculture. The technique is widely used in combination with the high technologies of protected cultivation (Dalrymple, 1973; Jensen, 1977; Levitt, 1980; Mussell and Staples, 1979; National Academy of Sciences, 1976; Rosenberg, 1980; Van Den Brink and Carolus, 1963; Wittwer, 1980 b; Wittwer and Honma, 1979). Mostly all beans (*Phaseolus vulgaris*) produced in China are trained on poles.

LIMITS ON FOOD PRODUCTION

Rising populations and increasing resource and environmental constraints have led to estimates of the carrying capacity of the earth and a review of the limiting factors in crop and livestock productivity. Interest has been generated in assessments of record yields, and the biological limits to productivity (Borojevic, 1978; Buringh, 1980; Evans, 1980; Goring 1980; Loomis, 1980; Ritchie, 1980; Ruttan *et al.*, 1980). The biological limits of crop productivity have been neither achieved nor defined. There have been remarkable increases in global grain production during the past 20 years (Table 5.2). The increase has more than kept pace with population increase.

The only possible exception for a major continent is Africa. Particularly significant have been some of the records in Japan, western Europe, Mexico, Colombia, Turkey, the USA, Peoples Republic of China and in the Punjab state of India. The most remarkable crop production record for all time has been in India's Punjab. A three-fold increase in food grain production was achieved in 10 years (1966 to 1976).

Table 5.2. Average, best and world record yields

Food Crop	Average 1979 (US)	Best Farmers (US)	World Record (US) (Metric Tons/Hectare)	Ratio Record/ Average
Maize	6.9	14.7	22.2	3.2
Wheat	2.3	6.9	14.5	6.3
Soybeans	2.2	3.6	5.6	2.6
Sorghum	4.0	17.8	21.5	5.4
Oats	2.0	5.6	10.6	5.3
Barley	2.7	9.0	11.4	4.3
Potatoes	31	68	95	3.1
Rice (crop/112 days)	5.1	9.1	14.4*	2.8
Sugarcane	84	140	250.0	3.0
Sugar beets	44	80	120.0	2.7
Milk/cow x 1000 lbs.	12.0	35.0	50.0	4.2
Eggs/hen/year	235.0	275.0	365.0	1.5

*28 Tons/Hectare in the Philippines.

The gap between what production is now and what it could be is the great food reserve on which nations can depend and call upon if needed for the support of future generations and the 21st century. The current world record for maize production is 353 bushels per acre (22.2 metric tons per hectare). The theoretical maximum potential yield, however, is over three times as high or 1066 bushels per acre. This could be achieved with optimum sunlight and concentrations of atmospheric carbon dioxide, plant nutrients, water, and with no diseases or insects or environmental stresses.

Many have estimated ultimate or maximum crop productivity. Global productivity in grain equivalents have been computed as 40 times the present level. It has been suggested that food production could be increased 9 to 10 times above the current level. Average (1979) world records and the estimated yields for the best farmers for some fo the major food commodities follow (Table 5.2). Record yields are now about one-half of the potential estimated maximum yields.

Maximum yield trials should become a major part of current and future agricultural research. They could represent the ultimate in use of high technology for food production. They are as important for practice as they are for theory. Records of production for many food commodities of 20 years ago are averages for today. Record

yields should not be regarded as abnormal occurrences, and a study of the comparative productivity of previously successful agricultural systems could be most rewarding. Scientists should be encouraged to constantly test the limits of available technology, as well as their ability to put together technology components in a systems approach to achieve maximum production. This is what successful farmers must do. Further major breakthroughs in food production will come only if the total agricultural production system is considered. This is true also of successful research programs and technology innovations. Simulation models depicting growth, development and yield of major food crops are now in progress. These include maize, sugarcane, sugar beets, potato, wheat, rice and field beans.

The operational approach for maximizing yields must be one which integrates the total input systems. Many systems and subsystems enter into total crop productivity.

*Table 5.3. Pockets of successful production in world agriculture**

Projects	*Accomplishments*
Grain Production in India's Punjab	A 3-fold increase in grain production in 10 years from 1965 to 1975
Rice Production in Colombia	Yields rose from 1.8 to 4.4 tons/hectare from 1965 to 1975
Wheat Production in Turkey	Increase in production from 7 to 17 million tons from 1961 to 1977
Hybrid Rice in China	20 to 30 percent yield increase (labor intensive high yielding technology)
Hybrid Cotton in India	Yields doubled – (labor intensive high yielding technology)
The White (Milk) Revolution in the Gujarat	Daily cash income, improved nutrition, labor intensive technology for 300,000 small farms
The Puebla (Maize) Project in Mexico	Yields increased by 30 percent from 1968 to 1972
The Comilla Project of East Pakistan	Rice yields and incomes of farmers doubled from 1963 to 1970
The "Masagana 99" Project in the Philippines	Rice yields increased by 36 percent in 3 years from 1973 to 1976
Maize in Kenya	Hybrids and fertilizer and management increased yields 4.8 tons/hectare
Hybrid Maize in the U.S.	3.5 fold yield increase in yield from 1940 to 1979

These include climate and weather, appropriate cultivars, soil nutrients, soil structure, soil moisture, temperature and sunlight. There are cropping systems, pest management systems, water management systems, soil management systems and tillage systems as a subset of soil management. Economic-simulation models are being developed for projecting world patterns of grain, oilseeds, livestock production, grain exports, stocks, and market stability. Weather-crop yield models are now available to assess the likely impact of weather on crop productivity. Programming of in-

*Wortman and Cummings, 1979

puts for optimizing productivity has reached a high level of technology in scheduling of irrigation for field crops and for greenhouse vegetable production in automated environments involving light-modulated temperature control and programmed $C0_2$-injections related to other environmental factors. Electronics will play an ever-increasing role in food production.

There are notable examples of successful food producing systems in the agriculturally developing world. Some of them are summarized (Table 5.3). The ingredients (technological, social, economic and resource inputs) that have gone into these pockets of success should be identified. Wider adoption of these models could give encouraging results elsewhere.

CONCLUSIONS – FOOD PRODUCTION TRENDS

A review of the research and technology needs for food production in the 21st century is significant for future food policies and the welfare of all societies. Any projections for the future are built upon identification of existing and emerging agricultural trends. These trends follow.

More food must be produced. It will be a response to rising populations, increasing demands, and greater trade and exports. This means that more land will be devoted to agricultural production, and there will be more production per unit land area per unit time; and the time for effective agricultural output will be extended by more crops per year through expansions in irrigation, improved pest control, advances in the use of protected environments, and an increase in the carrying capacities of range lands.

Greater stability and dependability in food production will be sought. Stability of agricultural productivity will parallel, in priority, production increases derived from expanded irrigation of cultivated crops, improved pest control, advances in protected environments for crops and livestock, alleviation of climatic and environmental stresses through genetic improvements, management, and chemical treatments, and emphasis on grain reserves and home storage. Plants with superior characteristics of mineral metabolism will be developed so that they will be productive on nutrient poor soils and under excesses of toxic elements and salt.

Research and technology will focus on pest control for the prevention of food losses, increased production, and the management of pesticide resistance. Integrated pest management will be pursued because it provides more than one line of attack (cultivar resistance, biological controls, management and cultural practices, and chemicals). While there will be more rather than less pesticide chemicals used, they will be more confined to target organisms. Additional naturally occurring insecticides will come into use. Excessive use of conventional materials will be reduced,

and timing will be more precise. Greater stability in food production will occur as a result of improved pest control strategies (U.S. Congress, 1979). Research will not be confined to crops, but will include added emphasis for reducing losses and the control of diseases in livestock and poultry.

Soil, water and energy conservation will be emphasized. Conservation tillage for the production of major and minor food crops will expand greatly as a concept and as a practice. Allelopathic (natural herbicide) responses of selected plant residues will be programmed with conservation tillage to greatly reduce or eliminate the use of herbicides.

While there will be increasing emphasis on technologies for improved water management and use efficiency, irrigation will expand greatly in the subhumid temperate zones, semi-arid tropics, tropics, and subtropics. There will be improvements in technologies for both irrigation and drainage. The technological revolution, initiated during the past decade in both irrigation and drainage, will continue. Supplemental irrigation in sub-humid areas will provide the next quantum leap in production of major food crops. Drip irrigation will continue to expand exponentially for high value food crops and for some of the major food crops. Interest in dynamic cloud seeding technologies for weather modification will mount and research on precipitation enhancement will increase as water supplies for agriculture and competitive energy uses become more limiting.

Resource conservation will become a byword for land, water and energy. The 21st century can be projected as a biological century. There will be renewed emphasis on the production and utilization of renewable resources. Food production must move toward a series of more science-based rather than resource-based (land, water, energy) technologies. Land will assume increasing importance not only for food production but as sites for disposal of wastes. There will be greater integration of waste or byproducts applied to land into food producing systems.

Energy uses for powering motor vehicles and farm machinery derived from food crops will emerge. These will range from ethyl alcohol produced from maize, sugarcane and cassava, and agricultural byproducts to the vegetable oils of sunflower, palm, soybean, cotton, and rape seed. Agriculture could become self-sufficient for energy currently derived from fossil fuels. The potential of vegetable oils, such as sunflower oil for fuel for motorized vehicles, as well as food for people will result in significant increases in their production.

We are now in the midst of the greatest biological revolution of all time. It is a renaissance for molecular biology brought on by the possibilities with recombinant DNA and the sequencing of genes.

Trends in food production research will bring an increasing emphasis on the basic biological processes that control productivity in crops and animals. For food crops, they will be the next generation of agricultural research. This means improved photosynthetic efficiency, biological nitrogen fixation and nitrogen fixation utilizing renewable resources, cellular approaches to genetic improvements, greater resistance to competing biological systems and environmental stresses, inhibition of nitrification and denitrification, a renewed emphasis on soil microbiology to include mycorrhizal interrelationships, bacterization of roots, and the use of farming systems in which

biological nitrogen fixation will result in stable high production; and finally identification of hormonal systems and processes which regulate growth, reproduction, and yield. For livestock, greater reproductive efficiency and the preferential production of more protein and less fat on the carcass will be pursued. There will be improvements in the utilization of ligno-cellulosic portions of crops for both increased energy production as well as feed for livestock. The current interest in aquaculture will expand as new technologies for culture of traditional and exotic species are introduced. Possible climate changes induced by rising levels of atmospheric $C0_2$ will give emphasis on research to alleviate climatic and environmental stresses for both crops and livestock. With appropriate research investments agriculture can cope with projected climate changes (Wittwer, 1980a).

The future will see new concepts in mechanization and size of farm operations (Martin, 1983). Labor saving technologies will continue to be developed for food production. Many farm operations will become computerized, as irrigation scheduling is now programmed in many parts of the world. The need for timely operations in almost all food producing areas mandates the use of machines of high performance that can complete jobs quickly such as seeding and harvest operations. The future will see increasing interest in intensified units and mechanization to fit appropriate technology concepts. How to make small farms economically viable units will be a continuing challenge. Machines adapted to seeding and harvesting of intercropped commodities will be developed. The future will see more crop and livestock diversification. There will be new and improved technologies and interest in aquaculture, agriforestry and organic farming.

Finally, environmental issues as they impinge on the science and technology of food production will continue to mount. Concerns about food safety and toxic substances in the environment will multiply, and constraints will increase in the use of chemicals for pest control, disease prevention, and growth regulation. The options for chemical usage will continue to decrease as the needs for food production continue to increase. This, coupled with the energy versus food decisions for the future, poses a challenge to research and technology needs and options for the 21st century.

How we can commit to aggressively expanded food production programs, agricultural exports, and biomass production for renewable energy resources, while at the same time achieve nondegradation of soils, reduce overdraft of ground waters, and avoid modifications and pollutions of the environment through increased use of irrigation, fertilizers and pesticides stands as the supreme challenge for future agricultural science and technology (Johnson and Wittwer, 1984). Faced with this magnitude of global food production opportunities and problems, we may discover quickly that the nominal – even token – investment of 3% of the $150 billion research and development budget per year for the world's oldest and largest industry is not enough. For industrialized nations including the U.S., an increase in agricultural research support will be needed to maintain a growing economy and meet expectations of a better life. For developing nations, increased agricultural research will be a matter of survival.

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CHAPTER 6
Germplasm Resources

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INTRODUCTION

GLOBALLY MAN DEPENDS on the land for 98% of his food supplies, and this is unlikely to change in the immediate future. Cereals supply over half the energy consumed and the past two decades have shown a 70% increase in cereal production. Continued improvement demands increased cereal production by means of increased productivity (FAO, 1980) and the lessening of ravages by pests and diseases and post harvest losses.

Improvements must be easily adopted by resource-poor farmers in developing regions where there are low-input conditions. The technologies developed in the 1960s (the "Green Revolution") led to the adoption of high yielding varieties and production technologies, which among other things provided direct benefit to the low income consumers (CGIAR, 1978).

Increased productivity – and the defence of gains already made in the past decades – must be sustained. Not only for cereals but also for other crops which feed man.

There are a number of inputs necessary for the gains needed in order to reduce the numbers of people suffering from protein-calorie deficient diets – numbers which are increasing (IFPRI, 1977). This paper reviews the need for advances in plant breeding and regards the provision of germplasm as a basic input.

PLANT BREEDING AND GENETIC RESOURCES

Modern breeding generally leads to a narrowing of the genetic base of a crop and technology-based agriculture tends to use a limited number of varieties over large areas. For success in breeding, genepools have to be available to provide the variability. Genetic diversity is the basis for sustained varietal improvement. It provides parental material from well-adapted reserves; it provides material to enhance local

adaptation to overcome disease and pest susceptibilities and it provides the foundation for breeding for novel requirements.

Until recently breeding was frequently based on a limited number of locally-adapted cultivars; hence leading to the narrowing of the genetic base. Breeding from a much broader genetic base is now being practised for many major crops (e.g., maize) (CIMMYT, 1980).

For each crop resources for the breeder range from the elite material and breeding lines through the obsolete varieties to the primitive cultivars and the closely related wild and weed species or races. The natural variability is to be seen in the centres of diversity where agriculture has been based, for millenia, on heterogeneous local cultivars and mixtures. These areas where such diversity is found are mainly located in the poorer countries. Here breeders could sample, when necessary, to obtain the materials needed. However accelerated agricultural development has caused major changes in the poorer countries: uniform high-yielding varieties have been introduced with the concomitant loss of the unimproved material. Not only are primitive cultivars rapidly displaced but so too are some of the related wild species as the ecosystems change.

The primitive cultivars consist of populations with balanced structures capable of some yield even under adverse conditions during particular growth cycles. They are heterogeneous both in time and space; and, due to their long periods of evolution, they have accumulated genes for resistance to limiting factors. Much of their diversity relates to gene complexes for adaptation assembled over time. These genetic resources are irreplaceable because the genotypes cannot be reconstituted in the laboratory or experimental field.

The need for the conservation of these materials is now in general accepted in order to preserve the variability for future use in breeding. The task of genetic conservation is large, not only in view of the areas of the world to be covered but also because the loss of material (genetic erosion) differs from crop to crop and from region to region (IBPGR, 1976). The magnitude of the task has been recognized by FAO since the 1960s (see Frankel and Bennett, 1970, and Frankel and Hawkes, 1975).

Following the FAO initiatives, (and not least those of its Expert Panel on Plant Introduction and Exploration under the Chairmanship of Sir Otto Frankel) the need for genetic conservation was supported by the UN Conference on the Human Environment at Stockholm in 1972. A number of other activities, especially those associated with the International Biological Programme, provided data and proposals for action (see Anon., 1971; Frankel, 1973; Matsuo, 1975) as did the USA Agricultural Research Policy Advisory Committee (USDA, 1973).

Finally in 1974 the International Board for Plant Genetic Resources was established as an institution of the Consultative Group on International Agricultural Research charged with the development of a global programme for genetic conservation. Further details of the IBPGR programme are provided in the following pages.

Table 6.1. IBPGR global priorities for collecting crops[a]

Cereals
1. Wheat, sorghum, *Pennisetum* millets, rice in Southeast Asia, India and Africa
2. Other millets, rice in other areas
3. Barley, maize, oats and rye
4. Grain amaranths, quinca, and teff

Grain legumes
1. *Phaseolus* beans
2. Winged bean, chickpea, cowpea, groundnut, soyabean, Asiatic *Vigna* sp.
3. Pigeonpea, *Pisum*, and *faba* beans
4. Lablab, lentil, Lupin, and *Mucuna*

Root crops
2. Cassava, potato, and sweet potato
3. Yam
4. Minor Andean and African tubers, taro and other aroids

Starchy fruits
2. Bananas and plantains
4. Breadfruit and jackfruit

Fibre crops (flax and linseed priorities not determined)
2. Cotton
3. Jute
4. Kenaf

Oil crops
1. Coconuts in Southeast Asia
2. Oil palm in South America, coconut in other areas
3. Oil palm, brassicas, olive, safflower and sunflower
4. Niger seed and sesame

Sugar crops
1. Beet in the Mediterranean and Southwest Asia
2. Sugar cane

Vegetables
1. Tomato, leafy amaranths, okra, cucurbits, *Momordica, Capsicum,* eggplant, brassicas and *Allium*
2. *Basella alba, Celosia argentia, Citrullus lanatus, Cindoscolus chayamansa, Cucumis melo, C. sativus, Corchorus olitorius,* carrot, lettuce, *Lagenaria, Raphanus, Sechium edule* and *Telfairia.*

Other Industrial Crops
1. Coffee
2. Rubber, cocoa and grape
3. Tea

[a] Priorities for fruits, nuts, forages and medicinal plants not yet available.

Table 6.2. IBPGR regional priorities

First Priority
Mediterranean: Southwest Asia: South Asia; Ethiopia

Second Priority
Central America, Mexico and the Caribbean; Western Africa; Andean region, Central Asia; Southeast Asia and Brazil

Third Priority
East Asia; Pacific Islands; Eastern Africa and Southern South America.

BREEDING METHODOLOGY

Plant breeding is a technology based on similar genetic mechanisms to those that caused the evolution of cultivated plants but the selection is largely artificial and the individual programmes have well defined objectives so that the products offer advantages over other varieties in terms of yield, quality or agronomy.

The relevant and fairly standard methods of breeding depend on the type of crops, i.e. whether they are inbreeding, outbreeding (or mixed) or vegetatively propagated. Improvement in the inbreeding crops began with selection and proceeded to crossing programmes and line selection. Improvement in the outbreeding crops began with mass selection followed by half-sib and full-sib family selection and simple recurrent selection, although the development of F_1 hybrids has become extremely important especially with the use of self-incompatibility or cytoplasmic male sterility. In vegetatively propagated crops, after crossing F_1 populations are produced and progeny subjected to increasing selection intensity. Thus there are four basic breeding populations: inbred lines, open-pollinated populations, hybrids and clones. From these the breeder uses the products of recombination which show enhanced adaptation. Simmonds (1979) provides a clear account of the various breeding methodologies.

Success in plant breeding: inputs

To be successful, the breeder must have available suitable parental material, especially locally-adapted material. Until recently the need for a broader genetic base, or at least the availability of gene pools if needed was hardly appreciated. Of course, many important crops had been successfully exploited from a very narrow base e.g. the oil palm industry in Southeast Asia derived from four trees introduced to Java; similarly rubber in Malaysia derived from 22 seedlings; potatoes in the north temperate regions derived from a few introductions, and maize in the corn-belt of the USA has been based on a handful of inbred lines. But the dangers of continuing without due consideration of the genetic base for breeding is now better realised following crises such as epidemics, many of which are well documented, for example, the Southern corn leaf blight epidemic in the United States in 1970–1971, the Irish potato famine due to late blight in the 1840s, and the shift from biotype 1 to 2 of the rice brown planthopper in the Philippines and Indonesia in 1974–76.

Special breeding techniques

It is not enough just to have an adequate supply of variability for breeding. Plant breeding utilises special methods to manipulate and manage the germplasm to maximise potential gains and to protect gains already made. Such methods include chromosome and cytoplasm manipulations including polyploids and genetic transfers from alien material as well as the use of *in vitro* methods e.g. the production of new meristems, cell fusions, or haploids in culture. However these methods at pre-

sent, in general, supplement more normal breeding techniques.

It has been thought, and indeed expressed (Brock, 1971) that we can induce any mutation that occurs naturally and also many which have never been produced spontaneously or have been lost from populations. Artificially induced genetic variation is being used effectively to supplement natural sources of variation for breeding; new alleles of known or unknown genes can be induced thereby broadening the genetic base by creating variability. Alleles of known genes not previously found naturally have been induced for short straw and waxlessness in barley (Lundqvist, 1976); new alleles of previously unknown genes have been induced for peas (Blixt, 1974) and other crops; linkages have been modified; and recombination in crosses may be stimulated and various other effects are possible.

Nonetheless notably successful varieties deriving solely from mutation-induction programmes have been relatively few. We must regard mutation breeding as a technique useful in generating variability but in a limited way. Mutations should be regarded as a supplement to genetic conservation.

The successes of plant breeding have depended on the use of novel genes and gene combinations. Developments in unconventional techniques may well become increasingly relevant for the future but the evidence points clearly to the need for genetic conservation as the basis for breeding (see Swaminathan *et al.*, 1979).

Breeders' collections

It must not be forgotten that breeders for a long time worked with collections of their crops: Vilmorin, in France established one ca. 1850 near Versailles and large collections were built up in the USSR (the famous Vavilov collection) and the USA earlier this century. Other breeders kept large collections of particular crops. Nevertheless all underwent some erosion because they were not maintained to adequate conservation standards and were grown out every few years with resultant loss through genetic drift, loss of viability, human error, etc. Many breeders' collections were simply discarded. None of the collections were adequately evaluated or documented; nor were they truly representative.

NETWORK OF GERMPLASM BANKS

The necessity for genetic conservation has been outlined above and the major task of the IBPGR is to create a world network of activities to safeguard material. Ideally countries within centres of diversity would establish a mechanism to do this and neighbouring countries would form a co-operative programme in which facilities, expertise and materials are shared. The IBPGR has found that, except in very few cases, regional centres are not acceptable to the individual countries. Hence support

has been given at the national level and the active participation of the countries in which resources are situated has led to many countries themselves appreciating their own resources (IBPGR, 1979).

For many of the major crops the International Agricultural Research Centres (IARC) form a most effective backbone. The International Rice Research Institute (IRRI) in the Philippines has major world responsibility for rice, the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) in India for sorghum, millet, pigeonpea, groundnut and chickpea; the International Potato Center (CIP) in Peru for potato; the International Center for Tropical Agriculture (CIAT) in Colombia for beans and cassava; the International Institute for Tropical Agriculture (IITA) in Nigeria for cowpea and other African crops and the International Center for Wheat and Maize (CIMMYT) in Mexico advises the IBPGR for programmes on wheat and maize.

Base and active collections

The IBPGR has started to designate a network of base collection centres i.e. genebanks where material is kept for long-term conservation and safety, and most of the IARCs are involved. In other cases the IBPGR has designated national programmes e.g. the responsibility for wheat is shared between the USSR (Vavilov Institute), the USA (National Seed Storage Laboratory), Japan (Kyoto University) and Italy (Bari Germplasm Laboratory). In other cases national programmes are asked to hold duplicates for safety. As far as possible the IBPGR is attempting to designate all suitable genebanks and in recent years those of national programmes in Argentina, Canada, Ethiopia, Federal Republic of Germany, India, Philippines and Sweden have co-operated in addition to those mentioned above (IBPGR, 1980).

In the past 3-4 years this network has grown and designation for most of the major crops of the world should be complete by 1985. The practical contribution made by the IBPGR has been slow due to the need to convince governments of their long-term commitment.

The expansion of the network to include the active centres where crops are multiplied, evaluated and distributed will take longer but the IBPGR is attacking this through its crop committees jointly co-sponsored with the IARCs and its working groups of breeders and scientists. In the case of some crops, these problems have already been solved e.g. for rice, where at IRRI, there is a programme for collection, evaluation, utilization and exchange (Chang, 1976).

Many national programmes have emerged in recent years. Apart from the long-established ones in the USSR and the USA, approximately 25 countries have developed national programmes mostly in the centres of diversity. The establishment of genebanks has been more rapid in the developed world (Ng and Williams, 1978) but the majority assure the IBPGR of their wish to participate internationally and to help in transfer of technology. The network of genebanks envisages the participation of all relevant institutes in the regions of genetic diversity and elsewhere and the guarantee of free availability of materials and information to all.

Other aspects of genetic conservation

In order to organize any network, co-operative programme or active centre linked to the base centre to function properly the documentation of the material and the accessibility of data are essential. Whereas a number of years ago it seemed that an international system could be developed and implemented, it now seems that with the diversity of hardware available the prime task is to standardize the descriptors for each crop and – as far as possible – ensure some degree of input-output compatability for the documentation systems used by centres holding the same crop. This should cope with the characterization of the materials; full evaluation – a pre-requisite to protect the investment made in collecting and conservation – will be a major task to be faced by all concerned with the utilization of the samples. This task will be essential in helping to develop new varieties for enhanced food production.

There is a lesson to be learned from the need to evaluate. When the Southern corn blight became an epidemic in the USA, breeders were able to overcome the losses within a year because the materials they were using were evaluated. This could not apply to many of the germplasm collections at present in holdings where the materials are inadequately documented and little understood. This provides a moral issue which should be faced in a world which needs more and better food.

NEW SOURCES OF FOOD

All the domesticated species have been derived from wild species and many progenitors of the important species were those which pre-agricultural man gathered for food. In general the wild relatives of crop plants have been used for breeding for resistance to diseases and pests but there are tremendous prospects in utilising these genepools. To date they are largely untapped by breeders and most existing collections are seriously deficient in such materials.

Genetic transfer in wide crosses has been used only on a limited scale mainly due to lack of knowledge; but where knowledge was available a new crop *Triticale* emerged as a practical proposition combining the yield of wheat with higher grain lysine, high spikelet number and hardiness of rye by making a synthetic amphiploid. Similarly synthetic amphiploids between closely related taxa have resulted in hybrid rye grass (combining *Lolium perenne* and *L. italicum* and synthetic *Brassica napus* (tetraploid oilseed rape, resynthesized from *B. campestris* and *B. olereacea* and hybridized with the naturally occurring hybrid). *Raphanobrassica* is also a cross between two cultivated species which might well be developed into a crop.

However these are examples of (a) the modification of existing crop plants by breeding or (b) the development of new crops but with similarities to existing ones. What about new domestication? Here we have two problems to consider: (1) species which have not been documented, and (2) very minor crops which are grown locally but could be developed.

Species which have not been domesticated

Of the 350,000 or so species of flowering plants of the world only a handful have been important enough to enter into the world's economy. The majority of the world's population is fed by the following species: rice, wheat, maize and sorghum; potato, sweet potato and cassava; bean, groundnut and soya bean; sugarcane and sugar beet; and coconut and banana.

Many wild species are of potential value to man, and many works have been published on the value of plants (e.g. CSIR, 1948-62; Uphof, 1968; Tanaka, 1967; Terrell, 1977). There are at least 8000 species of edible plants known but doubtless many undescribed useful plants still remain in nature especially in the tropical regions where several hundred diverse species of fruits and leafy vegetables are gathered. The U.S. National Academy of Sciences has been involved for some years in reporting on underexploited plants (NAS, 1975b) but on the whole the species belong to the category below.

Species which are locally cultivated

We know far more about these than the truly wild species and the potential can be seen from the following examples of pulses which could be exploited (from NAS, 1979).

Voandzeia subterranea (Bambara groundnut): seed food content equal to a high-quality cereal; useful in arid areas.

Lablab purpureus (lablab): high protein seeds; useful in arid and subtropical areas.

Vigna aconitifolia (moth bean); *V. umbellata* (rice bean); high protein seeds: useful in tropics and subtropics.

Phaseolus acutifolius (tepary bean) seeds complement cereal grain; useful in semi-arid tropics and subtropics.

Another legume *Cordeauxia edulis* is a shrub native to the arid, semi-desert border between Somalia and Ethiopia and the seeds provided valuable food during the Sahelian drought. We can expect some of these legumes to be developed on a similar pattern to the winged bean *Psophocarpus tetragonolobus* following the NAS publication (NAS, 1975a).

Vegetable species in the tropics have been documented by Grubben (1977) and Sastrapradja and Kartawinata (1975) and without doubt some of these could be developed into new crops. However, there are social limitations to such development since European-type vegetables are in demand in the markets.

PROSPECTS FOR NEW CROPS

Crops have been "developed" within historical times. Some major ones are:
Sugar beet: evolved by selection from a fodder crop in the late eighteenth century in Europe.
Strawberry: developed by hybridization.
Rubber: developed within the last hundred years as a crop in a part of the world (Southeast Asia) remote from its origin in the wild (Amazonia).
Forage species: in many there is no clear distinction between cultivated and wild. Only recently has true domestication taken place.
Lupins: *Lupinus angustifolia,* one of several hundred species of lupins, has been developed as a crop in Australia and parts of Europe (Gladstones, 1970). Several other species have potential.

On the whole we lack adequate data. There are few surveys similar to those of domesticated and wild native fruits in Japan (Iizuka, 1975), or Southeast Asia (Sastrapradja and Karawinata, 1975) although there are a number of publications listing useful plants of particular regions (see Section E in Hawkes, Williams and Hanson, 1976).

Thus the potential is there to develop new crops although the priority for such development will presumably take second place to extending the cultivation of crops into new environments (e.g. potato in the tropics), mixed and intercropping and transfer of technology for relevant changes in agronomic practice (e.g. integrated pest and disease management).

Need for more information

There should be more surveys and programmes such as the USDA New Crops Research Branch to screen the underutilized plants especially when we know that many have a great capacity for biomass production as well as producing plant parts. It is easier to envisage funding being made more readily available to screen plants of potential pharmaceutical value rather than those which might feed people.

Nature conservation

Because of potential domesticates the establishment of biosphere reserves under project 8 of UNESCO's MAB programme is most important especially for forest species. Other species which are more feral are not so well protected at present: nor can primitive agricultural systems be preserved. Jain (1975) argues convincingly that crop scientists should collaborate closely with nature conservation programmes.

In 1974 it was estimated that 5% of the species of flowering plants are threatened with extinction. (Heslop-Harrison, 1974). Inevitably we shall lose species and possibly lose them before we know whether they are potential plants for food or other economic use.

PROSPECTS FOR THE FUTURE

The strategy for genetic conservation is clear: representative material of all crops and their relatives will have to be preserved for the future. Although a start has been made there is still a tremendous amount of collecting to be done, the materials collected have to be stored with the minimum of loss or genetic change, and the materials have to be documented and readily available for use. There are still some large problems to be faced at the technical and organizational levels especially when clonal crops are concerned.

Nonetheless the urgency of the task is now fairly well understood. Leaving aside considerations of costs, the task is somewhat intimidating, but it is a task which provides evolutionary insurances for the future. The safeguarding of such inputs for agriculture (as well as forestry, pharmacy and other human requirements) will provide the future of plant adaptation to the needs of man. As Frankel and Hawkes (1975a) stated, "No longer are there reasons why material in the field should be lost through neglect or inadequate effort. No longer need potential users want for material or information they require. No longer need we feel that we are failing in our responsibility towards the present and the future".

With reference to potential new crops we lack sufficient information. Maybe we have a responsibility to accelerate surveys so that we do not fail in our responsibilities.

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CHAPTER 7
Climate and Production in the Semi-arid and the Humid Tropics

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INTRODUCTION

IN AN ASTRONOMICAL sense, the *tropics* are defined as the areas lying between the Tropic of Cancer (23½°N) and Tropic of Capricorn (23½°S). This definition need not be taken to be the strict delineation of tropics in terms of agronomy because the crops do not respect imaginary lines drawn on global maps. In terms of crop ecology, tropics could be defined as that zone of the earth where the temperatures are uniformly high. The uninterrupted heat which accompanies this, has important biological consequences which are discussed later. It is not so much the presence of very high temperatures that characterises the tropics, as it is the absence of cool temperatures. Few are the regions in the intertropical zone outside the highlands and foggy coastal deserts where the mean temperature of the coolest month falls below 20°C, a temperature which corresponds to the warmest month in a large part of the temperate zone (Tricart, 1972). The uninterruptedness of high temperatures during all months of the year is the fundamental characteristic of the tropics. Hence cold temperatures are seldom or never a limiting factor to crop production. In addition, the annual temperature range is always less than 10°C. Close to the equator, the average range is less than 5°C whereas extensive areas near the Tropics of Cancer and Capricorn have ranges between 5° and 10°C (Table 7.1). In some parts of the tropics, specially in the humid forest zone and in irrigated areas crop production is possible throughout the year.

The daily temperature range in the tropics was also recorded to be higher than the annual temperature range. For example, in some semi-arid regions of Sudan and India, the daily temperature range reaches approximately 15°C.

Another main feature of the tropical climate is the importance of wind (MacArthur, 1971). The impact on temperature and rainfall of some of the rain-bearing winds, especially the monsoons that are associated with large continental land masses, is well known, as are the more sensational hurricanes or typhoons. The winds

Table 7.1. Mean air temperatures at six locations in the tropics

Location	Lat.	Long.	Mean temperature (°C)												Annual
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Garba Tulla (Kenya)	0.3 N	38.32 E	28.6	29.4	30.3	30.1	28.9	27.3	26.5	26.7	27.5	28.7	28.9	28.3	28.4
Buea (Nigeria)	4.09 N	9.14 E	26.6	27.4	27.7	27.4	27.7	26.6	25.1	25.2	25.7	26.0	26.5	26.7	26.5
Kota (Ghana)	5.52 N	0.59 E	27.4	29.5	29.9	29.3	28.2	26.8	25.9	25.8	26.4	27.1	27.7	26.9	27.6
Maidu-guri (Nigeria)	11.51 N	13.05 E	26.9	28.6	29.9	29.9	27.7	26.3	25.8	25.7	25.8	26.4	27.3	26.6	27.3
Menaka (Mali)	15.52 N	2.19 E	22.5	25.3	28.5	31.2	32.8	31.1	28.4	26.9	27.6	28.1	26.2	23.2	27.7
Ahmad-abad (India)	23.04 N	72.38 E	15.7	17.0	20.4	21.9	21.8	22.0	22.1	22.1	21.8	21.3	18.9	16.5	20.1

that originate over the hot deserts have an intense drying effect as is felt in the sub-Saharan Africa.

The variation in daylength throughout the year in the tropics is little. The solar radiation and air temperature during the day may undergo fairly rapid changes depending on the humidity of the air and cloud cover. These factors influence the crop growth and development and even after harvest when the high humidity and/or temperature could affect the storage of the produce resulting in high losses. The warm temperatures in addition to favoring good crop growth also are conducive for the growth of several species of weeds, fungi, and parasites. These problems lead to a high risk of pests and diseases.

Rainfall in the tropics as a whole also exhibits some common characteristics. The nature of the rain-producing mechanisms in the tropics, mainly due to convection, causes marked contrasts in rainfall within short distances over a short period of time. The torrential rains which occur cause associated problems of runoff and soil erosion. Even in the dry regions of semi-arid Sahel or the semi-arid zones of interior Australia, torrential rains are important and contribute a relatively high fraction of the annual total. In large parts of the tropical world, the degree of uncertainity attached to rainfall is high with both drought and flood as serious possibilities that occur frequently.

Because of the higher temperatures, high rates of evaporation are very common in the tropics thereby reducing the rainfall effectively available to the crops. Important differences exist between locations within the tropics in temperature, rainfall, and evaporation, depending on the elevation, terrain, and the proximity to mountains ie., windward or leeward sides, and such other factors. However, the common characteristics of high temperatures, daily range and annual range in temperatures and the rainfall-runoff-erosion relationships are unmistakable and demarcate the tropics from other climatic zones. Where water supply and soil fertility is adequate to reap the best advantage of the ample solar energy, the production potential of the tropics, according to Bradfield (1968) is high enough to harvest one rice crop and three sorghum crops in 12 months giving 5,000 kg of rice and 16,500 kg of sorghum.

THE SEMI-ARID TROPICS

The semi-arid tropics (SAT) are characterised by a high climatic water demand. Several definitions of the SAT exist and the criteria used in each are also different (Koppen, 1936; Thornthwaite, 1948; Troll, 1965; Hargreaves, 1971). In view of the importance attached to the high climatic water demand in the SAT which is a result of the uniformly high temperatures throughout the year, the system proposed by Troll (1965) is probably the more meaningful of existing definitions. According to Troll, regions in which the mean annual rainfall exceeds potential evapotranspiration for only 2 to 4.5 months are termed as dry SAT and where the duration is 4.5 to 7 months

Table 7.2. Monthly rainfall received at the ICRISAT Center from 1972 to 1981 and normal rainfall

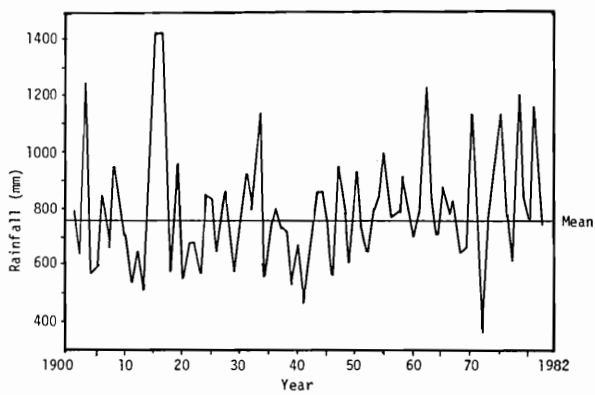
Month	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	Normal rainfall (mm)
	mm										
January	0	0	0	35	0	0	17	0	0	16	2
February	0	0	0	0	0	0	21	41	4	0	10
March	0	0	0	24	1	0	4	0	9	77	13
April	0	0	15	0	91	8	56	3	7	3	23
May	8	3	15	2	22	36	15	78	18	2	30
June	107	60	120	98	86	67	181	58	141	203	107
July	83	161	89	195	219	184	228	107	127	209	165
August	60	231	160	139	299	194	516	101	306	218	147
September	63	69	186	422	74	40	82	345	153	287	163
October	26	216	279	174	1	59	71	20	6	155	71
November	7	11	5	15	30	28	10	80	0	2	25
December	0	1	0	0	0	2	1	0	2	0	5
Total	354	752	869	1104	823	618	1202	833	773	1172	761

the areas are defined as wet-dry semi-arid tropics. The emphasis in this classification is on the duration of dry and humid months rather than on an assignment of climatic boundaries based on annual values of precipitation, temperature and humidity. According to Troll, the following climatic values prove satisfactory to explain the vegetation zones of tropical Africa and South America.

Humid months	*General vegetation*
12 to 9.5	Tropical rainforest and transitional forest
9.5 to 7	Humid savannah
7 to 4.5	Dry savannah (wet-dry semi-arid tropics)
4.5 to 2	Thorn savannah (dry semi-arid tropics)
2 to 1	Semi-desert (arid)
1 to 0	Desert (arid)

The semi-arid tropics are extended over 49 countries in the world covering Latin America, West Africa, Southern Africa, East Africa, West Asia, Asia, and Australia. About 750 million persons live in these semi-arid regions.

Figure 7.1. Annual rainfall at Hyderabad (1901–1982)



SAT regions are characterised by a highly variable rainfall. The co-efficient of variability of rainfall in SAT is 20 to 30‰. For example, at Hyderabad the mean annual rainfall varied from 320 mm (1972) to 1400 mm (1917) (Figure 7.1). For the savannah region in West Africa, Kowal and Kassam (1978) showed that at 16°N latitude and 0°meridian, the mean annual rainfall of 376 mm is expected to have a range in seasonal variation within 242–502 mm. The variability is encountered inter-yearly as well as seasonally. As shown in Table 7.2, there is a wide variation in the monthly rainfall recorded over a period of time. For example in 1981, September was the wettest month with 267 mm of rainfall while in 1978 which was also a 'wet' year, rainfall in September (82 mm) was the lowest. These temporal variations have a marked influence on the water availability and hence on crop growth and development.

Table 7.3. Rainfall intensities at three locations in the semi-arid tropics

Location (year)	*Size of storm*	*% rainfall with intensities higher than*		
		20	*50*	*100 mm/hr*
Niono, Mali (1977)	All	60	32	12
	> 20 mm	78	51	21
	10–20 mm	53	17	3
	< 10 mm	28	2	0
Niamey, Niger (1963)	All	72	52	17
	> 20 mm	78	61	21
	10–20 mm	69	42	16
	< 10 mm	-	-	-
Hyderabad, India (1975)	All	43	18	11
	> 20 mm	48	25	14
	10–20 mm	27	0	0
	< 10 mm	25	0	0

Source: Hoogmoed (1981)

Table 7.4. Runoff and soil loss under two differently treated Vertisol watersheds at the ICRISAT Center

Year	Rainfall (mm) (seasonal)	Broadbed and furrow lay-out with improved crop management system		Traditional flat with bunds, rainy season fallow system	
		Runoff (mm)	Soil loss tonnes/ha	Runoff (mm)	Soil loss tonnes/ha
1976–77	688	73	0.80	238	9.20
1977–78	586	1.4	0.04	52.7	1.68
1978–79	1125	273	3.40	410	9.70
1979–80	690	73	0.70	202	9.47
1980–81	730	116	0.90	166	4.58
Mean	763.8	107.3	1.17	213.8	6.93

Source: Miranda *et al.* (1982)

A substantial proportion of the rainfall usually occurs in a few high intensity storms. The intensity of rainfall in SAT usually from 20 to 60 mm/hr in most instances, but intensities as high as 120 to 160 mm/hr are not uncommon (Table 7.3). Hence the soil loss that accompanies the run off caused by such high intensity storms could be substantial. For example Miranda *et al.* (1982) showed that over a five year period from 1977–81 at ICRISAT Center in a traditional rainy season fallow system average soil loss was 6.93 tonnes/ha/year (Table 7.4).

Although the rainfall at two locations is similar, if the degree of atmospheric

demand for water between the locations is different, it can make a significant difference in the water requirement of the crop. Before the rainy season or at the beginning of the rainy season, the Potential Evapotranspiration (PE) is usually high in the tropics. For example, in central and northern India the average PE in June ranges between 16–20 mm per day while in northwestern India and Pakistan, it exceeds 20 mm/day. Mean monthly and annual PE averaged over 169 locations in India is shown in Table 7.5. These data show that the variability in PE is much lower when compared to rainfall and that the atmospheric demand for water is consistently high.

Table 7.5. Potential evapotranspiration (PE) statistics for 169 locations in rainfed areas of India

Month	Mean PE (mm)	Standard deviation (mm)	Co-efficient of variation (%)
January	85	27	32
February	103	24	23
March	151	23	15
April	177	21	14
May	207	33	16
June	174	34	19
July	132	27	20
August	122	21	18
September	122	18	15
October	119	15	12
November	90	19	21
December	78	25	32
Annual	1556	196	13

High rates of evaporation coupled with low and unpredictable seasonal rainfall often lead to periods of water shortage in the SAT that could have serious implications to the very survival and production of crops. When rainfall exceeds PE, soil moisture reserves are recharged. When rainfall is less than PE, soil moisture reserves are utilised. As shown in Figure 7.2, at six locations in the SAT, there is only a 2 to 3 month period during the year when rainfall exceeds PE, allowing some soil moisture recharge followed by utilization in the succeeding months. The soils of the SAT show great diversity in texture, structure, type of clay, organic matter content, and depth. Among other things, the precipitation actually entering the soil depends upon the type, surface conditions, and moisture status of the soil.

Infiltration of water is low in the SAT (depending on the soil type) on account of the rain falling on a soil hardened by the drought and also due to the textural composition of the soils. For example it was shown for the Alfisols at ICRISAT Center that the initial infiltration rate of 73 mm/hr in the first half hour after rain goes down to 15mm/hr by two hours. Infiltration rate is greatly reduced during the early rainy season by surface scaling caused by the impact of rain drops on bare soil (Table 7.6).

Figure 7.2. Monthly variation in rainfall (———) and potential evapotranspiration(------) at six selected locations in the SAT ⊡ Water deficiency ⊡ soil moisture recharge

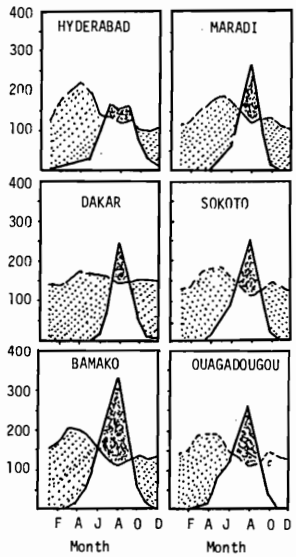


Table 7.6. Initial and equilibrium infiltration rates of Vertisols and Alfisols at the ICRISAT Center (based on field measurements using double concentric basins)

Time from start (hrs)	Infiltration rates	
	Vertisols (mm/hr)	Alfisols (mm/hr)
0–0.5	76	73
0.5–1.0	34	18
1.0–2.0	4	15
After 144	0.21 ± 0.1	7.7 ± 3.7

Source: Srivastava *et al.* (1982)

From an agricultural stand point, in most of the SAT three distinct seasons could be delineated.

1. A humid or rainy season the duration of which varies from 2 to 4½ months. In the season as a whole, rainfall exceeds evapotranspiration but prolonged rainless periods are not uncommon. About 90 per cent of the annual rainfall occurs during this season.
2. A dry postrainy season of 140 – 150 days when there is little or no rain, with the

crop production dependent mainly on stored soil moisture and, where possible, stored water from tanks or wells.

3. A hot, dry season of 100–200 days duration which is not well suited for crop production because of high water requirement.

THE HUMID TROPICS

While the humid tropics share the commonality with the semi-arid tropics of some of the temperature limits discussed earlier, there are some very important and significant differences in the moisture status as the very term 'humid' would imply. For example in West African humid tropics where the forests abound, the mean annual rainfall exceeds 1200–1500 mm and the dry season is less than four consecutive months. In equatorial Africa, with abundant rain and no dry season, the forests are evergreen. Greenland (1977) defined the humid tropics as those areas where the rainfall exceeds evapotranspiration for at least seven and a half months in the year. The humid tropics by this definition roughly conform to those areas between latitude of 10°N and S. This belt is distinguished from the other humid regions of the earth by the fact that it is constantly warm and in that the average daily range of temperature exceeds average annual range. Humid tropics are by far the most widespread of the great climatic groups, they occupy about 36 per cent of the entire earth surface – nearly 20 per cent of the land surface and approximately 43% of the ocean surface (Trewartha, 1968).

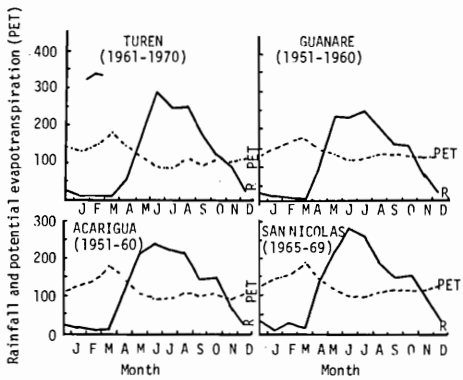
In the humid tropics two climatic types are distinctly differentiated. The humid tropical wet climates and the humid tropical wet-dry climates. The humid wet climate is found astride the equator and extending out 5 or 10° on either side. The Amazon basin of South America; the Congo basin of Africa and oceanic margins of parts of Tropical West Africa, and the insular-peninsular area of southeast Asia comprise the most extensive regions with tropical wet climate. Eastern central America and parts of the Caribbean islands, western Colombia, the Guianas, the Atlantic margins of Brazil, eastern Madagascar and southern Sri Lanka are other smaller and more dispersed parts.

The wet and dry humid climates, often referred to as Savanna climates are spread from 5 or 10° out to 15 or even 20° on either side of the equator. Extensive areas are located in South America, (Venezuela, Colombia, and the Guianas; south central Brazil, Bolivia, and Paraguay), eastern and southern Africa, northern Australia, and southern and southeastern Asia.

The mean annual rainfall in the humid tropics is variable depending on the region. In the humid tropics of South Asia rainfall is determined by regional as well as local phenomena. The monsoonal rains are regional in nature while the convectional rains are a local phenomenon. The mean annual rainfall in the humid tropics of South Asia ranges from 5000 mm in the very wet regions to 1250 mm in the wet-dry region. The

inter-monsoon convectional rains consist of short duration, high intensity thunderstorms that could, infrequently attain intensities of up to 100 mm per hour (Panabokke, 1977). In the humid tropics of Venezuela, during the wet season most of the rainfall is concentrated in a few days with frequent dry spells. Potential evapotranspiration rates are high, even during the rainy season, because of little cloud cover in the dry periods between rainfall (Figure 7.3). In the western Amazon basin and innermost Congo basin the rainfall is well distributed throughout the year that no months are dry. The skies are almost always cloudy with a maximum in the warm hours of the afternoon. In the humid tropical Indonesia the climate is characterised by short dry seasons and long rainy seasons near the equator with a gradual lengthening of the dry season towards the south and southeast as shown by Oldeman (1980). This is evident from the data shown in Table 7.7, where the mean annual rainfall is shown to decrease from 3180 mm near the equator to 1413 mm at Kumpang located at 10° 10'S.

Figure 7.3. Rainfall (R) and potential evapotranspiration (PET) distribution in four different locations in Venezuela



In the wet-dry tropics, the annual rainfall varies from 1200 – 1500 mm with a marked dry season of more than two months duration at the time of low sun. The variability in the rainfall here is larger than in the wet climates with the variability reaching up to 25 per cent for example in Northern Australia.

As mentioned earlier, in the humid tropics, the rains are erosive because of the high intensity of storms. Lal (1976) computed the frequency distribution of rainfall intensities in western Nigeria. As shown in Figure 7.4, intensities exceeding 75mm/hr were recorded for 15% of the rainstorms during 1972 and 10% of those during 1973. Intensities greater than 100 mm/hr were recorded for 7% of the storms during 1972 and 3% of those during 1973. In 1974, 14% of the rainstorms had intensities greater than 100 mm/hr, half of those with intensities of 130 mm/hr. These intensities lead to erosion problems of considerable magnitude with the annual soil loss on bare fallow plots with 15 per cent slope reaching 250 tonnes/ha. As Greenland and Lal (1977) con-

Table 7.7. Monthly precipitation for selected locations in Indonesia

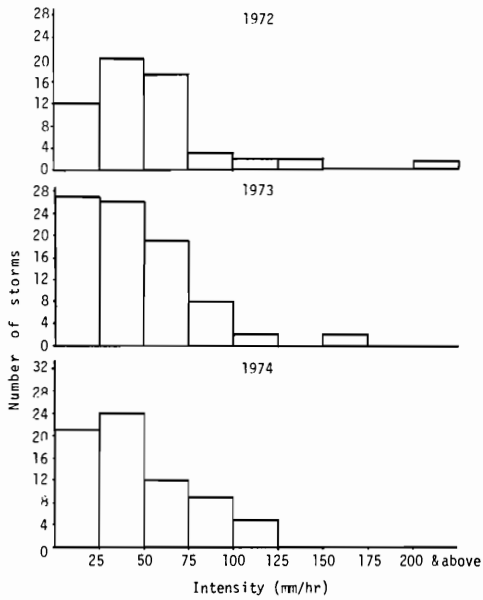
Location	Latitude	Monthly rainfall (mm)												Annual total (mm)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Pentian-ak	0°01′ S	277	208	242	278	282	222	164	204	228	365	388	322	3180
Kota Bumi	4°40′ S	364	264	316	228	165	127	100	83	107	146	181	342	2423
Serang	6°11′ S	265	218	180	149	138	119	81	68	74	106	178	218	1794
Pasu-ruan	7°50′ S	259	271	222	133	90	62	22	5	6	16	59	171	1316
Kupang	10°10′ S	386	347	234	65	30	10	5	2	2	17	83	232	1413

Source: Oldeman (1980)

cluded, in the humid tropics soil erosion is a serious problem, certain to become a threat in the immediate future as the need to use soils for intensified food production expands.

In the wet tropics near the equator seasonal variation in total daily radiation is small, not only by virtue of the small changes in sun angle and length of the day, but also because there are no distinct periods of clear and cloudy skies.

Figure 7.4. Rainfall intensity distribution of storms from 1972 to 1974 in Western Nigeria



METEOROLOGICAL FACTORS AFFECTING CROP PRODUCTIVITY IN THE TROPICS

The growth, development and yield of crops are to a large extent dependent on the environment in which they are grown. Although the term environment in its broadest sense could include the entire complex of physical, chemical, and biological factors influencing plant growth, the manner in which atmospheric factors, or weather influence plants is least known. The greatest fluctuation in crop yields in time and space could be attributed to the uncontrollable factor in the environment complex surrounding crops ie., the climate.

In describing the climatological factors affecting crop production in semi-arid and humid tropics, the discussion here is mainly confined to the aerial environment of plants, although changes in edaphic factors affecting plant development depend in turn on variations in climatic factors. For the sake of simplicity, crop production ie., conversion of solar energy, water, and nutrients into economic end products, can be viewed as a process that is dependent on a heirarchy of climatic factors.

Solar radiation

The ultimate source of practically all energy exchanged in the biosphere is the sun. In the absence of all other limiting factors, crop growth would be determined by the amount of solar radiation received. The flux density of solar radiation received on a horizontal surface depends on the solar altitude, the turbidity of the air and the type and amount of cloud cover.

In the arid and semi-arid regions of the world, 3,000 to 4,000 hours of bright sunshine are recorded in a year. Due to clear skies and low relative humidities more or less throughout the year, the total shortwave radiation is uniformly high. It is a maximum during summer months (600 – 700 cal/cm^2/day) and a minimum during winter months (340 – 520 cal/cm^2/day).

Budyko *et al.* (1962) published the atlas of heat balance of the earth which included maps of total radiation balance of the earth's surface and also maps of components of heat balance of the earth's surface, namely the loss of heat for evaporation, turbulent heat transfer and redistribution of heat by marine currents. In the tropics, the distribution of radiation is closely connected with the distribution of cloudiness. For example, the maps for July in northern latitudes and for January in southern latitudes showed that radiation totals in intermediate and high latitudes are considerable (exceeding 14 kcal/cm^{2}month) and often exceed the income of radiation in the tropics, due to the longer day in summer. However, the annual values of radiation balance show that the total of radiation balance over the semi-arid and humid tropics generally exceeds 70 kcal/cm^2, indicating that shortwave absorption exceeds the effective longwave radiation.

For the arid and semi-arid regions of India, it has been shown that a gradient in radiation intensities on clear days exists in winter, with low values in the north and high in the south as a result of the increasing inclination of the sun rays and decreasing length of day with increasing latitude. A reversal in the gradient occurs during May-July, with the apparent northward movement of the sun and the onset of monsoon over the peninsula. During these months, radiation received in the north is less than that received in the south by nearly 146 cal/cm^2/day. The highest values of solar radiation are recorded during April-June in the arid and semi-arid regions of the subcontinent and the lowest values occur in July-August and November-February.

In the savanna region of West Africa, there is a pronounced tendency for the annual radiation to increase northwards along the north-south axis. Kowal and Kassam (1978) showed that the relationship between the amount of annual solar radiation (Ri) and any geographical position described by latitude (LA) and longitude

(LO) in degrees and decimals of a degree estimated from 51 stations within the savanna region is

$$Ri = 307.4 + 11.46\,(LA) + 1.67\,(LO) \quad r' = 0.74$$

The values ranged from 388 cal/cm^2/day along the southern boundary to 480 cal/cm^2/day along the northern boundary.

In the central Congo basin the global shortwave radiation has an annual mean of approximately 410 cal/cm^2/day. In the humid tropics the solar movement and cloud cover dictate the intensities of solar radiation observed. Due to rapid changes in the cloud and atmospheric turbidity the interdiurnal variability of solar radiation can be very high. In the Congo basin, two maximum ie., in March (454 cal/cm^2/day) and November (422 cal/cm^2/day) and two minima ie., in July (345 cal/cm^2/day) and December (373 cal/cm^2/day) are observed (Griffiths, 1972).

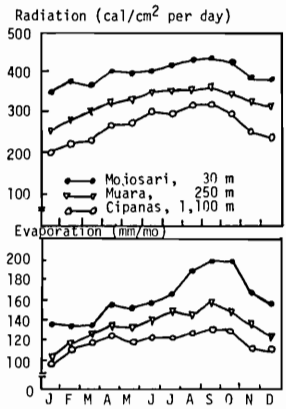
Analysing the role of solar radiation in the production of dryland rice in West Africa, Lawson (1980) showed that solar radiation values generally increase from south to north in West Africa in inverse relation to the rainfall pattern. This is evident from the monthly global solar radiation values computed for 9 locations in a transect from 4°N latitude to 14°N latitude (Table 7.8). Radiation levels in the far south decrease to 294 cal/cm^2/day by August. However, it was felt that the limiting role of poor light on rice production may not in fact come into play under low to moderate yields that are obtained at present. However, the need to improve these yields must take cognizance of low radiation as a constraint, particularly when water and nutrient requirements are improved. The problem with low radiation levels in the humid tropics was also referred to by Oldeman (1980) who showed that in Indonesia, low radiation intensities and low evaporation values occur during the wet season and values increase during the dry season. Because of increased cloud cover, radiation is much lower in mountainous areas than in coastal regions or inland plains (Figure 7.5).

Table 7.8. Mean monthly global radiation for selected months and stations in West Africa[a]

Station	Location		Global radiation (cal/cm^{2}per day)[a]				
	Latitude	Longitude	Apr	Jul	Aug	Sep	Oct
Tambac-ounda	13°56′ N	13°41′ W	553	464	405	431	435
Mopti	14°30′ N	4°12′ W	500	489	463	474	438
Zinder	13°48′ N	9°00′ E	534	516	448	482	491
Daru	8°00′ N	10°51′ W	490	394	304	358	415
Markurdi	7°41′ N	8°37′ E	487	425	341	391	426
Bouake	7°41′ N	5°02′ W	429	377	317	367	398
Ibadan	7°24′ N	3°53′ E	434	384	335	367	401
Monrovia	6°18′ N	10°48′ W	443	354	298	332	395
Port Harcourt	4°46′ N	7°01′ E	397	314	294	322	357

[a]Computed from sunshine hours data (Lawson, 1969).

Figure 7.5. Seasonal fluctuation of radiation and evaporation at three locations in Indonesia



Efficiency of utilization of solar radiation

Plant leaves are effective filters and they have a sharp absorption cutoff at about 700 mm. Leaves absorb strongly in the visible wavelengths, but weakly in the near infrared. With increasing light intensity, photosynthesis of the single leaf obeys the law of diminishing returns. Extremely high light intensities even have an inhibitory effect on photosynthesis – a phenomenon called solarization (Wang, 1963).

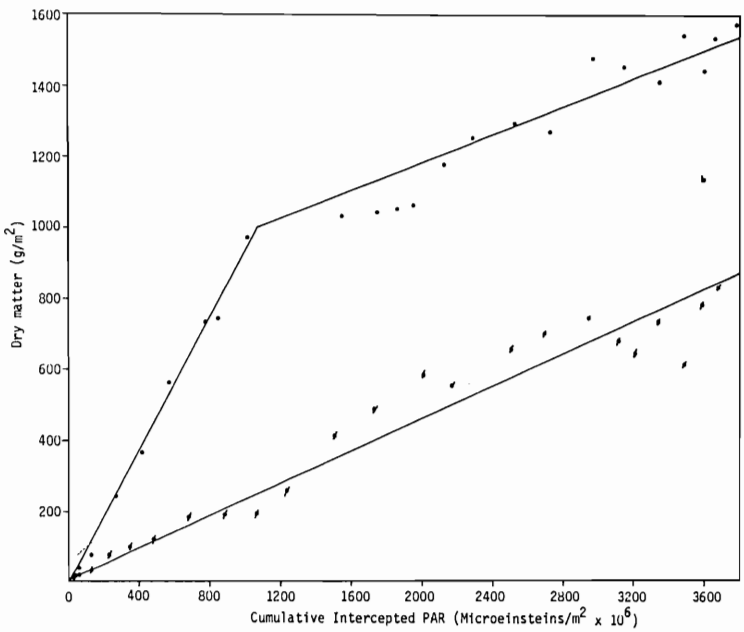
The theoretical maximum rate of carbohydrate production per unit area through photosynthesis has been calculated by Loomis and Williams (1963) as 710 kg/ha/day, assuming a solar energy input equivalent to the average radiation during a summer tropical growing season. If maintained year round, this would give a yield of about 260 tons/ha/yr of dry matter and would represent a solar energy efficiency of 5.3 per cent of total radiation or 12 per cent of visible radiation. From the potential productivity figures calculated for different regions of the world by de Wit (1965), it appears that the semi-arid and humid tropics have a great agricultural production potential per unit of around 120,000 kg of carbohydrate/per year. For Benin City in Nigeria, Wilson (1969) calculated that annual dry matter production of widely spaced sunflower plants where nutrient and water supply are non-limiting is 5110 g/m^2/year.

The theoretical values described above assume a crop intercepting all the radiation and converting it into dry matter, water, and nutrients nonlimiting and free from diseases and pests. The highest grain yields recorded from a single crop are 21 and 16 tons/ha from corn in Michigan and rice in Southern Australia respectively. In the tropics, however, such yields from a single crop have not been recorded. But the temperature regime in the tropics is conducive for continuous cropping throughout the year and the scientists at IRRI in Philippines have shown that it is possible to harvest 26 tons/ha from three crops of rice in a year. This represents an energy utilisation of 0.5 per cent of total radiation.

In reality, there are few places in the world where three crops could be raised every year under good crop and pest management. For rainfed cereals in semi-arid tropics the general level of yield is 0.5 to 1.0 ton/ha, equivalent to only 0.01 to 0.02% solar energy conversion (Norman, 1979). Using 25°C as the approximate daily mean temperature in the savanna region during the wet season at an incoming radiation level of 500 cal/cm^2/day, Kowal and Kassam (1978) calculated the maximum net dry matter production in the savanna region at 51 g/m^2/day.

Summer and winter radiation levels are important in rice-growing systems in summer-rainfall climates where irrigation permits dry-season cropping. In the humid tropics, specially in depressions, rice is the preferred cereal because of its ability to perform under water logging. In the monsoon climates, if other conditions are not limiting, higher yields are obtained in the high radiation winter dry season (Norman, 1979). At IRRI, it was shown that a high correlation exists between grain yield and solar radiation during the ripening period (Moomaw *et al.* 1967) or during the 45 days from 15 days before flowering to harvest (De Datta and Zarate, 1970). Spikelet number per square meter was shown to be highly correlated with solar radiation which implies that spikelet number is linked to photosynthetic production during the reproductive stage. A high percentage of sterility (empty grains) was shown to occur at high nitrogen levels combined with low solar radiation prior to heading and also under rainy weather conditions (Togari and Kashiwakura, 1958).

Figure 7.6. Relationship between cumulative intercepted PAR and dry matter produced for maize/pigeon pea • and pigeon pea ϕ



With negligible light wastage, a close relationship can be expected between total radiation and the yield of a dense crop. However as Chang (1968) explained, such a correlation cannot be expected for a crop that has a highly variable light wastage and whose ground coverage is far from complete. For example, from field to data on growth and interception of Photosynthetically Active Radiation (PAR) for a Maize/Pigeonpea intercrop, sole maize, and sole pigeonpea crops, grown at Hyderabad, India, Sivakumar and Virmani (1980) showed (Figure 7.6) that growth efficiency for Maize/Pigeonpea intercrop was 7.3% followed by maize and sole pigeonpea with 5.3 and 1.8%, respectively. Growth efficiency was calculated as per the definition of Biscoe and Gallagher (1977). Slow growing legume crops such as pigeonpea, with a low leaf area index for the first 80 days after planting, seem to show a photosynthetic response to increasing incident flux much like that of a single leaf and reach light saturation fairly early. But when grown along with a cereal crop such as maize, the total leaf area index for the intercrop is high and shaded leaves at the bottom of the canopy can continue to respond to an increase in incident light flux even if leaves high in the intercrop ie., of maize, are light-saturated. The success of such intercrops has been shown also to be associated with complementarity in time and the possibility of higher plant pressure, both of which result in greater light interception (Fisher, 1975; Willey and Natarajan, 1978).

As Budyko (1974) suggested from his theoretical analysis, total assimilation shows a strong dependence on radiation flux at its small values when the assimilation depends to a small degree on other factors. On the contrary at large values of radiation, the total assimilation does not principally depend on it. Under conditions of sufficient soil moisture, the productivity of vegetation cover is affected most strongly by two factors – photosynthetically active radiation and temperature.

Temperature

Air temperature

Because of the high radiation levels uniformly distributed throughout the year, the semi-arid tropics have a warm environment. The mean annual temperature in the semi-arid tropics is normally above 18°C. For several representative semi-arid stations in India (Table 7.9), the mean annual temperatures exceed 24°C (Virmani *et al.*, 1980). Air temperatures in the hot arid and semi-arid climates are the highest in the world (Critchfield, 1966). Using theoretical calculations of primary productivity it has been shown that productivity could be doubled with every 10°C between the temperatures of −10° and 20°C. The curve relating mean annual temperature to primary productivity is sigmoid in shape and beyond 20°C, the increase in primary productivity is smaller. These calculations show that the generally high mean annual temperture in the semi-arid and humid tropics favors high productivity. Generally the skies are clear which permit maximum radiation incidence during daytime and rapid loss of heat at night leading to wide diurnal ranges in temperatures. The diurnal changes in temperature normally associated with the light and dark period have pronounced effects on plant growth and development.

Table 7.9. Air temperature for some representative Indian locations[a]

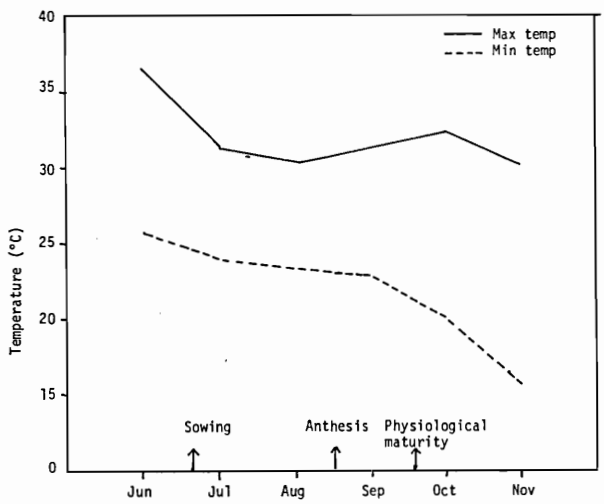
Location	Lat.		Season[b]									Annual average (°C)
			Summer			Rainy			Winter			
			Max. (°C)	Min. (°C)	Ave. (°C)	Max. (°C)	Min. (°C)	Ave. (°C)	Max. (°C)	Min. (°C)	Ave. (°C)	
a) *Mean annual temperature 18°C*												
Hissar	29°	10′	41.6	24.6	33.1	35.5	26.1	30.8	21.7	5.5	13.6	25.1
New Delhi	28°	35′	40.5	26.6	33.6	33.7	26.1	29.9	21.3	7.3	14.3	25.3
Bareilly	28°	22′	40.5	25.8	33.1	32.6	25.6	29.1	22.0	8.6	15.3	25.2
Lucknow	26°	52′	41.2	26.5	33.8	32.5	26.0	29.3	23.3	8.9	16.1	25.9
Gorakhpur	26°	45′	39.0	25.9	32.5	32.3	26.2	29.3	23.0	9.9	16.5	25.7
b) *Mean monthly temperature 18°C*												
Amraoti	20°	56′	42.2	27.8	35.0	29.8	23.0	26.4	28.9	15.5	22.2	27.2
Sholapur	17°	40′	40.4	25.5	32.9	31.3	21.9	26.6	30.8	15.8	23.3	27.1
Visakhapatnam	17°	43′	34.0	27.8	30.9	32.0	26.0	29.0	27.7	17.5	22.6	27.3
Nizamabad	18°	40′	41.5	27.7	34.6	30.1	23.0	26.5	30.0	15.3	22.6	27.0
Hyderabad	17°	27′	38.7	26.2	32.4	29.5	22.1	25.8	28.6	14.6	21.6	25.9

[a]*Based on 1930–1960 norms published by India Meteorological Department.*
[b]*Data of the months of May, August, and January have been taken to represent the summer, rainy, and winter seasons, respectively.*

Analysing the role of high temperatures on dryland rice production in West Africa, (Lawson, 1980) observed that the high daytime temperatures should induce a faster rate of growth and development, reducing vegetative growth and shortening grain filling period. High night temperatures could induce higher rates of respiration and reduce net photosynthesis. Hence it was concluded that the high temperature constitute a performance constraint on dryland rice in the region.

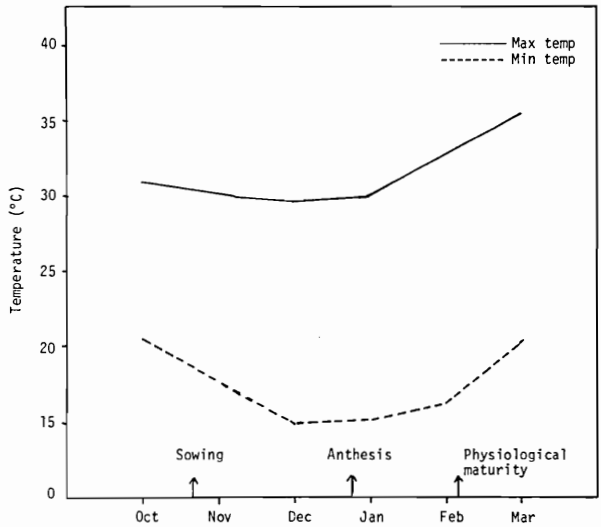
To illustrate the average range in the maximum and minimum air temperatures during a crop growth season in the semi-arid tropics, the case of sorghum which is grown during the rainy as well postrainy seasons in India makes an interesting study (Sivakumar and Virmani, 1982). The seasonal variations in the average maximum and minimum temperatures computed from 25 representative stations for each season along with average dates of anthesis and physiological maturity for CSH-6 (a rainy season hybrid sorghum) and CSH-8-R (a postrainy season hybrid sorghum) are shown in figures 7.7 and 7.8. It is evident from the data that the maximum temperature variation during the rainy season is not significant but the minimum temperatures decrease from 25°C to 20°C by physiological maturity. In the postrainy season however the maximum temperature increases from 30°C at the end of October to 35°C by March. What is relevant in terms of crop phenology is that the diurnal range in temperature is rather small in the rainy season and the uniformly high temperatures should promote good vegetative growth and grain filling. In the postrainy season the diurnal range in temperature especially around flowering is rather large and the minimum temperatures are consistently low.

Figure 7.7. Seasonal changes in maximum and minimum air temperatures during the rainy season



During the rainy season, in the semi-arid and humid tropics when the incident solar radiation is low, the photosynthetic rate will be proportional to light intensity because

Figure 7.8. Seasonal changes in maximum and minimum air temperatures during the postrainy season.



it is limited by a photochemical process and the temperature dependence of photosynthesis could be small. However on clear days when the light dependency of the photochemical process is negligible, the effect of high temperatures could be rather large. Moss *et al.* (1961) showed that at excessively high temperatures photosynthesis appeared to become heat-inactivated and with increasing respiration, the apparent relatively small rates of photosynthesis declined rapidly. Also crops growing on a poor or dry soil may have been anamalously dependent on temperature (Monteith and Elston, 1971).

Under conditions of extremely high temperatures, flower formation in certain species may never occur. For example, it was shown that Wedgwood Iris will remain vegetative indefinitely when stored at 25.5°C. The heat-killing temperature for a plant may be defined as the temperature at which 50% of the plant is killed (Levitt, 1972). The highest recorded temperatures for a growing higher plant are 60–65°C. Pasternak and Wilson (1969) showed that when sorghum plants were exposed at head emergence to simulated heat waves for 5 days, most of the enclosed flowers were killed. In the case of 25 species of plants, the temperature maximum for assimilation (36° – 48°C) was from 3 to 12 degrees below the heat killing temperature (44° – 55°C). High percentages of sterility and partially filled grains were observed when rice plants were exposed at heading time to maximum air temperatures of 36°C and minimum of 27°C (Moriya and Nara, 1971).

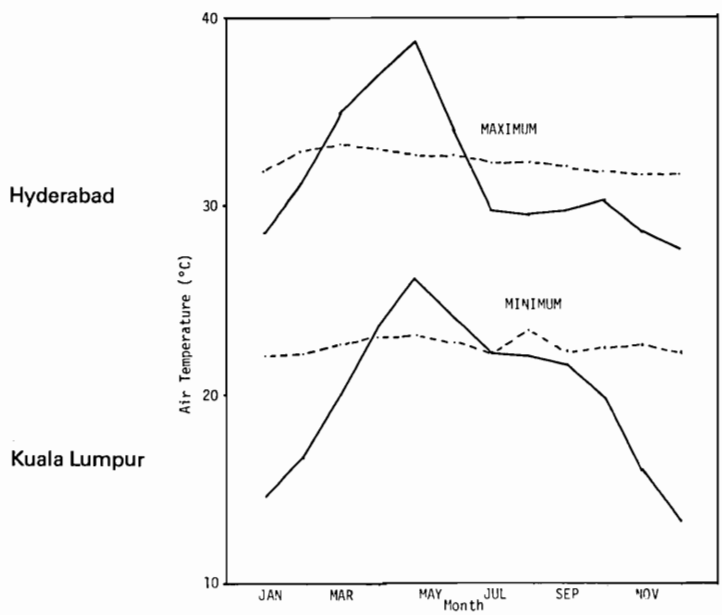
The harmful effects of higher temperature are usually aggravated by lack of available moisture. Hot dry winds further increase the damage. The yield of sorghum is adversely affected by high temperatures occurring at flowering (Skerman, 1956).

In the humid tropics, the temperatures do not rise sufficiently high or fall sufficiently low to seriously limit plant growth for any prolonged time throughout the

year. For example, the characteristic temperature variations in semi-arid tropical and humid tropical areas is shown in Figure 7.9 for Hyderabad, India, and Kuala Lumpur, Malaysia. The moderation in the maximum air temperature is attained in the humid tropics through the presence of moisture in the atmosphere almost throughout the year and the cloud formation at night reduces the loss of radiation at night so that temperatures are not reduced to the low values reached in the semi-arid tropics where clear skies permit rapid cooling at night. The range of temperatures which occur in the humid tropics are closer to the broad optima for growth of tropical species (Williams and Joseph, 1973). Unlike the semi-arid tropics where the high temperatures and shortage of water limit growth, the humid tropics are potentially more productive. However at high altitudes in the tropics, low air temperatures cause sterility of grains (Vergara *et al.*, 1970).

In the humid tropics where cropping is possible in the cool winter season because of good water storage in the soil, a winter rainfall component or irrigation, the temperature regime has a strong influence on the type of the crop grown. For example, in the irrigated areas of Bangladesh, the effective beginning of the rice-growing season is determined by winter temperatures. Night temperatures in December, January and part of February fall below 13°C which severely retard the growth of rice. Brammer (1977) hence concluded that the optimum date of sowing is one which will allow the seedlings to stay above 13°C.

Figure 7.9. Annual variation in the maximum and minimum air temperatures at Hyderabad and Kuala Lumpur



Leaf temperature

Plant leaf temperatures are controlled by energy exchange processes due to radiation, convection, and transpiration. Atmospheric temperature affects transpiration through its influence on leaf temperature and hence on leaf-water-vapor pressure (Kramer, 1969). When the rate of water supply to the leaves is inadequate for transpirational cooling, leaf temperatures increase rapidly, sometimes 5° – 10°C above the air temperature (Pearcy *et al.*, 1971). For example, supplemental irrigation studies during the postrainy season in a semi-arid tropical environment with chickpea (*Cicer arictinum*) showed that when the available soil moisture pofile is reduced to 100 mm in a 187-cm deep Vertisol profile, the canopy temperatures could raise to 5° – 10°C above the air temperature (Sivakumar *et al.*, 1983). In the past decade, plant canopy temperatures have been used extensively in the studies on prediction of evapotranspiration, scheduling of irrigations, and grain yield predictions (Ehrler, 1973; Idso and Ehrler, 1976; Idso *et al.*, 1977; Walker and Hatfield, 1979).

The temperature at which the rate of respiration and photosynthesis are equal is called the 'temperature compensation point'. If the plant's temperature rises above the compensation point, the plant's reserves will begin to be depleted. As the temperatures rise above the compensation point, the respiration rate continues to increase and photosynthesis to decrease and therefore, the starvation rate would increase exponentially (Levitt, 1972).

Soil temperature

Soil temperatures – particularly the extremes – influence the germination of the seed, the functional activity of roots, the rate and duration of plant growth, and the occurrence and severity of plant diseases. The temperature of a bare soil surface fluctuates in phase with the incident radiant energy, the amplitude of diurnal fluctuation being affected by radiation intensity, soil reflectivity and soil moisture content. The average soil temperatures in the West African savanna are much higher than in the temperate regions ranging from 25 – 35°C at 30 cm depth. Surface soil temperatures at the start of the rains reach 45 – 55°C. The surface soil temperature in the semi-arid and humid tropics is influenced to a large extent by the soil moisture content – wet soils absorb more radiant energy than dry soils. Most of the energy is used for vaporization of moisture, the rest being used to heat the soil. On the other hand, dry soil surfaces are considerably hotter since most of the incident energy is directly absorbed by the soil with little apportioning for vaporization of moisture. Warm, moist soils (20–30°C) are a favourable medium for most of the cultivated crops that are grown in the arid regions (Arnon, 1972). Plants differ in their sensitivity to soil temperatures. Water absorption is reduced more at low temperatures in warm-weather crops such as cotton or maize, than in typical cool-season crops, such as the small grains. The temperature below which water absorption by warm-weather crops becomes limiting is approximately 20°C (Kramer, 1963).

As Monteith and Elston (1971) concluded, the response of a crop to temperature

depends on the inter-relation of many processes governing dry matter production, growth of leaf area and development at particular stages in the life of a crop. Not only are the absolute temperatures of individual organs important, but diurnal ranges of temperature and temperature difference between different plant organs must also be considered.

Water

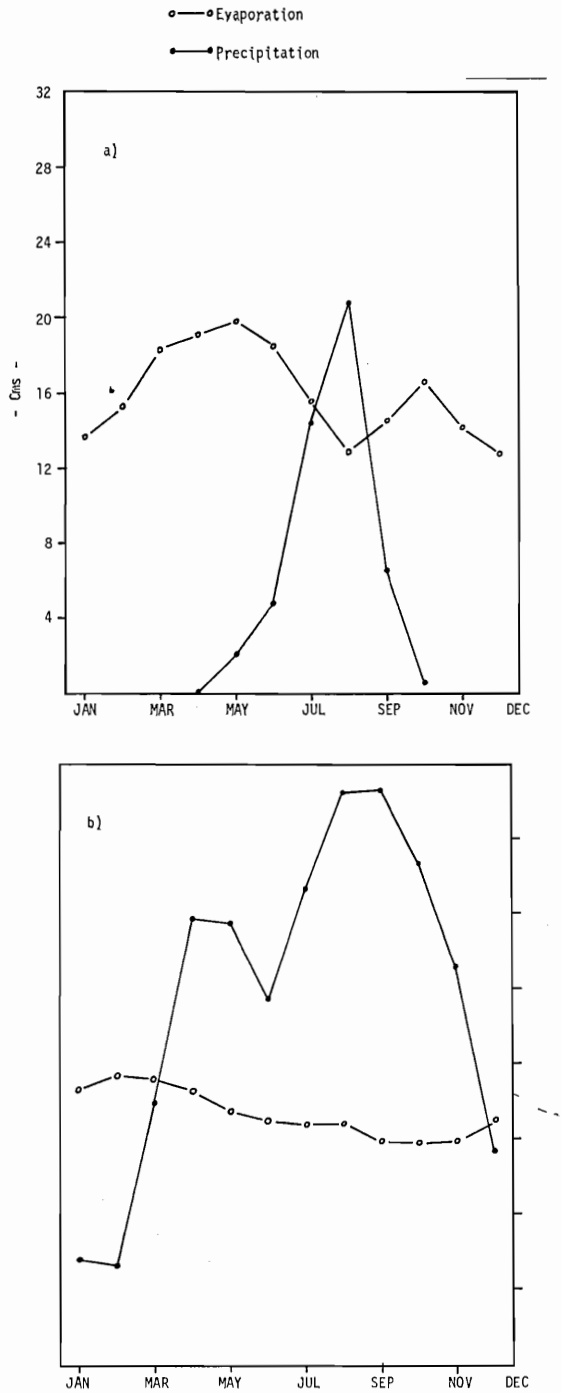
Water is the most important climatic factor contributing to stability/instability in agricultural production in the semi-arid tropics. As Russell (1959) pointed out, even in regions of average annual water surplus, water deficiencies are common in specific locations because of deviations of annual rainfall from average values, failure in seasonal rainfall to meet crop water needs, excessive runoff resulting from high intensity precipitation, steep topography or low infiltration rate and low soil moisture storage capacity. The coefficient of variability of rainfall in humid climates is about 10 to 20 per cent, whereas in semi-arid climates it may vary from 20 to 30 per cent.

Gangopadhyaya and Sarker (1965) showed that 75 per cent of the total variations in wheat yield in India could be accounted for by rainfall distribution. The study revealed that for the region covered in the study, additional rainfall above average for a period of one month prior to sowing and during germination is in general beneficial to the crop whereas more rainfall during tillering phase is detrimental. For the upper Jordan valley, Lomas (1968) showed that the correlation between mean annual rainfall and yield of wheat was fairly high (0.879). Cocheme and Franquin (1967) showed that although mean annual rainfall is a very useful parameter for the semi-arid area in West Africa south of the Sahara but additional accuracy and information were obtained by determining the deviation and dates of occurrence of availability of water at various levels of potential evapotranspiration. It is important to consider variations in evapotranspiration in assessing crop water use because both soil capillary conductivity and atmospheric evaporative demand interact to influence the transpiration rate from a crop. On a hot dry day, the rate of transpiration is so much in excess of water uptake that plants will wilt at a soil moisture content at which on a cooler or more humid day they would not have shown any signs of stress.

A quantitative description of the water regimes could be presented using the analysis of the amount and the pattern of distribution of rainfall and evapotranspiration. Moisture balance diagrams where the annual march of rainfall and evapotranspiration are plotted, are useful in identifying times of moisture adequacy and moisture deficit. An example of the moisture balance diagram for Zinder, a semi-arid location in Niger with an annual rainfall of 493 mm and Alor Star in Malaysia, a humid station with 2290 mm annual rainfall is shown in Figure 7.10. It can be seen readily from the figure that there is a very short period of moisture adequacy at Zinder while at Alor Star the moisture is adequate for as many as nine months during the year.

However, use of average rainfall figures to differentiate crop growing environments may be misleading because of large contrasts in the rainfall regime between the wetter and drier parts of the country. Hargreaves (1975) defined Dependable Pre-

Figure 7.10. Moisture balance diagram (a) Zinder (Niger) and (b) Alor Star (Malaysia)



cipitation (DP) as the amount of rainfall which could be received at 75 per cent probability. One would expect that dependable precipitation levels are usually smaller than the mean rainfall figures. Hargreaves also showed that the ratio of dependable precipitation to potential evapotranspiration (DP/PE) defined as Moisture Availability Index (MAI) could be used to describe rainfall adequacy to meet crop demands at a given location. These analyses, however, do not give information on the continuity or breaks in rainfall and the moisture adequacy to meet environmental demand on a short-term basis. Using the ratio of R/PE › 0.33 as a threshold value for each of the 52 weeks in a year, Virmani et al. (1978) could differentiate between the rainfall climatology of two semi-arid Indian locations, Hyderabad and Sholapur, with fairly similar climatic features. The analysis showed that monsoon crop growing season at Sholapur is highly erratic and undependable, leading to a poor agricultural production efficiency. On the other hand, probabilities of R/PE at Hyderabad showed a greater promise for crop production during the monsoon season.

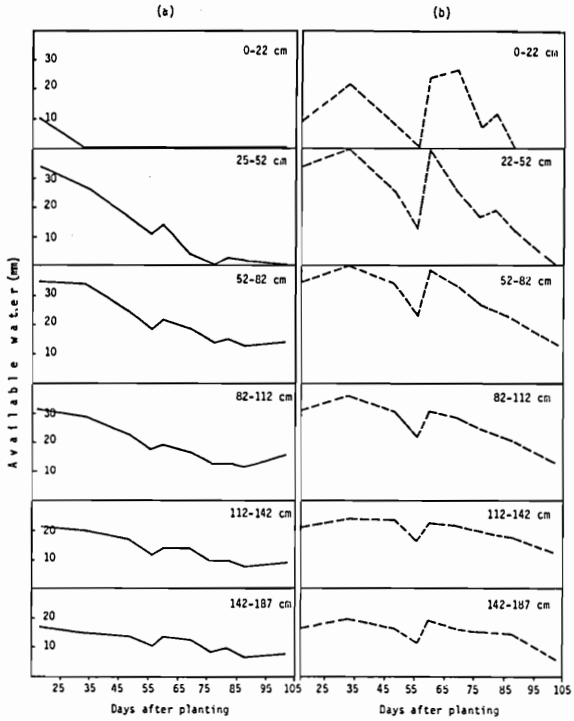
Nix and Fitzpatrick (1969) used a crop-water stress index which is defined as the ratio between estimated available water in the root zone at the start of the "critical" period and the mean potential evaporation (PE) during that critical period. The simple index gave highly significant correlations with grain yields, accounting for 60 – 83 per cent of yield variation within individual wheat (and grain sorghum) variations at one location. Shaw and Burrows (1966) by means of calculating "stress days" which are defined as days on which soil moisture content is lower than that required to keep the plants from being subjected to moisture stress under the prevailing atmospheric conditions, showed that in maize, there is a linear relation between dry matter production and number of stress days.

Each crop has a characteristic water-use pattern throughout the season. The length of the water availability period and the atmospheric evaporative demand are important factors which determine the water-use pattern. The capacity of the soil to store water and to release it to roots is determined by its depth and porosity. The distribution and movement of water within the soil profile are important from the standpoint of solute transport and providing water to plant roots. It is also generally accepted that the movement of soluble salts in soil is directly related to the movement of soil water. As the use of fertilizers, herbicides, and pesticides increases, the need for understanding water movement within the soil profile also becomes exceedingly important.

The time and depth changes of soil water provide an indication of the depletion of soil water and evapotranspiration. This knowledge is also required to ascertain survival probabilities of various types of vegetation between rainfalls in low rainfall areas and to determine the susceptibility of uppermost soil particles to wind erosion.

Sivakumar *et al.* (1979) used the changes in the available soil water in six layers of a deep Vertisol profile under rainfed and irrigated sorghum during the postrainy season at Hyderabad, India to characterize sorghum response to available soil water. Of the 175 mm of water transpired by the rainfed sorghum, the percentages obtained from each of the six depths of the profile were 28, 23, 20, 12, 9, and 8 (Figure 7.11). The corresponding values for the irrigated crop which transpired 310 mm water during the 112-day growing season were very similar, 25, 30, 18, 13, 9, and 8. These data

Figure 7.11. Change in available soil water in different layers as a function of time during the growing season for (a) nonirrigated sorghum and (b) irrigated sorghum



suggest that there was little difference in root development patterns of these rainfed and irrigated sorghum crops and that the amount of available water in the various layers was the dominant factor influencing the time and depth patterns of water use. Russell (1980) also showed that for chickpea in a semi-arid tropical environment, differences in the water uptake between an irrigated and non-irrigated crop could be attributed to the greater depletion and high soil moisture suction that existed in the upper parts of the profile in the non-irrigated plots.

The influence of soil water deficit on crop behavior in the field has been the subject of many agronomic field trials, the results of which are often specific to location, climate, crop, and soil. The need to evaluate the influence of environmental stresses and soil water potential on plant physiological processes (Wearing and Cleary, 1967; Reicosky *et al.*, 1975; and Reicosky and Deaton, 1979) combined with improved means of measuring plant water status in the past two decades led to increased emphasis on evaluating plant response. For example, reduction of leaf-water potential to a critical level which is different for different species, has been shown to result in permanent wilting. Growth was completely halted in control environment by a drop of leaf-water potential to −4 bars in sunflower (Boyer, 1970), −7 bars in maize (Acevedo *et al.*, 1971) and −12 bars in soybeans (Boyer, 1970). Field studies with soybeans under water stress showed that a major decrease in leaf enlargement

occurred near – 8 bars: and at a leaf-water potential of – 12 bars, the growth was completely halted (Sivakumar and Shaw, 1978).

The final yield of a crop, however, would depend not only on the degree and duration of water stress at different growth stages of the crop but also on the relative sensitivity of the crop to water stress at that stage.

Other climatic elements

Amongst the other climatic elements that affect crop production specially in the semi-arid tropics is the wind. In the coastal areas of both the semi-arid and humid tropics, the land and sea breezes help moderate the temperatures during day and night. In West Africa during the dry season in the northern hemisphere winter the 'harmattan' regime prevails with parching winds coming from the desert areas northeast of the zone. During the rainy season there is a monsoon regime with humid winds from the Atlantic ocean and humid equatorial Africa to the southwest. The higher average wind speeds and large moisture deficit of the air masses during the early part of the year result in an extreme drying out of the soil before the rainy season begins. In West Africa, if the harmattan returns temporarily after the early rains occurred the seedlings of the crop already planted may be completely desicated. The diurnal variation in the surface winds results in high speeds near midday, when higher insolation, temperature and wind speed all combine to increase the evaporative demand of the atmosphere and the stress on the plants.

Strong winds in the humid tropics also cause considerable damage to the plants. The major banana-producing countries are in the cyclone regions which occur north and south of equatorial zone where wind is a factor in increasing the crop risk. Of the important tropical crop species bananas and rubber as well as many fruit tree species are particularly susceptible to wind damage. In bananas, leaf damage and crown distortion are reported to occur in winds of 24–32 km/hr with gusts up to 56 km/hr in the West Indies. Winds of 64 km/hr are sufficient to cause considerable damage while with winds of 95 km/hr complete destruction occurred (Simmonds, 1966).

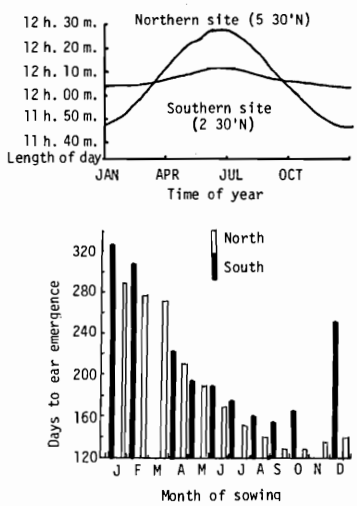
At higher latitudes on light sandy soils winds are known to cause soil erosion. This problem is recognised to be of considerable magnitude in Sub-saharan Africa and in Northwestern India and Pakistan.

The saturation deficit or Vapor Pressure Deficit (VPD) which is the difference between the actual vapor pressure of a sample of air at a given temperature and the saturation vapor pressure corresponding to that temperature is another climatic element that is of importance. Even when the soil moisture level is high, a large VPD could impose moisture stress on the plant. Jarvis (1976) described the functional relationship between stomatal conductance and leaf water potentials at a given VPD. Stomatal conductance rates are usually higher at low VPD. An increase in the VPD at a given leaf-water potential reduces stomatal conductance. Raschke (1976) points out that even at higher relative water content of leaves, dry air may cause the epidermis to lose water more rapidly than can be replaced from within the leaf, which might result in a narrower stomatal aperture than would be the case in moist air. VPD values

are generally larger during the day and smaller at night. Values during the rainy season are much below those of dry season.

Among the tropical crop species most crops appear to have no photoperiodic or other triggering requirement for flowering. There are some notable exceptions to this pattern, however, such as rice, sugarcane, and some vegetable crops. Within the photosensitive species, a great range of types is obtained showing varying degrees of sensitivity to the photoperiod. Near the equator there is only a small variation in the photoperiod, but surprisingly, this small difference has a marked effect in controlling flowering and determining the period to maturity among tropical rice varieties. Examples of variation in flowering and maturation time in relation to sowing date and latitude of rice varieties in Malaysia are given by Dore (1960). Daylength variation at the two sites and variation in maturity time with date of sowing at these two sites are shown in Figure 7.12. The shortest maturity periods at both the sites are achieved at planting dates which allow a progressively decreasing photoperiod during the active growth phase of the plant. In the semi-arid tropics of West Africa, an important adaptive feature of local sorghums is through their responsiveness to photoperiod because the date of heading is closely related to the average date of termination of local rain (Curtis, 1968). Consequently seed set occurs as the weather becomes dry. If the heading occurs earlier during the rains, the grains are attacked by moulds and insects. Hence Curtis (1968) concluded that local cultivars were found to yield better in their own regions than in regions north or south, because heading in the new locality was still related to the average date of the end of rains in its original locality.

Figure 7.12. Number of days to ear emergence in rice variety Siam 29 grown in northern and southern sites in Malaya



CROPS OF THE TROPICS

The tropical regions as described so far are endowed with abundant radiation and high temperatures which enable year-round cropping provided water is not limiting. It has often been stated that the source of agricultural wealth, whether plant or animal, lies in the soil, in the water and in solar energy. In the humid tropics the rainfall is abundant but the distribution of rainfall prevents growing more than, for example, one rice crop per year. However the total amount of rainfall is adequate for year-round cropping if irrigation systems can be installed. In the humid tropics rice is the most important crop with over 45 per cent of the world production coming from this area. Maize is also widely grown. In the humid tropics of West Africa, root and tuber crops such as yams, sweet potatoes and cassava are important components in the diet. In comparison to a total cereal production of 11 million tons, root and tuber production exceeds 30 million tons (fresh weight). Grain legumes represent a relatively modest part of the agricultural output; 1.15 million tons. In the humid tropics, plantation crops such as cocoa, coffee, tea, sugarcane, pineapples, coconuts, oil palms, and rubber provide extensive employment opportunities and contribute towards economic development.

In the semi-arid tropics coarse cereals such as sorghum and millet are predominantly grown in the place of rice and to some extent maize because the length of the growing season is often restricted by rainfall. Amongst the grain legumes, groundnut is the most important crop in the semi-arid tropics accounting for 67% of the world production. Pigeonpea, chickpea, cowpea, and drybeans are other important pulse crops. Soybeans are of late being tried in these areas and are becoming popular. In India castor and cotton grown in the rainfed area account for 69 and 61 per cent respectively of the nation's acreage under these crops. In West African savanna rice is grown as a non-paddy crop in the upland areas and in the fadama areas with a high water table, as a paddy crop in the fadama areas and on the river banks which are seasonally flooded and in paddies in which rainfall or irrigation water is impounded Cowpea is the major grain legume crop in West African savanna. Groundnut is grown prominently in the Sudan and Northern Guinea savanna bioclimatic regions of West Africa. Cassava, yam, sweet potato, and cocoyam are the other important crops.

Intercropping ie., growing two or more crops simultaneously is a common feature in the semi-arid tropics. It is most common amongst small farmers and where farmers have least access to irrigation. As many as 84 different crops are used in traditional intercropping systems in semi-arid India, but seldom more than three at one time. The systems used to fall into four main categories (Jodha, 1980), viz: mixtures of differing maturities, mixtures of drought-resistant and drought-sensitive crops, cash crop-food crop mixtures, and legume-non-legume mixtures. Intercropping spreads labor requirements more evenly and is a hedge against disaster.

AGROCLIMATIC CONSTRAINTS TO INCREASED CROP PRODUCTION IN THE SEMI-ARID AND HUMID TROPICS

Considering the discussion presented so far, the following could be considered as the main agroclimatic constraints to increased crop production.

In the semi-arid tropics

1. Water is the most limiting factor and improved crop production should be aimed at optimising its use. The length of the growing season is limited by the duration of the rainy period.
2. Variability in the rainfall at the beginning and the end of the growing season and unreliability during mid-season are not uncommon and pose a risk to arable cropping.
3. Evapotranspiration rates are usually high reaching up to 2400 mm per year. Evapotranspiration at the beginning and the end of the growing seasons is high resulting in an increased need for water.
4. High temperatures, increased wind speed and advective energy enhance the atmospheric demand for water.
5. In view of the water shortages, it is important to choose varieties which cover ground quickly and flower early to finish grain filling before moisture deficits set in.
6. Soil erosion is a serious problem and land and water management practices that reduce runoff and erosion are urgently required.
7. Cropping systems and crop management practices that establish a crop at the very beginning of the rainy season to make most efficient use of moisture throughout the rainy and postrainy seasons for high sustained levels of yield are necessary.
8. Soils with shallow depth and low water-holding capacity present problems even during the rainy season.
9. Due to increased population and increasing food needs, steeper and more erodable lands are frequently over-cropped and over-grazed and forest lands are denuded causing permanent damage to vast areas.
10. Little or no use of fertilizers under a continuous cropping situation is leading to a declining productivity potential of land leading to a quest for more land.

In the humid tropics

1. High rainfall and rainfall intensities cause severe soil erosion problems.
2. Leaching of nutrients and loss of fertile soil in erosion lead to low fertility status of soils.
3. Soils with poor drainage are prone to waterlogging and could restrict production.

4. Reduction in solar radiation due to heavy cloud cover in the middle of the growing season could limit photosynthesis and dry matter production.
5. Hot and humid conditions during the growing season favor pest and disease buildup.
6. Temperatures are generally suitable for a large range of tropical crops throughout the year but are too high for temperate crops such as wheat even in the cooler season.
7. Crops which come to grain filling under heavy rains during the growing season face the risk of pests and diseases infesting the grains.
8. Application of fertilizers unless carefully timed can result in high losses of nutrients due to the frequent heavy rain storms.
9. The effect of the photoperiod on days to ear emergence in crops such as rice which exhibit photoperiod sensitivity and the time taken to grain filling are critical in determining the yield potential.

POTENTIAL FOR INCREASED PRODUCTIVITY

Semi-arid tropics

The dry tropical regions depend primarily on agriculture: the present low income levels are caused by low and unstable agricultural production.

Most of the cropping in the semi-arid tropics will continue to be done in rainfed conditions by small farmers with meagre resources producing staple cereals of low value for which few price incentives to production exist. Currently yields are low and production is unstable due to aberrant weather and the high incidence of pests and diseases. The semi-arid tropics with 13% of the world's land and 15% of its people produces only 11% of its food.

Food production can be increased in the rainfed semi-arid tropics; in India mainly through improved technology, in Africa mainly by increasing the land area under cultivation. Average yield levels in India for the major rainfed cereals and grain legumes are between 300 and 800 kg/ha. They can be doubled by the use of improved technologies. Taking sorghum as an example, the average yield is 800 kg/ha and the potential under rainfed conditions is at least 2500 kg/ha. More importantly, better farmers are already obtaining 1500 to 2000 kg/ha in rainfed conditions using improved seeds and some fertilizers. The highest yields are obtained on fields where the farmer can use supplementary irrigation. For pearl millet the average is around 600 kg/ha, the potential in rainfed agriculture is about 1500 kg/ha and better farmers are obtaining yields of 1000 to 1200 kg/ha. Raising the averages to the level of better farmers' yields will mean more food production, more agricultural employment or higher returns to labor, more food for the farmers and their dependents, and significantly increased gross returns and profits.

Needless to say, the potential for improving food production in the water-scarce rainfed semi-arid tropics is very encouraging and an interdisciplinary approach aimed at understanding the climate, soil, and the crops would go a long way in designing appropriate technologies. One such example where a team of scientists from different disciplines contributed to the development of a technology is available from ICRISAT which showed the suitable means for the management of deep black soils in relatively dependable rainfall regions of India. The technology options include moderate inputs which are within the reach of the small farmers in the rainfed semi-arid tropics. The components of the technology include:

- cultivating the land immediately after the previous postrainy season crop when the soil still contains some moisture and is not hard; improved drainage with the aid of field and community channels and the use of graded broadbeds and furrows;
- dryseeding of crops before the monsoon rains arrive;
- the use of improved seeds and moderate amounts of fertilizers; improved placement of seeds and fertilizers for better crop stands, and finally attention to improved plant protection, particularly for the legume crops.

On-farm verification of this technology in Taddanpalle village gave a rate of return on the additional expenditures of 244%. Sorghum-pigeonpea intercrop system was found to be the most profitable of the nine cropping systems tried (Ryan *et al.*, 1982).

The sorghum in this combination has a similar growth pattern to the sole crop and produces 90-95% of the sole crop yield. The pigeonpea, after sorghum harvest, compensates ie., it spreads to make use of the entire field space, and can produce 70% of the sole crop yield. Experiments conducted at the ICRISAT Centre at Patancheru, India showed (Swindale *et al.*, 1981) that Vertisols with their better water holding capacity than Alfisols enable intercropping pigeonpea to produce much better growth in the postrainy season resulting in higher relative yields and greater yield advantages (Table 7.10). Cropping systsems researched at ICRISAT also showed that with nine of the cropping systems tried on Alfisols, the net monetary returns over a two-year period ranged from 1133 Rs/ha for a sole groundnut crop to 3393 Rs/ha for the millet + relay horsegram system.

Proportionate cropping, allocating land resources to crops based on formular relating crop durations to the probabilities of adequate soil moisture can help decrease the risk of loss and increase overall farm productivity. Research conducted at Haryana Agricultural University in Northern India showed that allocation of 40% of the land to guar, a very drought resistant crop, with a 120 day growing season, 40% to pearl millet, a drought resistant crop, with a 70 day growing season and 20% of land to mungbean with a 50 day growing season allows the farmer to harvest all the three crops in the best years and at least two crops in all but severe drought years.

During the postrainy season in South and Central India, supplemental irrigation can substantially boost crop yields because residual soil moisture is usually insufficient to prevent some drought stress at important physiological stages of growth. Sivakumar *et al.* (1979) showed that supplemental irrigations given at the time of panicle emergence and flowering of grain sorghum grown on a deep Vertisol gave an additional yield of 3,560 kg/ha over the control treatment (2,430 kg/ha). The net benefit accruing from the supplemental irrigations was Rs. 2,500/ha.

Table 7.10. Grain yields and land equivalent ratios in sorghum/pigeonpea intercropping on two soil types (Average of 3 years)

	Vertisols					Alfisols				
	Yield		Land equivalent			Yield		Land equivalent		
	Sole	Inter-crop	LES*	LEPP**	Total	Sole	Inter-crop	LES*	LEPP**	Total
Sole crops										
Sorghum	4500		1.00	-	1.00	4573	-	1.0	-	1.00
Pigeonpea	-	1314	-	1.00	1.00	-	1770	-	1.0	1.00
Intercropping										
1:2 Sorghum/ Pigeonpea	4240	945	0.94	0.72	1.66	3641	1140	0.80	0.64	1.44

*LES (Land equivalent ratio for Sorghum) is the relative land area required by a sole crop of sorghum to achieve the yields produced by the same component in the intercrop.
**LEPP (Land equivalent ratio for Pigeonpea) is the relative land area required by a sole crop of pigeonpea to achieve the yields produced by the same component in the intercrop.

The situation in the Sahel and other regions of semi-arid Africa is less promising. Improved technologies, and, particularly, improved seeds, are not as much available and the institutions and infrastructure necessary for successful propagation of new technologies are less developed (OECD, 1976). The differences between average yields, best farmer practices and potentials appear to be much narrower than in India from the limited available evidence.

There is scope to increase the area under cultivation in Africa without environmental loss. FAO in developing a food plan for Africa considered that for increased production of staple cereals in the Sahel; improvements in cropping patterns would contribute 17%, improved yields 36% and increased acreage 48% (FAO, 1978). Even if the necessary improvements and increases are made, the combined self sufficiency ratio in the Sahel for maize, sorghum, and pearl millet will still be below 100 by 1990, with a deficit in excess of 200,000 tons of grain. The total deficit in food grains in the Sahel in 1990, including irrigated crops, is projected to be more than 700,000 tons.

Crop rotations are used particularly in semi-arid West Africa to increase production. In low intensity cropping, the cropping sequences include a fallow season. Charreau (1974) recommends one year of fallow or green manure plowed under followed by groundnut by cereal and finally by groundnut or cowpea. The cereal is usually a long season pearl millet or sorghum. The effects on soil physical properties of incorporating green manure are well known resulting in beneficial effects on rooting and production of the succeeding crop. Where rainfall is fairly low and irregular as in northern and central Senegal, a four-year rotation of fallow or pearl millet as a green manure followed by groundnut followed by cereal followed by groundnut is recommended or a five-year rotation such as fallow of green manure – pearl millet – groundnut – pearl millet – groundnut.

In intensive cropping, the fallow period is eliminated and plowed under grass, fallow or green manure is replaced by plowed under straw of short-season cereals (Charreau and Nicou, 1971).

Humid Tropics

The humid tropics are endowed with abundant rainfall and non-limiting temperatures to enable continuous cropping in general. However, crop yields have remained low. For example, the average yield of rice in the humid tropics of Asia is approximately 1,400 kg/ha. No one factor is responsible for the low yields. Poor water management or – more specifically – control, inadequate erosion control, ineffectual weed control, inadequate and untimely fertilizer application leading to losses of nutrients, problems with pests and diseases in the favoured humid environment and use of varieties that respond poorly to added inputs are some of the constraints. In the African humid tropics most of the food crops produced are grown in various mixtures by subsistence farmers relying on shifting cultivation and bush fallow systems to replenish soil fertility. While such systems are stable when land is not a limiting factor, they tend to break down when the number of people in the land must support becomes such that fallow periods are substantially reduced. Research to develop methods of land use and crop management suited to the humid tropics that will ena-

ble sustained production of food crops and the most efficient use of farmers' natural resources is needed.

Available research results indicate considerable promise for increasing the crop yields in the humid tropics. Use of improved varieties, fertilizers, insecticides, and weed control enable the harvest of two or three crops a year resulting in a high level of productivity. For example scientists at the International Rice Research Institute showed that farmers' yields of rice at Laguna in Philippines ranged from 3.5 to 6.0 t/ha and averaged 6.6 t/ha. On 3 farms nitrogen applied by the farmers averaged only 17 kg/ha. Use of 100 kg/ha contributed 67% to the yield increase, improved insect control contributed 26% and improved weed control accounted for 7% (IRRI, 1980). For irrigated lowland rice crops, effective water management is also an important factor that could increase water use efficiency. In a study of 85 farms in a 145-ha irrigated unit, scientists of IRRI found that of the 940 mm of water supplied for completion of transplantation by all farmers, about 225, 445, and 160 mm were lost as surface drainage from the area, seepage, and percolation, and evaporation respectively. If irrigation water was supplied throughout land preparation at the maximum designated rate of 22 mm/day instead of the actual mean discharge of 9 mm/day, a saving of 189 mm of water could have been achieved (IRRI, 1978).

In Africa the concept of alley cropping is being tried with good results as a transition from the shifting cultivation or bush fallow system to continuous cultivation. Results indicate a potential for developing a stable, low-input, productive system of continuous cultivation with a small tree or shrub component which recycles nutrients (N with leguminous trees or shrubs), provides mulch and supports twining crops. The intercropping of maize-cassava, cowpea-cassava, maize/sweet potato-pigeonpea, and sweet potato-pigeonpea showed good promise (IITA, 1980).

The role of adequate fertilization for increased crop production in the humid tropics has been adequately recognised. Apart from food crops, plantation crops also have received considerable attention in this regard. Scientists at the college of agriculture of the University of Philippines have demonstrated a 100 per cent increase in yield of coconut trees through cultivation and fertilizer applications.

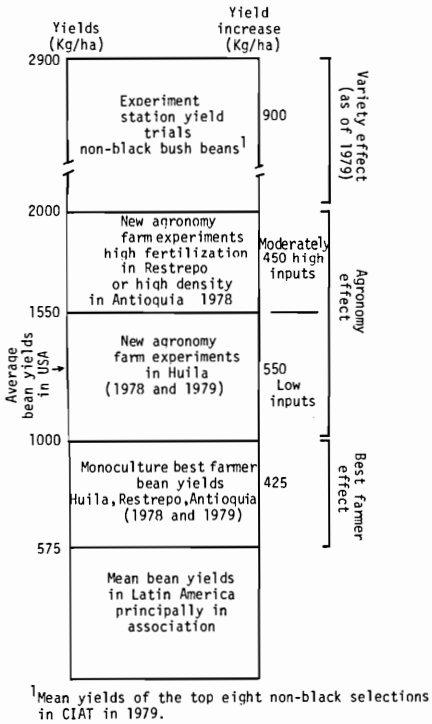
In Colombia scientists at CIAT have shown that the present yield gap between Latin American bean yields and CIAT experimental line yields in 1979 was almost 2.5 t/ha (Figure 7.13). Almost 0.5 t/ha of the yield gap was explained as the difference between bean yields at low density in association and in monoculture with higher densities found on better farms. A 1 t/ha difference was obtained from improved agronomy with farmers' varieties. The variety effect was 0.9 t/ha (CIAT, 1979).

In the case of cassava grown in Latin America, farmers use low plant populations which do not vary between monoculture and intercropping systems. Fertilizers are not commonly used. In the traditional technology yields average 7 t/ha. With improved management practices such as increased plant population, fertilization, and use of improved varieties yields of 12 to 13 t/ha were obtained. These data point to the need for adopting improved practices at the farm level.

In summary, it should be mentioned that the productivity of traditional agriculture is declining and the threat of serious food shortages is rising but the potential for increased food production in the tropics does exist. If successful technologies can be

transferred and the necessary institutional and infrastructural support is provided, this potential can be usefully realised and exploited for the benefit of the people in the tropics.

Figure 7.13. Bean yields in farmer's fields, on-farm experiments, and experimental station



[1]Mean yields of the top eight non-black selections in CIAT in 1979.

Acknowledgements

We thank Mr. P. Rama Krishna for typing the manuscript and Mr. George Thomas for help with the figures.

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CHAPTER 8
Water Resources and their Role in Food Production

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INTRODUCTION

WATER HAS TRADITIONALLY been regarded as an inexhaustible gift of nature. Such a complacent view, however, is detrimental to the development of the human race and the continuance of plant and animal life on earth. The unabated growth of population and associated increase in demand for water for domestic consumption, industry and agriculture increase pressure on the fixed quantity of the world's water resources. If this trend continues, there will soon be a critical shortage of water of suitable quality, unless special measures are adopted to radically improve water use and management practices in various sectors.

Estimates of the total water resource potential of the world indicate the existence of a huge amount of water. However, more than 97 per cent of the world's water resource is in the oceans and is unavailable for human, animal and agricultural use, except for the aquatic life adapted to marine situations. A major proportion of the remaining water resources is not readily available at the places where needed. Further, there is wide variation, both in time and space, of these available water supplies.

The enormous and continuing deficit in food and agricultural products, as revealed by the World Food Conference (FAO, 1974), calls for priority action on the development and efficient use of the available water resources. The need for a worldwide program for the efficient management of water in agriculture was recognised at the Conference. The essential features of such a program include the following (FAO 1977):

1. Improvement of existing irrigation with the objectives of raising productivity with minimum cost and delay;
2. Improving efficiency in water use and preventing waste and degradation of water resources;

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3. Developing appropriate technology for efficient use of the available water resources;
4. Adopting improved technology for rainfed agriculture and livestock production in the arid and semi-arid regions, involving better management of the soil moisture reservoir and the development of additional land for sustained agricultural production;
5. Intensification of the utilization of marine fishery resources.

WATER RESOURCES

Water occurs in both static and dynamic states. The frozen ice caps, oceans, deep ground water, surface reservoirs and lakes hold water in static state. The processes of precipitation, streamflow, evaporation and seepage represent the dynamic state of water. Quantitative information on these basic forms of water resources is essential for the assessment of the potential and planning their efficient utilization. An assessment of the water resources of the world including an inventory of water resources in the static form, the global water movement and distribution, and identification of water resources potential in different regions of the world is presented briefly in this section.

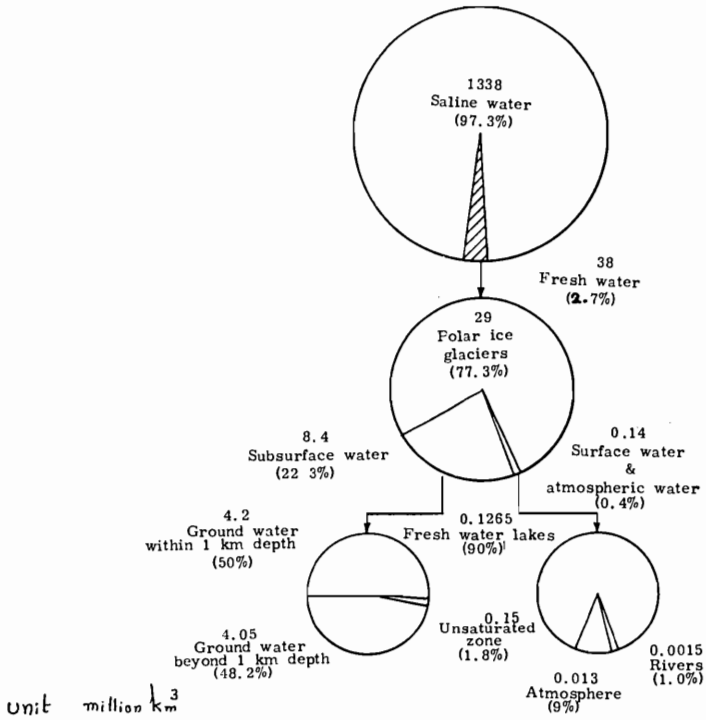
Inventory of world's water resources

Out of the earth's total surface area of 510m.km^2 about 71% (361 m.km^2) is covered by seawater which has a volume of about 1338 m.km^3. It is estimated that the total volume of water on the earth is 1376m.km^3. Of this, sea water constitutes 97.3 per cent. It is unsuitable for terrestrial plant and animal life as it contains more than 3.5 per cent dissolved salts. Of the remaining 2.7 per cent (38m.km^3), which constitutes fresh water, more than 75 per cent (29m.km^3) is held in permanent ice caps and glaciers. Ground water accounts for 8.4m.km^3 while rivers, streams and fresh water lakes hold 0.14m.km^3 of water (Figure 8.1). About 4.33m.km^3 of water, comprising the fresh water lakes, rivers and the extractible ground water occurring within one kilometre depth of the earth's surface, exists in the form of fresh water which is available for plant, animal and human life. This is less than 0.4 per cent of the total water on the globe.

Global water movement and distribution

The solar energy absorbed by the oceans and open water bodies causes the water to circulate and exist in different phases. The continuous, cyclic movement of water in

Figure 8.1. Inventory of global water resources



and around the earth's atmosphere, is called the *hydrologic cycle*. Water circulates from the surface of the earth to the atmosphere and back to earth through the hydrologic cycle. The evaporation process is continuous from the oceans and open water bodies. The evaporated water later precipitates to the land and ocean surfaces. Most of the water precipitating on the land surface evaporates back to the atmosphere while the remaining is utilised for plant, human and animal biological build-up, and to recharge the ground water. As oceans cover about 71 per cent of the earth's surface, a major part of the precipitation occurs on the ocean surface and all of it is returned back to the atmosphere without being effectively utilised.

The hydrologic cycle is an eternal process. Literally, every drop of water in and around the earth's atmosphere undergoes this cyclic process appearing in various phases at different times. For instance, the part of the rainfall that reaches the ground water body may stay there for millions of years before it appears above the ground surface and gets evaporated to reappear as rain at a later stage. The estimated duration of residence of water in various phases is given in Table 8.1.

Barring sea water, deep ground water, frozen ice caps and glaciers, which are not practically useful, the remaining sources of water have a relatively small residence time. These waters actively influence the annual water balance in both time and space.

Table 8.1. Estimated duration of residence of water in various phases

Phases of occurrence	Estimated duration of residence
Deep sea water	2500 years
River channels	2–3 weeks
Swamps	Several years
Moisture in plant root zone	6 months to 1 year
Lakes and man made reservoirs	1 to few years
Ground water	Milleniums
Frozen ice caps, glaciers	Decades to milleniums
Atmosphere and biological water	Up to 1 week

Sources: Falkenmark and Lindh (1976) and Philip (1977).

A quantitative description of the world's hydrologic cycle provides the global water balance. The water balance for a period is an expression of the law of conservation of mass which may be stated as follows:

$$\text{Inflow} - \text{outflow} = \text{change in storage}$$

This can be expressed mathematically as follows:

$$P = E + R + C + \triangle s + \triangle A$$

in which P = Precipitation (mm), E = Evaporation; including transpiration (mm), R = Runoff (surface runoff and interflow), mm, C = Consumptive use in building up of plant biomass and consumption by men and animals, mm, $\triangle S$ = Changes in storage of water in lakes and other surface water sources and underground reservoirs and $\triangle A$ = advection (mm).

In terms of annual averages, it can be assumed, without introducing significant errors, that the quantities C and $\triangle S$ are nearly constant so that their annual fluctuations can be ignored. Thus, for gross accounting purposes, the expression for the annual waterbalance can be written as

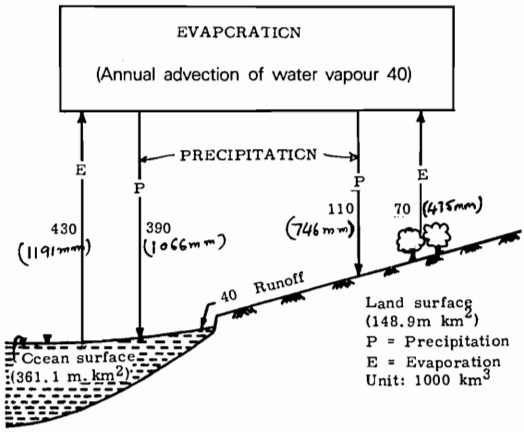
$$P = E + R + \triangle A$$

The world's renewable water resources are derived from an average annual precipitation of 746mm on the land area and 1066mm on the ocean surface (Figure 8.2). Thus, the average annual global precipitation is estimated at 973mm. As the total surface area of the globe is 510.m.km^2, the volume of rainfall of an average depth of 973mm is equal to 496,300km^3. About 64 per cent of the precipitation on the land surface is consumed through evaporation and transpiration. A minor fraction of this evapotranspiration provides water for food, fibre and forest crops. About 36 per cent of the precipitation or 40,000km^3 of water, constitutes the average annual runoff from all the streams and rivers in the world.

While 1066mm of precipitation occurs on the ocean surface, 1191mm are evaporated back into the atmosphere annually (Figure 8.2). The volume of the excess water evaporated is about 40,000km^3. This is the amount of moisture advected from the ocean surface towards the land surface and is also equal to the runoff reaching the oceans. Hence the global annual water balance equation simplifies to

$$P = E$$

Figure 8.2. Global annual water balance



Thus, annually about 496,300km^3 of water undergoes the cyclic process of evaporation from the free water bodies and precipitation.

Hydrologists, meteorologists, geographers and oceanographers have studied the water budget to assess the quantity and distribution and exchanges of water over the earth with special reference to related disciplines. Baumgartner and Reichel (1970) summarised most of the studies related to the world water balance. Later, the regional distribution of the major components of the water balance, namely, precipitation, evaporation and runoff for the entire world was described in detail with maps by the same authors (1975). The global distribution of the earth's surface area, rainfall, runoff and stream flow are given in Table 8.2.

The occurrence and availability of the world's water resources are highly variable in both time and space. There is considerable variation of rainfall from region to region. Even in one region, rainfall varies widely from season to season and year to year. Even greater variation occurs in evaporation, runoff and stream flows. Further, in areas of high precipitation and runoff, a series of dry years may occur, resulting in serious drought problems. Both floods and droughts of varying severity and duration are experienced occasionally across the world. The amount of runoff that is available for development depends on the annual runoff, ground water recharge possibilities, the storage capacity of surface and sub-surface reservoirs, and potential evapo-transpiration, all of which vary widely.

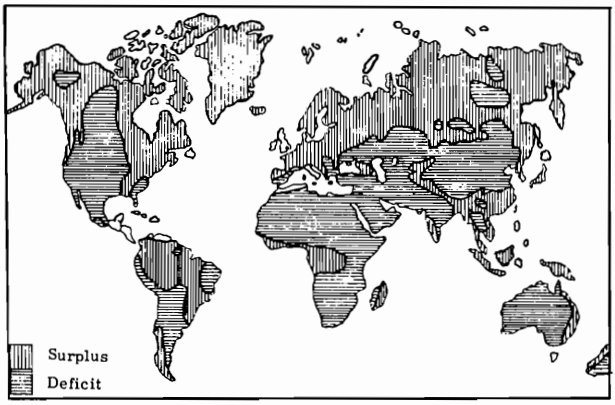
The relative values of evaporation and rainfall are of importance in crop growth. Areas with rainfall exceeding evaporation are considered as water surplus areas. Likewise, areas with evaporation exceeding rainfall are called water deficit areas. Figure 8.3 shows the water surplus and water deficit areas in the world. From Figure 8.3 it is seen that large areas in Africa, Asia and Australia have water deficits. Many

Table 8.2. Global distribution of earth's surface area, precipitation, evaporation and runoff

Region between latitudes	Continents/regions	Earth's surface area	Precipitation, P		Evaporation, E		Run off (P–E)	
			Average depth	Percentage* of total volume	Average depth	Percentage of total volume	Volume	Depth
		m.km^2	mm		mm		km^3	mm
1. 0°–30°N & 0°–30°S	Africa, South America, Middle East, Indian sub-continent, South East Asia, South China, North Australia	254.15	1180	61	1307	67	−32066	−127
2. 30°–60°N & 30°–60°S	Southern part of South America, Africa, Australia, USA, Canada, most of Europe, USSR (excl. Siberia) North China, Japan etc.	187.04	908	34	812	30.6	18165	97
3. 60°–90°N & 60°–90°S	Remaining land surface. (Greenland, Siberia, etc.)	68.82	379	5	176	2.4	13901	202
World total 4. 0–90°N & 0–90°S		510.01	973	100	973	100	0.00	0.00

*Source: Baumgartner and Reichel (1975).

Figure 8.3. Water surplus and deficit zones in the world



Source of data: Falkenmark and Lindh (1976)

of the developing countries lie in this region. These areas coincide with the arid and semi-arid regions of the world. Evidently, agricultural development in these countries is dependent on managing the water deficits by appropriate water conservation and crop management.

About 40 economically poor countries in the world in the continents of Asia, Africa and South America are situated in or near regions of either snow caps where excessive snowmelt causes floods or deserts where excessive water deficit is experienced (Falkenmark and Lindh, 1974). Information on locations of surplus and deficit areas alone does not precisely bring out the details of the relative magnitudes of precipitation and water requirements of plant life. Relative distribution of water in different phases, namely, precipitation, evaporation, and runoff in various continents of the earth as given in Table 8.3 is also needed.

Water resources potential in different parts of the world

Average values of water balance do not reflect adequately the spatial and temporal availability and demand for water which depend considerably on the exact location, climate, population needs and other factors.

Distribution of Surface Runoff

It is seen from Figure 8.2 that the annual surface runoff of the land area of the earth is 40,000km^3. Of this 38,820km^3 are available for use since the remaining part occurs in uninhabited areas like Greenland and Antarctica.

The annual runoff comprises stable flow or flow during the non-flood season and unstable flow during the flood season. Stable flows are derived from ground water and surface water regulated by lakes and reservoirs. The distribution of stable and

Table 8.3. Water distribution among the continents of the world

Continent	Land area m.km^2	Precipitation		Evaporation		Runoff	
		Vol 10^3km^3	Depth mm	Vol 10^3km^3	Depth mm	Vol 10^3km^3	Depth mm
1. Africa	30.31	21.10	766	16.87	626	4.23	140
2. Asia (excluding USSR)	27.53	19.30	701	0.76	354	9.54	347
3. Europe (excluding USSR)	4.87	2.50	513	0.14	29	2.36	484
4. Oceania	8.51	7.80	917	5.83	686	1.97	231
5. N.America	24.47	15.40	629	9.44	385	5.96	244
6. S.America	17.87	27.72	1551	17.34	970	10.38	581
7. USSR	22.40	15.50	692	11.12	496	4.38	196
8. Antarcitica	14.94	1.78	134	0.0	0.0	1.18	79
Total World	148.90	111.10	746*	70.50	473*	40.00	269*

**Average value*

Source: Baumgartner and Reichel (1975); Korzen and Sokolov (1977); Lvovich (1973).

Table 8.4. Distribution of annual runoff in the continents

Continent	Annual runoff in km^3		
	Stable	Unstable	Total
Africa	1,905	2,320	4,225
Asia (excluding USSR)	2,900	6,644	9,544
Europe (excluding USSR)	1,020	1,342	2,362
Oceania	495	1,470	1,965
North America	2,380	3.580	5,960
South America	3,900	6,480	10,380
USSR	1,400	2,984	4,384
World total	14,000	24,820	38,820

Source: Lvovich (1973), USSR National Committee for I.H.D. (1974).

unstable flows in various continents is given in Table 8.4. South America and Asia have very high annual runoff accounting for more than 50 per cent of world's value. Nearly 65 to 70 per cent of the long-term annual flow occurs during the flood season, a major part of which cannot be utilised effectively for irrigation and other purposes and runs off as waste towards oceans.

Climatic and topographic factors considerably influence the planning and utilisation of runoff. Economic and technological limitations often restrict the utilizable quantum of runoff. It is, therefore, logical to distinguish the part of the runoff that can be utilised readily with the present level of technology, as a '*readily available source*' and the remaining part as '*other sources*' (Nikitopoulos 1967a, 1967b and De Mare, 1977). The readily available sources include rivers, lakes and ground water. The other sources such as deep ground water, transport of huge icebergs, cloud seeding, large scale desalinisation of sea water, etc., require specialised technologies which need further development.

The distribution of readily available water in the world varies considerably from region to region. In regions where a high level of economy and technology operates, a higher percentage of the total water resources can be readily developed. This is also the case in regions where the climate and topography permit easy utilisation of water. By taking the above factors into consideration the proportion of readily available water of a region can be estimated. The estimated quantities of the readily available water resources of various continents are given in Table 8.5. These values are obtained by using different percentage values assumed to be applicable to various continents. The readily available water resource of the world is about 25000km^3 which is 64.4 per cent of the annual runoff. The estimate of the readily available resources compares favourably with the figure of 24,432km^3 arrived at by De Mare (1977) and 25,000km^3 estimated by Falkenmark and Lindh (1974).

Distribution of water in storage

Apart from the surface runoff, a considerable volume of water is held in man-made

Table 8.5. Estimated readily available water resources of the world

Continent/ Country	Total water resources* km^3	Readily available water resources: Percentage of total water resources **	Readily available water resources: Volume km^3
Africa	4225	70	2961
Asia (excluding USSR)	9544	67	6392
Europe (excluding USSR)	2362	80	1891
Oceania	1965	80	1576
N.America	5960	75	4470
S.America	10,380	45	4671
USSR	4384	70	3066
World total	38,820	64.4	25,027

* From Table 4
** estimated from the data of De Mare (1977)

and natural surface and sub-surface reservoirs. It is estimated that the total volume of fresh water stored in lakes (0.2m.km^3) is about five times the average annual runoff from all the land areas. Further, about 250km^3 of water is stored in man-made reservoirs. These lakes and reservoirs play an important role in the regulation and use of water.

The region up to about one metre depth below the ground surface constitutes the potential root zone. This zone holds a considerable amount of moisture, mostly under unsaturated conditions. The amount of moisture thus held is a function of the physical and chemical characteristics of the soil. It is estimated that a total of about 0.15m.km^3 of water is held in the plant root zone over the entire world (Philip, 1977).

Ground water reservoirs are efficient storage reservoirs in as much as they do not suffer from the water losses through evaporation and seepage and that they cost less compared to man-made surface reservoirs. An estimated volume of 8.43m.km^3 of water is stored in the ground water, about half of which can be exploited with relative ease.

Extent of utilization of water resources

About 20 per cent of the world's average annual stable flow was developed for utilisation till the year 1975. In Israel, however, a much higher proportion was developed. It is anticipated that by the year 2000 A.D., the world's projected population of approximately about 6 billions would be using a much larger proportion of the stable water flows. Further, in order to maintain certain minimum standards of water quality, flows from industrial, domestic and agricultural areas need to be diluted with huge amounts of water. If the utilisation increases beyond 20 to 25 per cent of the

readily utilisable annual flows, the amount of water needed for proper dilution would be very large and hence the water cannot be effectively diluted. Such a situation leads to perpetual deterioration of the quality of water, unless special measures are undertaken to ensure that waste waters are properly treated before letting them into the streams and rivers. Thus, future water use calls for not only the management of water in its quantity but also in respect of its quality. The situation emphasises the importance of judicious use of water and the need for intensification of research for new sources of water.

WATER FOR IRRIGATION

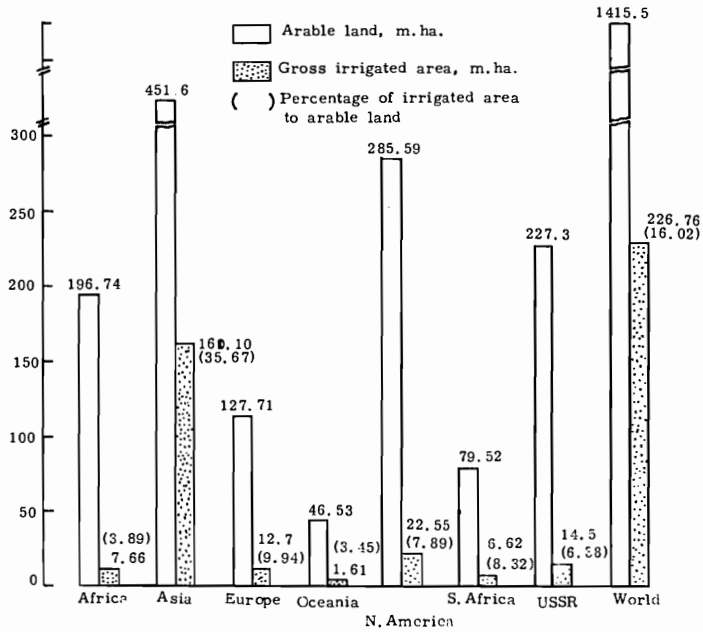
Agriculture is the major user of water resources. The domestic and industrial sectors use relatively smaller quantitities of water. The disparity is more predominant in the developing countries. For instance, in India, as of 1975, about 95 per cent of the water developed was used for irrigation. The corresponding use in the USA is 40 per cent. The quantity of water used for irrigation in the world as of 1975, is 2197 km^3 which constitutes about 80 per cent of the world's developed water resources. In spite of this, only about 16 per cent of the world's arable area could be served with irrigation (FAO, 1976). The productivity of land in agricultural use is increasing rapidly in response to new and improved technology. Part of this increase is obtained through irrigation.

Table 8.6. Irrigation development in developed and developing countries of the world

Category No	Area in million hectares			
	Irrigated area	Unirrigated area	Total arable land	Percentage of area irrigated to total arable area
1. Developing countries	174.38	563.6	728	23.95
2. Developed countries	52.36	634.64	687	7.62
World total	226.74	1188	1415	16.02

Source: F.A.O. (1976).

Figure 8.4. Continent-wise arable and gross irrigated area in the world (1975)



Irrigation development in the world

The total area irrigated in the world was 226.0 m.ha in 1975. The extent to which irrigation facilities exist in different parts of the world varies widely (Figure 8.4). The distribution of irrigated and non-irrigated lands varies considerably in the developing and in developed countries. While the area irrigated constitutes 23.95 per cent of the gross cultivable land in developing countries, it is only 7.6 per cent in the developed countries (Table 8.6).

Irrigation accounts for 80 per cent of the total water demands of the world. It is expected to continue to be the largest user of water. In contrast to large strides in the water use efficiency anticipated in the domestic and industrial sectors, irrigation efficiency as measured by the the ratio of requirement and withdrawal of water per hectare, is expected to show only modest improvement. The rates of annual growth of irrigation facilities in the world were 8.48, 4.10 and 3.32 million hectares during the periods 1960–65, 1965–70, and 1970–75. This amounts to an overall average annual growth rate of 5.32 m.ha over the period 1960 to 1975. In view of the increasing demand for food, while it is necessary to develop irrigation facilities for the future, it is imperative to improve irrigation efficiency.

AGRICULTURAL WATER NEEDS

Agricultural water includes use of water for irrigation and livestock. The latter forms a negligibly small portion of the total water use and hence for all practical purposes, only irrigation is considered as agricultural water use. Irrigation is practised under several situations in the world. In arid regions, a life-saving irrigation makes all the difference between a complete crop failure and a good crop yield. In humid areas, irrigation regulates the water supply to the crops and thus prevents crop failures during the drought periods and increases crop productivity in normal years. In regions of extreme temperatures, irrigation is advantageously practised to maintain conducive temperatures in the root zone.

Use of water for irrigation has considerably increased since 1960. This trend is related to a wide variety of factors including the increase in population, developments in technology and agricultural research and socio-economic conditions. It is expected to increase further in the future.

Projections of irrigation water requirements for different continents can be made based on (i) per capita needs, (ii) consumptive use requirements, and (iii) projections of the irrigated area in the world.

Irrigation water requirements based on per capita needs

Kalinin and Shikolomonov (1974) suggested per capita values of annual irrigation water requirements after a detailed analysis of numerous statistics and special reports concerning future irrigation water needs. However, these projections do not include the water held in storage primarily meant for irrigation. Accordingly, the consumption rates suggested by Kalinin and Shikolomonov were modified marginally to include water in storage also. Further, by the year 2000, water use efficiency is anticipated to improve in the developing countries also. Hence slightly lower per capita rates can be adopted for the year 2000. Projections of irrigation water use based on per capita consumption are given in Table 8.7 for the year 2000.

Irrigation water requirements based on consumptive use of crops

Water consumption of major cereal crops

The amount of water transpired and evaporated into the atmosphere from growing crops has all along been a subject of intensive investigation. The water needed for photosynthesis and to sustain the plant tissues is only a small fraction of the total amount used. The rest of the water is consumed in dissipating solar energy.

Basic food grains, namely, wheat, maize and paddy provide nearly three quarters of man's food supply. The effective evapotranspiration or consumptive use for these three major grains during their growth periods are given in Table 8.8.

Table 8.7. Projections of agricultural water requirements in the world, based on population growth, in the year 2000

Continent/ country	Agricultural water requirement			
	1 pd/cap	m^3/yr/ cap	km^3/yr	Percentage of world total
Africa	1206	440	261.8	7.48
Asia (excluding USSR)	1630	595	2284.8	65.32
Europe (excluding USSR)	520	190	105.5	3.02
Oceania	2260	825	16.5	0.50
N.America	3040	1110	333.0	9.52
S.America	570	208	77.9	2.22
USSR	3700	1350	418.5	11.96
World total			3498.0	100.00

Table 8.8. Consumptive use for selected cereal crops

Item	Crop		
	Wheat	Paddy	Maize
1. Crop duration, days	140	120	120
2. Consumptive use per crop, cm			
a) Measured for irrigated crops (Blaney and Criddle, 1962)	30 to 45	62	30 to 45
b) Doorenbos and Pruit (1975)	36.0	50 to 95	40 to 70
c) Estimated consumptive use under 'good' farming practice, Hammond (1967)	35.6	63.5	51.0
3. Recommended average values, cm	35.0	65.0	40.0

Projections of area and production of cereals

Farming operations are practised under a variety of conditions that affect the yield. Variables such as the type of seed, latitude, weather, water supply, farming techniques, pest control, types of soil, and fertilizer supply, etc., can all vary over wide ranges and lead to considerable variation in yields.

The progressive values of area and production of all cereals for the years 1965–80 were analysed and projections were made for the years 2000 and 2025. The projections of areas were based on the average annual growths for the period 1965–70, 1970–75 and 1975–80. Long-term (2000-2025) average growth rates are expected to

be marginally lower than the short-term values. Accordingly the short-term average values were modified for the purpose of projections. It was assumed that the average yield of all crops will be 3.0 tons ha^{-1} in 2000 and 5.00 tons ha^{-1} in 2025 using improved technology which includes irrigation to a substantial area.

Due to the development of technology of efficient water management, the irrigation efficiency is expected to increase to at least 40 per cent from the present (1975) level of about 30 per cent, by the year 2000 and to 45 per cent by 2025. Further, besides cereals, other crops such as oil seeds, pulses, fruits and vegetables, tuber crops, and fibre crops also need irrigation. In view of developments in the technology needed for higher levels of production of crops, irrigation requirements are expected to rise steeply for these crops also. The projected values of irrigation water needs for all cereals and non-cereal crops are also given in Table 8.9.

Table 8.9. Projections of area, production yield per ha. and the irrigation water requirements for cereal and non-cereal crops for the years 1976, 2000 and 2025

Item	1976	2000	2025
1. Total cereals:			
Area, m.ha	760	880	1000
Production, m.tons	1477	2640	5000
Yield tons/ha	1.95	3.0*	5.0*
2. Production per capita, kg	365	440	555
3. Percentage of area irrigated	22.38	30*	40*
4. Irrigated area under cereal crops, m.ha.	170	264	400
5. Average water requirements per hectare, m^3	4500	4500	4500
6. Irrigation efficiency (including conveyance, application and leaching requirements) percentage value.	30	40*	45*
7. Annual irrigation water needs, for cereal crops, km^3	2550	2970	4000
8. Irrigation water requirements of all other non-cereal crops, km^3/yr.	250	300	500
9. Total irrigation water requirements for all crops, km^3/yr.	2800	3270	4500

*Anticipated value.

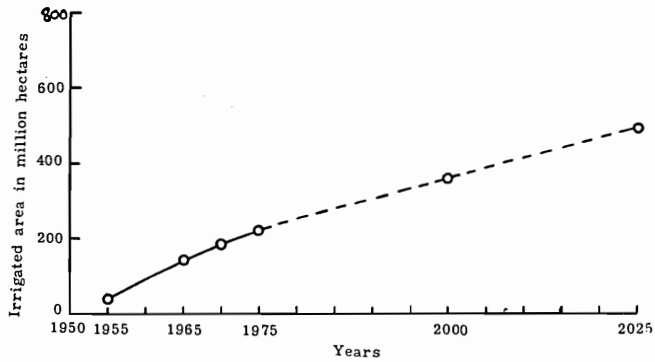
Irrigation water requirements based on the projections of irrigated area in the world

Out of 1415 m.ha of culturable area of the world only 226 m.ha had irrigation facilities as of 1976. This works out to about 16 per cent of the cropped area. The area under irrigation has been progressively increasing during the past two decades (Figure 8.5). Projections for the future indicate that area to be irrigated by the years 2000 and 2025

would be 360 m.ha and 500 m.ha respectively (Figure 8.5). Assuming that an average of 95 and 90 cm of depth of water is used for irrigation in the years 2000 and 2025, the volumes of water required are 3420 km^3 and 4500 km^3 respectively.

Thus, the above analysis for the estimation of agricultural water requirements based on the three different criteria provide comparatively close values (Table 8.10). Hence the irrigation water needs by the years 2000 and 2025 may be taken as 3400 and 4500 km^3, corresponding to about 360 and 500 m.ha of irrigated area.

Figure 8.5. Projections of irrigation development in the world



Source: F.A.C. Production Year book, 1976

Table 8.10. Comparison of estimates of agricultural water requirements by different methods

Basis of estimation	Total volume of irrigation water required km^3/yr	
	2000	2025
1. Per capita needs	3498	4926
2. Consumptive requirements of crops	3270	4500
3. Projections of irrigated area in the world	3420	4500

COMPARISON OF AVAILABILITY AND DEMAND FOR WATER RESOURCES

The distribution of utilisation patterns of the readily available water resources as of

1975 in comparison to the available values are presented in Figure 8.6. On an average, as of 1975, only 11.23 per cent of the readily available water resources are utilised. Except for Asia and North America, utilization is less than ten per cent. Higher levels of utilization in Asia can be due to huge population while for North America, it is due to the higher level of economic development. The estimates of projected water needs for domestic, industrial and agricultural purposes are shown in Figure. 8.7.

The per capita availability of land and water resources dwindle as the population continues to grow. The estimated values of the per capita availability of water resources are 4171 m^3/yr and 2781 m^3/yr respectively for the years 2000 and 2025, while the per capita requirement of water for the corresponding years reach a near constant value of 970 m^3/yr. Thus, the proportion of water needed increases from 23 per cent to 35 per cent of the readily available water resources. Such high levels of utilization limit economic development and calls for a high level of management of available water resources. This also requires evolution of technology for development of alternate resources of water.

Figure 8.6. Potential and readily available water resources and their utilization in different continents of the world (1975)

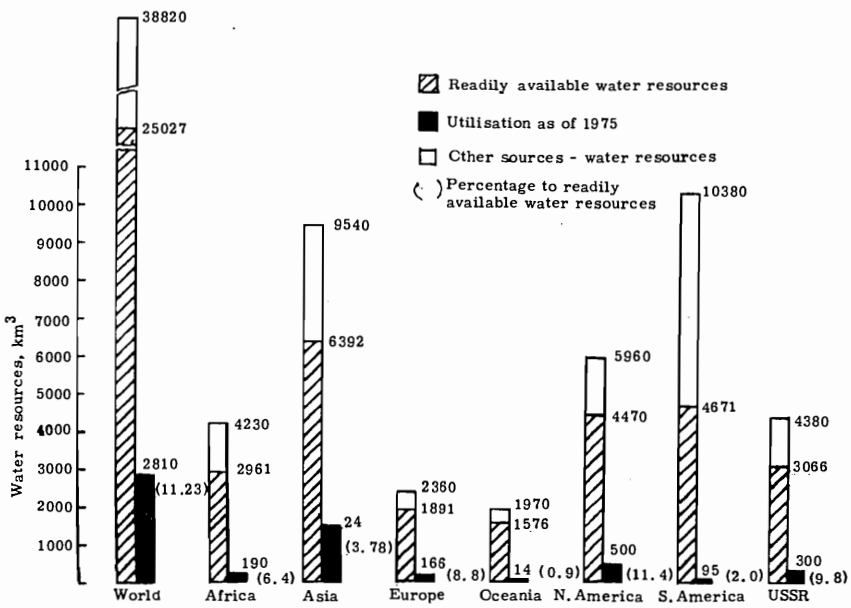
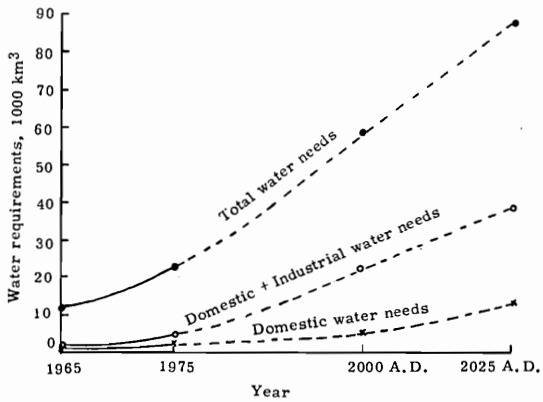


Figure 8.7. Projections of global water requirements for different uses for the year 2000 and 2025



DEVELOPMENT OF WATER RESOURCES THROUGH UNCONVENTIONAL METHODS

Besides conventional development of natural water resources, it is also possible to develop additional water resources through artificial manipulation of naturally occurring physical and chemical processes in the hydrological cycle. Cloud seeding, suppression of evaporation, water harvesting, desalination of saline water, reclamation of waste water and tapping of glaciers are the principal unconventional methods of developing additional water resources. Some other unconventional methods are long distance towing of water by super tankers and transportation of icebergs from arctic regions. In most of these approaches, the cost of production often exceeds the value of water, as many of these techniques are energy intensive.

Cloud seeding technique for rain formation

The process of precipitation involves growth or conversion of about a million very small cloud droplets to much larger precipitation elements. Under certain favourable conditions, it is possible to artificially accelerate the process of formation of the precipitation elements. This is normally done through seeding of clouds with chemicals, such as sodium chloride, silver iodide, ice crystals, etc. These materials enhance the condensation, collision and coalescence processes of water particles, initiate and accelerate the growth of the ice precipitation process, and in some cases, change the dynamic properties of the clouds.

The success of artificial rain making depends primarily on a clear understanding of the physics of precipitation under complex atmospheric conditions. A number of large scale experiments were successfully carried out in the United States of America, Australia, Israel and other countries. It was observed that proper seeding with silver iodide can increase precipitation by 18 per cent (Neumann *et.al.*, 1967). Dynamic cloud seeding is reported to produce even more effective results in as much as causing a precipitation increase of 3 to 10 times (Kantor, 1977). Since most of the cloud seeding experiments are being done in the natural atmosphere and not under controlled conditions, evaluation of their performances has to be based on statistical analysis which is often inconclusive. Although the technique has promise for the future, its economic viability is yet to be established.

Control of evaporation

Loss of huge quantities of water by evaporation from reservoirs and land surface is considered a major problem in the arid and semi-arid regions of the world. Research to increase water availability by suppression of evaporation from plant and water bodies and land surfaces is underway for more than half a century. At the farm level, this is achieved through conserving soil moisture by appropriate tillage practices, covering the soil with artificial mulches, spraying of anti-transpirants and reflectant materials on plants.

Reduction of evaporational losses from open water bodies like lakes and ponds can be achieved if the factors causing evaporation can be inhibited at the water surface. Use of granular particles of white perlite ore, or polystyrene beads or hydrophobic amorphous calcium carbonate powder to form a floating surface which is highly reflective to solar radiation, are common methods adopted to reduce evaporation losses from reservoirs and lakes.

Spreading suitable chemical films on the water surface can suppress evaporation. These films may be multi or monomolecular in thickness. The most commonly used chemicals are hexadeconal and octadeconal. Mixtures of these two are used in the form of dry powder, suspensions and emulsions. The films formed are non-toxic to human, plant and animal life, relatively impervious to water and are stable up to wind velocities of about 24 kmph (Burnett and Florey, 1967).

This method of reducing unproductive loss of water resources is particularly useful for large sized irrigation reservoirs and ponds in arid and semi-arid regions. However, the economic feasibility of the technique is yet to be established. The amount and cost of the water saved by spreading monomolecular films vary considerably. Results from some of the experiments conducted in the United States and elsewhere are given in Table 8.11.

Except in a few cases, none of the methods proved to be of practical use in large scale applications. Additional research is needed for the development of economically viable technology.

Table 8.11. Results from field experiments of studies in control of evaporation from open water bodies

Location	Reduction in evaporation %	Wind velocity kmph	Cost/m^3 U.S.$ *	Source of information
1. Lake Hefner	9	11.2	0.05	U.S. Bureau of Reclamation, 1959
2. Lake Saguaro	14	8.0	0.06	–do– 1961
3. Lake Cachuma	8	11.2	0.055	–do– 1962
4. Pactola reservoir	14	9.3	0.06	South Dakota Univ. 1964 Anonymous
5. Kishon reservoir (Israel)	10–22	N.A.	20.00 (approx.)	Kontor, 1977
6. Unnamed reservoirs Australia	40	<8	0.01	Fitzgerald and Vines, 1963
	10–20	<16		

* Costs are as of the date shown against each case.

Water harvesting

In rainfed agriculture, the frequency of occurrence and duration of dry spells have an important bearing on the growth of crops. Some crops are highly sensitive to moisture stress and wither away if the moisture is not repleted in time. This can lead to partial and in some cases total failure of the crop. A single irrigation at such critical times can save the crop from total failure. Most of the rainfall is lost as runoff. A major part of the rainfall could be collected and stored so that a crop life-saving irrigation could be given. This concept forms the central theme of *water harvesting technology.*

Water harvesting in its narrow definition is the process of collecting and storing or harvesting precipitation from an area which was treated to increase runoff of rainfall and snowmelt (Myers, 1964). However, a more general definition would include the integrated procedures to collect and store efficiently a major part of the runoff from storms in small reservoirs built in micro-watersheds. The potential of this time tested technique can be appreciated in terms of the volume of water that can be harvested. If 10 mm of rainfall occurs on 1 ha of impermeable area, the amount of rain water that could be collected is 100,000 litres, which could meet the domestic needs of a small community of 100 persons for one full week. Treatment of top 15 cm. of the soil with chemicals like $CaCO_3$ leads to conversion of 72 per cent of rainfall to runoff at a nominal cost (Tiwari, 1984). This method is particularly suitable for arid regions with unproductive soils.

Desalinisation of brackish water

Brackish water is saline and contains more than 1,000 ppm of total dissolved salts. Backwaters of the seas and oceans and many inland lakes and rivers prone to sea water ingression are brackish and are unfit for domestic, industrial and agricultural use. In addition, there are enormous underground reservoirs of saline water in several parts of the world including Canada, Middle East, Mexico, North West Africa, Southern and Western Europe, Southern Italy, coastal regions of South America and the United States. Estuaries are formed when rivers empty into the sea with a gradual change in bed elevation. Estuaries contain a mixture of fresh and sea water, the proportion being dependent on the tidal activity. Estuaries of some rivers extend to several kilometres inland from the sea coast and are major sources of brackish water. The technique of desalinisation has immense potential for the creation of new water resources.

As a sequel to the research and development during the 1960s and 1970s, the technology for large scale desalinisation is reasonably well developed. A number of desalinisation plants are in operation in Australia, Japan, Gulf countries, African countries, Middle East, Phillipines, Holland, Italy Israel, Bermuda and the United States of America. By 1975, there were about 1036 desalinisation plants in the world with a total capacity of 2.17 million m^3/day. Several plants have a capacity of 4000 m^3/day or more.

An important factor concerning the desalinisation process is the selection of the source of energy. Desalinisation requries large quantities of energy, whether it be nature's solar process, electrodialysis, reverse osmosis process, or the distillation process. The energy requirement depends on the salinity of the water. A theoretical estimate of the minimum energy requirement is about 0.7 kw-hr per cubic metre of the saline water processed. But in practice, it is far higher. The membrane process is normally used for salinity up to 10,000 ppm of total dissolved salts while the distillation process is used for higher salinity. Distillation, vapour compressions, electrodialysis, and the chemical process cost more than the reverse osmosis process (Table 8.12).

Power plants that produce large amounts of power and desalted water proved to be more economical. Use of nuclear energy in such dual purpose plants has acquired importance in the recent years. In advanced countries nuclear power has proved to be effectively more economical than the conventional water and fossil based power. The multi-stage flash evaporation process is commonly adopted on a large scale in most of the dual purpose plants.

The technology of desalinisation appears to have great promise provided the energy consumed and thereby the costs involved can be reduced to an economic level. As at present the cost of production of desalinated water makes it prohibitive for use in agriculture. The capital and annual cost of the plant per unit volume of desalinated water reduce considerably as the size of the plant increases. Judged from the current level of water use efficiency, the use of water produced at such prohibitive costs call for a very high level of technology of irrigation water management. The conventional surface methods of irrigation are often not feasible. The crops raised should have high monetary value so that the economic efficiency of the irrigation

Table 8.12. Comparison of the performance of various desalinisation processes for production of 1m³ of desalinised water

Item	Unit	Type of Process				
		Multi stage flash	Multi effect distillation	Vapour compression	Reverse Osmosis	Solar drying
1. Energy requirement	kwh/m³	70.0	68.5	36.0	6.1	-
2. Capital investment cost	U.S. $/m³/yr	2 to 3	2 to 3	3 to 5	0.8 to 1.2	30 to 60
3. Cost of production of desalinised water	U.S. $/m³	1.00	0.98	1.05	0.44	5.0

Source: Kantor (1977).

activity will be high. An example of such an activity is that of vegetable crops grown in air inflated plastic greenhouses in Mexico, maintained under controlled environment. As the moisture is not allowed to escape from the greenhouses, the evapotranspiration is reduced to one tenth of the normal value. Such plants are in operation on commercial scales in Abu Dhabi, and Arizona also.

There is considerable scope for research in the development of low cost desalinisation plants. Extensive recourse to the use of nuclear energy holds promise in reducing the cost of production of desalinated water. In view of the increasing trend of large scale use of water in agriculture, research in these areas is very desirable to produce large amounts of desalinated water at low costs.

Reclamation of waste water

The increased use of water in domestic, industrial and agricultural sectors leads to enormous quantities of waste water. Discharging of such waste water into fresh water bodies causes ecological pollution and deterioration of the water quality. Hence, it is necessary to treat the waste water before it is discharged into fresh water bodies. Municipal waste water contains approximately 0.1 per cent of impurities (dissolved salts). It will be a colossal waste of precious water resources, if the remaining 99.9 per cent of this water is wasted. Reclamation and reuse of this waste water holds the key to efficient and effective utilisation of the limited water resources through unconventional means. In view of the relatively low impurities in comparison with brackish water (which contains nearly 10 to 30 times as many impurities), the treatment of municipal water is far cheaper than the desalination process. Reclamation of waste water has the added advantage of considerably reducing the pollution hazard, besides being an effective source of additional water resources. This latter aspect is more relevant to regions where there is a severe shortage in the availability of fresh water. For example, Israel has used up most of the available water resources and reclaims and reuses several million cubic metres of waste water every year. The proposed Dan region project (Kantor, 1977) alone envisages reclamation and recycling of about 120 million m^3/yr. South America and the United States of America are two other countries where municipal and industrial waste water is extensively reclaimed and recycled.

The total water use in the world is expected to increase to 5828 km^3/yr. by the year 2000. The corresponding amount of waste water would be about 3000 km^3/yr. Even if 50 per cent of the waste water is reclaimed and recycled, it would give an additional water resource of over 1500 km^3/yr.

In the agricultural sector, recycling of drainage water after appropriate dilution to keep the salts within tolerable limits will facilitate extensive irrigation from limited water resources. Such recycling is highly suited for high water use crops like paddy, sugarcane, etc. (Ateshian and Mohamed, 1967). If municipal or industrial waste water is to be used for irrigation, the treated water may have to be stored either above or below ground level because of the seasonal nature of irrigation demand. In such cases, adequate precautions are to be taken to protect the community from environ-

mental pollution, particularly if surface storage is adopted.

The reclaimed waste water can be used for irrigation and other purposes, provided the treated water conforms to the specified hygenic and chemical standards. The degree of purification to be obtained will be different for different uses.

The existing technology of waste water treatment is reasonably efficient. The emphasis shall be more to choose and adopt appropriate techniques of treatment rather than developing new technology. This would include characterising the quality of waste water, specification of the target water quality required, depending on the purpose and nature of expected water use and selection of appropriate economic processes from among the alternatives.

Ground water recharging is perhaps the most preferable method for treating and storing the municipal and industrial waste water. The waste water is either spread over the ground surface or injected below the ground through the existing wells so that it may reach the local ground water reservoir and get diluted. The chemical, biochemical, adsorption, absorption and ion-exchange processes that occur while the water seeps through the subsoil improve the quality of the effluent. Further, storing effluent below the ground level has the added advantage of being the cheapest method, and safe from the point of view of environmental pollution.

The cost of waste water treatment depends mainly on the biological load indicated by the biological oxygen demand (BOD), the surface detention time, the mechanism needed for handling the sludge, and above all the level of treatment required. The cost of treatment, as of the prices of January 1976 (Kantor, 1977), was estimated to range from U.S.$ 0.03 /m^3 of treated water for direct irrigation use restricted to crops that are not consumed uncooked, to U.S.$ 0.25/m^3 for municipal use.

Waste water reclamation and recycling has become a well established technology of development of unconventional sources of water, and hence efforts to plan, develop and effectively utilize water resources should include a well planned programme of waste water reclamation and general reuse. Establishment of regional multi-purpose authorities to control water supply – waste disposal and water reuse, is a logical approach to handle the problem of water use in its total perspective.

Inter-basin and inter-continental water transport

One of the ways to meet the further demands for fresh water is manipulation of water resources on a scale larger than the various countries have been practising now (1980). Many of the world's major rivers discharge enormous volumes of unutilized water into the oceans (Table 8.13).

Most of the rivers listed in Table 8.13 do not have cultivable lands nearby or the local topography is unfavourable for the development of water resources. Such situations call for inter-regional or interbasin transfer of water. Inter-regional transfers even within a country hold the key for the manipulation of water resources on a large scale. Snowy river water to be linked to the Murray river in Australia, the transfer of water from the North to Southern region of Israel etc., are some of the examples of such inter-regional transport of water resources on a large scale.

Table 8.13. Some rivers in the world with large quantities of unutilized flows

Continent/ country	Name of the River
Africa	Niger, Congo, Zambezi
South America	Amazon, Orinee, Parana
South East Asia	Irrawady, Salween, Mekong
China	Yangtze, Yellow
USSR	Ob, Yenisei, Lena
India	Brahmaputra

Source: Adapted from Framji and Mahajan (1967)

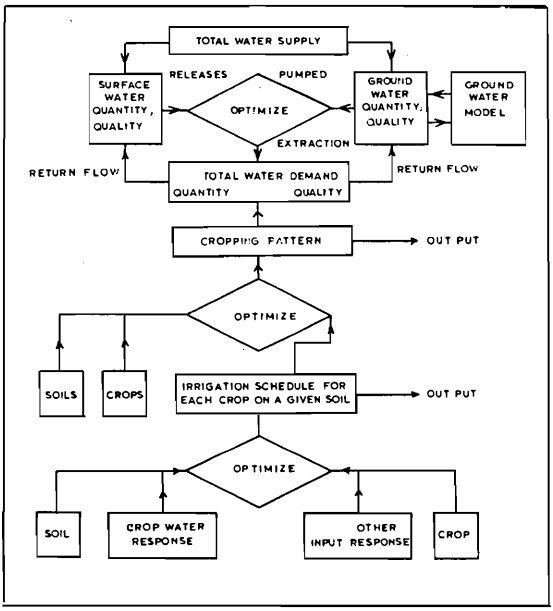
Another form of inter-regional transport of water is the possibility of towing huge polar icebergs across the oceans from the Antarctic region to arid continental coasts. The proposal to tow a huge iceberg of several cubic kilometers of volume from Antarctica to the Atacama desert in Chile in about seven month's time with a water loss of about 30 per cent is an example. It was proposed to moor the iceberg at a distance from the coast and get it quarried or melted for various purposes. However, the technical and economic viability of such an operation to be adopted in other places remains to be established.

Conjunctive use of river-aquifer systems

Optimal conjunctive operation of water from various sources in a region is basic to the problem of planning for efficient water use. This involves selection of suitable combinations of available river flows, ground water, and water from other sources such as reclaimed waste water, harvested runoff, etc.

The amount of ground water within the top 30 metres of the earth's surface is of the order of 4,500 km^3, a substantial portion of which can be readily developed. Large scale conjunctive management of river flows and local ground water basins not only facilitates efficient utilization of the resources but also creates additional water resource potential. For example, the conceptual model of the "Ganges Water Machine" (Revelle and Lakshminarayana, 1975) envisages the creation of an additional irrigation potential of 25 m.ha in the Gangetic Plains of India. It was proposed to empty the local ground water basin before the commencement of the flood season of the Ganges river so that the aquifer gets recharged during the flood season. A considerable part of the flood flows which would have otherwise caused extensive flood damage in the nearby plains, and ultimately flowed as a waste to the Bay of Bengal, could then be used to recharge the aquifer and stored as ground water for use during the non-flood season. Another classic example is the conjunctive use of surface and ground water in the Indus Valley in Pakistan (Thomas and Burden, 1965) to combat the problem of waterlogging and soil salinity in the irrigated areas. While the techniques of solving a variety of optimisation problems are now available, a com-

Figure 8.8. Optimization of water use in agriculture



prehensive picture linking the interacting problems at various levels of water use in agriculture is yet to emerge. The totality of the problem emerges when the allocation of water between surface and underground sources to various crops in a region for an optimal cropping pattern is linked with an optimal irrigation schedule both in terms of timing and quantity of irrigation water application (Sarma and Rao, 1980).

EPILOGUE

Over centuries, man has been using water flows from rivers and springs to supplement rainfall for irrigating the crops. The fast increasing population and associated need for food and fibre calls for the speedy expansion of irrigation, both by strengthening and renovating the existing facilities and the creation of new irrigation facilities. The large quantities of water used in irrigation and the generally low water use efficiency are indicators of the immediate need to develop methods and schemes for conservation and effective management of the water resources.

Efficient water management is one of the most effective means of increasing agricultural output and obtaining sustained productivity in irrigated areas. Besides

efficient management of the available water resources, the development of additional water resources through unconventional methods needs to be pursued on a large scale to meet future water demands. The necessary technology is available for development, planning and efficient utilisation of the water resources. If governments and decision makers are prepared to embark on programmes of proper management of water, alleviation of hunger in the world can be achieved.

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CHAPTER 9
Fertilizer Nitrogen: Requirements and Management

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INTRODUCTION

FERTILIZER NITROGEN HAS contributed largely towards meeting man's needs for food and fibre. The use of fertilizer nitrogen for crop production began in the early part of the nineteenth century and currently countries like the Netherlands are using as high as 738 kg N/ha (FAO, 1983). Even in developing countries such as India where the fertilizer use on the farms began only in 1950s nitrogen application has increased from less than a kilogram to 34.6 kg N/ha (FAO, 1983). The rate of increase in the fertilizer nitrogen consumption has been faster in the countries where land area was relatively smaller and pressure of population was more intense.

Food needs of the world

The available estimates indicate that 2421.6 million MT of cereals will be required in 2000 AD as against the 1980 production of 1566 million MT, about 50% more production in the next 20 years. The available data also show that the developed countries are already producing more than what they will need in 2000 AD and the countries with centrally planned economics are also fairly well off, currently producing 76% of their needs in 2000 AD. It is only the developing countries where the production of cereals has to be almost doubled in twenty years. While in most African countries this can be easily achieved by bringing more land under cultivation, in Asia it has to be attained by a more difficult task, by increasing production per unit of land per unit of time. The Indian experience, however, clearly brings out that this can be easily achieved by giving due attention to agricultural research and extension and by adopting appropriate Government policies.

Nitrogen requirements of the world

The 1980 world consumption of fertilizer nitrogen was 57.19 million MT (Table 9.1). To produce an additional 856 million MT of cereals, an additional 85.6 million MT of fertilizer N would be needed. This is based on the assumption that on average each kg N would produce 10 kg cereal grain (Randhawa and Tandon, 1982). Thus, the total N requirement to meet the world's cereal needs works out to 142.8 million MT. This is very close to the UNIDO (1978) estimate of 145.4 million MT (Table 9.1). According to UNIDO estimates the production capacity of fertilizer nitrogen in the world in 2000 AD would be of course much more (234.6 million MT). The additional fertilizer N requirement would be equivalent to 1072 million barrels of crude. Considering the problems which many countries, particularly the developing nations face in meeting their energy needs, it will be wise to substitute a part of the fertilizer nitrogen needs by biological N_2-fixation. The current thrust on research in biological N_2-fixation in the world is, therefore, appropriate and desirable.

According to UNIDO estimates the capital investment in the fertilizer nitrogen industry during 1982–2000 would be 64.6 billion U.S. dollars (Table 9.2) and the industry would employ 181,200 additional men. In the year 2000 AD about 125.7 x $10^9 m^3$ of natural gas, 9.8 million MT of Naptha, 13.8 million MT of fuel oil and 39.4 million MT of coal would be required by the fertilizer nitrogen industry.

CONTRIBUTION OF BIOLOGICAL NITROGEN FIXATION

A global inventory of nitrogen in the biosphere (Table 9.3) shows that N is distributed in terrestrial, oceanic and atmospheric components in the ratio 1 : 70 : 11818. Thus the bulk of the biospheric nitrogen is in the atmosphere. The atmospheric column on an hectare of land will approximately contain 8.4 x 10^4 MT/ha nitrogen (Stevenson, 1965), yet for meeting 100-200 kg N/ha required by most cereal crops one has to apply equal or larger amounts of fertilizer nitrogen. The main reason is that most higher plants with the exception of legumes and a few members of other families cannot utilize nitrogen present in the atmosphere (including soil air). Nitrogen has, therefore, to be applied either as chemical fertilizer or organic manure.

Nitrogen fixers can be broadly classified into free-living organisms and those living in association with plants. Nutman (1971) has made a fairly detailed listing of N-fixers of both the groups. Total biological nitrogen fixation by all the different types of organisms is estimated approximately 175 million metric tons per year, of which legumes alone account for almost half (80 x 10^6 MT) per year (Hardy and Havelka, 1975). Estimates of global fixation and losses of N by different sources are given in Table 9.4, while the N-fixation in kg/ha/year by some organisms or systems are given in Table 9.5.

Although the overall process $N_2 \rightarrow 2NH_3$ is exergonic (–104 kJ/mole), high energy

Table 9.1. Current world nitrogen consumption, production and forecast for 2000 (million metric tons of N)

Groups of countries	1980[1/] Consumption	Production	2000 AD[2/] Consumption	Production Capacity	Additional Needs Amounts	Energy equivalents Million of barrels of crude
Developed ME	22.64 (39.6)	26.86 (45.0)	40.6 (27.9)	68.4 29.2)	17.96	216.2
Developing ME	11.33 (19.8)	8.12 (13.6)	45.5 (31.3)	69.2 (29.5)	34.17	411.4
Centrally Planned Economics	23.22 (40.6)	24.78 (41.4)	59.3 (40.8)	97.0 (41.7)	36.08	434.4
Total	57.19	59.76	145.4	234.6	88.21	1072.0

1/ FAO (1980)
2/ UNIDO (1978)
3/ Figures in parentheses are percentages of world total
ME – Market Economies

Table 9.2. Capital investment, manpower and raw material needs of fertilizer nitrogen industry, 1982–2000

Group of countries	Capital Investment Billions of US Dollars (1977 value)	Manpower '000 Men	Raw materials requried in 2000 AD			
			Natural gas 10^9 m3	Naptha million MT	Fuel oil million MT	Coal million MT
Developed ME	11.6	23.4	35.4	2.8	3.9	11.1
Developing ME	27.6	92.2	38.9	3.0	4.3	12.2
Centrally Planned Economies	25.4	65.6	51.4	4.0	5.6	16.1
Total	64.6	181.2	125.7	9.8	13.8	39.4

Source: UNIDO (1978)
ME – Market Economies
MT – Metric Tons

Table 9.3. Global inventories of nitrogen in the biosphere (million tonnes N)

Terrestrial:	Plant biomass	$1.1-1.4 \times 10^4$
	Animal biomass	2×10^2
	Litter	$1.9-3.3 \times 10^3$
	Soil organic matter	3×10^5
	Soil insoluble inorganic	1.6×10^4
	Soil soluble inorganic	3×10^3
	(soil micro-organism included in total soil organic matter)	5×10^2
Oceanic:	Plant biomass	3×10^2
	Animal biomass	1.7×10^2
	Dissolved organic matter	5.3×10^5
	Particulate organic matter	$0.3-2.4 \times 10^4$
	N_2 dissolved	2.2×10^7
	N_2O dissolved	2×10^2
	NO_3^- dissolved	5.7×10^5
	NO_2^- dissolved	5×10^2
	NH_4^+ dissolved	7×10^3
Atmospheric:	N_2	3.9×10^9
	N_2O	1.3×10^3
	NH_3	0.9
	NH_4^+	1.8
	NO_x	1–4
	NO_3	0.5
	Organic N	1

Source: Winteringham (1980)

input (940 kJ/mole) is required to rupture the N = N bond and thus whatever be the source, manufacture of nitrogen fertilizer is highly energy dependent (Leigh, 1977). The interest in biological N_2–fixation is due to the fact that it uses solar energy, the most inexhaustible energy source for producing ammonia from nitrogen in the protoplasm of the organisms.

Nitrogen fixation by legumes

It was almost a century ago when Hellreigel and Wilfarth (1888) first pointed out the symbiotic relationship between legumes and Rhizobium species. However, growing of legumes for maintaining and building up soil fertility has been practised since ancient times (Raychaudhari and Kaw, 1964; Zohary and Hopf, 1973). It is now well established that enzyme nitrogenase is involved in nitrogen fixation both in free living organisms and those living in associations. The nitrogenase enzyme complex in combination with the necessary reactants catalyses the reduction of nitrogen to ammonia. This enzyme complex consists of two protein components; a larger molybdenum-iron protein having a molecular weight of 2-2.7 x 10^5 and containing one or two atoms of molybdenum, 17 to 36 iron atoms and 14 to 28 acid labile sulfur atoms per protein molecule and an iron-protein molecule having a molecular weight of 55-67 x 10^3 containing 4 atoms each of iron and acid-labile sulfur per mole of protein (Evans and Barber, 1977).

Table 9.4. Global rates of nitrogen fixation and denitrification

Process	Amounts (million MT/yr)
Terrestrial biofixation	
Legumes	36
Rice	4
Other crops	5
Grasslands*	45
Forests*	40
Others	10
	139
Oceanic biofixation	20–120
Industrial fixation (including fertilizers)	89
Terrestrial combustion processes	19
Terrestrial denitrification as N_2O	16–69
Terrestrial denitrification as N_2	91–92
Oceanic denitrification as N_2O	20–80
Oceanic denitrification as N_2	5–99
Global river discharge (mainly as NO_3) from land masses to oceans (excluding polar and desert areas)	8

Source: Winteringham (1980)
Would also include legumes.

Table 9.5. Biological nitrogen fixation by different organisms/systems

Organism or system	N-fixed (kg/ha/yr)
Legumes	
forage	57–700
grain	17–270
Nodulated non-legumes	
Alnus	40–300
Hippophae	2–179
Ceanothus	60
Coriaria	150
Plant algal associations	
Gunnera	12–21
Azollas	31
Lichens	39–84
Free-living micro-organisms	
Blue green algae	25
Azotobacter	0.3
Clostridium pasteurianum	0.1–0.5

Source: Nutman (1971) and Evans and Barber (1977)

Smith *et al.* (1976) believed that the functional unit of the enzyme complex is made up of a one-to-one combination of the iron and molybdenum-iron proteins while Orme-Johnson (1976) suggested a unit of two iron proteins for each molybdenum-iron protein. The nitrogenase enzyme complex is highly sensitive to oxygen and the half life of molybdenum-iron protein in the air ranges from 4 to 10 minutes (Postgate, 1975).

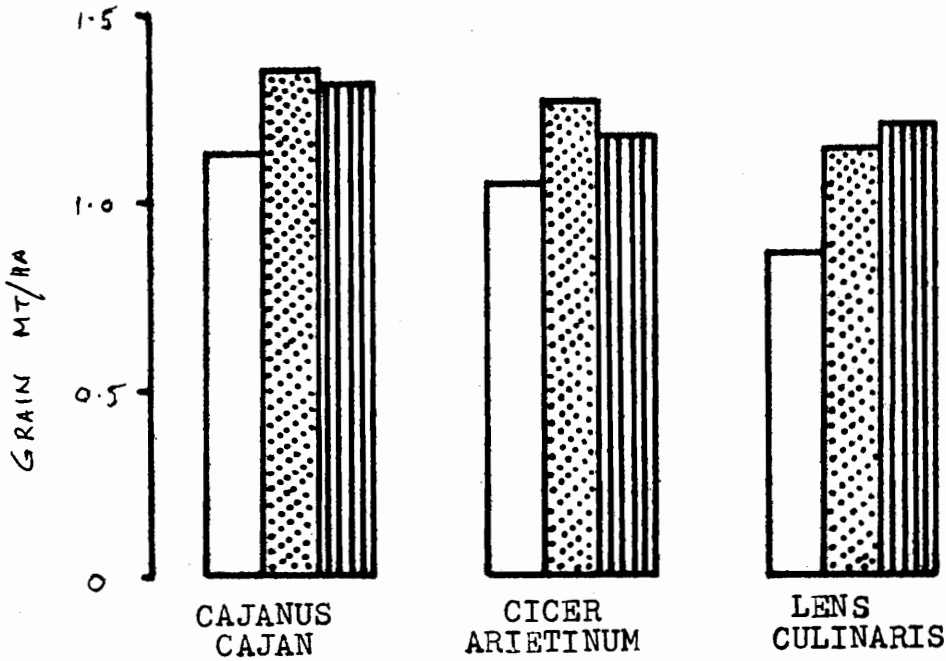
The root nodule of the legumes is a highly developed plant organ containing leghemoglobin which saves the nitrogenase enzyme complex from oxygen toxicity. Tjepkema and Yocum (1974) demonstrated that near the periphery of nodules, there is a barrier (consisting mainly of hemoglobin) to the diffusion of oxygen. In air, leghemoglobin in soybean nodules is about 20% saturated with 0_2, but the dissociation of 0_2 from oxy-leghemoglobin is so low that the concentration of free 0_2 at the bacteroid surface is only about 10 nanomolar (Evans & Barber, 1977). As a matter of fact the nodules have several other advantageous mechanisms in favour of nitrogen fixing bacteria (Rhizobia). The bacterioids in nodules are located in several individual packets, each with 3 or 4 bacteroids surrounded by a membrane (Bergerson, 1974). The bacteroids are supplied with water and carbohydrates from the plant (Pate *et al.*, 1969) as well as with atmoshperic CO_2. The first product of nitrogenase reaction is ammonia and it is excreted from the bacteroids into the cytosol, where it is converted into glutamine, asparagine and a variety of amino acids (Pate *et al*(1969). These amino acids are secreted into the xylem vessels of the roots through a group of highly specialized cells that surround the xylem vessels and function as secretory glands (Pate *et al.*, 1969).

Schubert and Evans (1976) observed that the majority of nodulated legumes examined in the initial survey lost 30 to 60% of the energy supplied to nitrogenase as evolved H_2. A few legumes and several nodulated non-legumes apparently have evolved mechanisms whereby the H_2 from the nitrogenase reaction is recycled (Evans and Barber, 1977). This takes place through a series of sequence of reactions; the first one involves activation of H_2 through a hydrogenase. Strains of *Rhizobium Japonicum* that produce nodules and also utilize energy more efficiently have already been developed (Evans and Barber, 1977). This needs to be done for other Rhizobia too.

There is no doubt a specificity between *Rhizobium* strain and the legume and the compatibility between the two is essential for successful nodulation. This necessitates using specific cultures for different legumes and for growing a new legume species its *Rhizobium* culture must be applied. The benefits of seed inoculation with specific *Rhizobial* cultures have been proved the world over. Some recent Indian data are given in Figure 9.1.

There is considerable variation in nitrogen fixation by different legumes, perennial legumes cut for forage generally fix more than 100 kg N/ha ; sometimes as much as 400-600 kg N/ha. Both temperate and tropical species are equally effective. As compared to forage legumes, grain legumes fix appreciably less (Table 9.6), because of their shorter growing season and because the nitrogen left in the haulm is usually not recorded. The estimates of quantities for the pasture species are normally distributed with a mean of 125 kg N, whereas the distribution of estimates for grain species is

Figure 9.1. Effect of seed inoculation with rhizobial culture on the grain yield of legumes



positively skewed with a mode at about 50 kg N/ha (Nutman, 1971). As can be seen from the data in Table 9.6 there is a considerable range in nitrogen fixation even by the same species. This is somewhat related to the grain and drymatter yields of these crops ; the higher the biomass the more is the nitrogen fixed. It would be appropriate to indicate at this juncture that the average yield of grain legume in developing countries is only 481 kg/ha as compared to 1290 kg/ha (FAO, 1981) in developed countries. Since people in many of the developing countries suffer from protein malnutrition serious attention and attempts need to be made for augmenting grain legume production, which would automatically result in higher N-fixation by these legume crops. Although developing countries in Africa and Latin America can increase grain legume production by increasing the area under these crops, countries in Asia have to achieve it mainly by increasing the production per unit area per unit time and this calls for breeding for better and high yielding varieties and for agronomic research to develop the package of practices for their production on the farm. Also intercropping systems, where a grain legume is grown in between widely spaced cereal crops such as maize, sorghum, millet, cotton and sugarcane, are being developed in India. These intercropping systems permit the production of grain legumes as a bonus crop (Table 9.7) and accompanying bonus nitrogen fixation. In some of these experiments additional yields of the main crop have been reported suggesting some transfer of nitrogen from the companion legume crop. Also multiple and relay-cropping systems have

Table 9.6. Nitrogen fixed by different legumes

Legumes	kg N/ha/yr
FORAGE LEGUMES	
Temperate	
Clovers	23-620
Lucerne	164–300
Tropical	
Stylo	30–196
Tick clover	700
GRAIN LEGUMES	
Temperate	
Vetch and tick beans	57–190
Peas	46
Lupins	128
Tropical	
Lentil	35–77
Pigeonpea	41–150
Cowpea	73–354
Soybean	17–206
Cluster beans	37–196
Groundnut	33–111
Chickpea	41–270
Mung beans	224

Source: Nutman (1971) & Franco (1977)

been developed with one legume crop as a component. Thus the development of better and high yielding varieties, practicing a recommendation package of agronomic practices, following newly developed intercropping and multiple cropping systems would permit better utilization of the potential of legumes in fixing atmospheric nitrogen.

Table 9.7. Grain yield of sorghum based intercropping systems at Hyderabad

Cropping system	*Grain yield (t/ha)* Sorghum	Intercrop	LER	Gross Return Rs/ha
Sole crop sorghum (45 cm row)	6.8	-	1.00	6772
Sorghum paired row (60–30)	7.7	-	1.12	7571
Sorghum + Soybean	7.3	4.1	1.43	7806
Sorghum + Groundnut	7.0	1.8	1.26	7521
Sorghum + Castor	6.5	4.4	1.29	7614
Sorghum + Pigeonpea	6.8	8.7	1.54	8422

Source: Tarhalkar and Rao (1981)

Little work has been done for estimating the amounts of N fixed by naturally occurring legumes, which are widely distributed as herbs in grasslands, bushes and trees in Savannah and trees and creepers in tropical forests. Orchard and Darb (1956) reported that a plantation of *Acacia mollisima* fixed as much as 270 kg/ha/yr. By fixing atmosperic nitrogen legumes provide stability to natural ecosystems.

Nitrogen fixation by blue-green algae (cyanobacteria)

Singh (1961) carried out detailed studies on the periodicity of cyanobacteria in the rice fields of Uttar Pradesh and Bihar states of India. His studies were made at a time when it was believed that only heterocystous forms fixed N and showed that the dominant types were *Aphanothece pallida, Schizothrix arenaria, Porphyrosiphon notarisii, Microcoleus chthonoplastes, Annabaena* sp., *Auylosira fertilissima, Scytonema ocellatum, S. hofmanni, Campylonema lahorense, Nostoc muscorum, N.Calcicola, N.humifusum, Cylindrospermum licheniforme, C. gorakhporense, C. muscicola, Hapalosiphon welwitschii, H. intricatus, Tolypothrix* sp. *Fischerella* sp. It is now established (Stewart *et al.*, 1979) that not only all the heterocystous cyanobacteria but also the unicellular *Aphanothece* and the non heterocystous filamentous *Microcoleous* fix N aerobically, microaerobically and anaerobically.

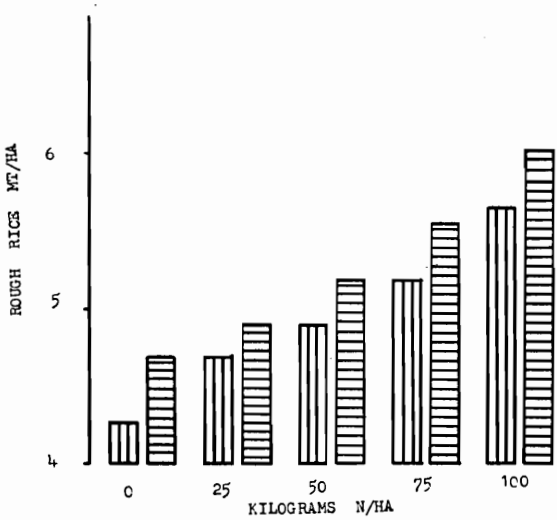
Singh (1961) suggestd that annual N_2-fixation by blue green algae in Indian rice fields may exceed 70 kg N/ha, while Reynaud and Roger (1978) reported considerably lower values (1-30 kg N/ha/yr). Watanabe *et al.* (1977) measured C_2H_2 reduction before and after removing cyano-bacterial growths from the rice field and concluded that the nitrogenase activity could account for a daily input of approximately 0.5 kg/N/ha. According to Venkataraman (1979) blue-green algae contribute 25-30 kg N/ha per cropping season depending on ecological conditions. Data (Figure 9.2) from extensive field trials conducted in many parts of India support this finding suggesting that one third of the recommended N fertilizer could be saved without affecting crop productivity.

Azolla-anabaena systems

"The art of feeding the people", a book on Agricultural Techniques written in 540 A.D. by Jia Ssu Hsieh, describes the cultivation and use of *Azolla* in rice fields in china (Chu, 1979). *Azolla* has therefore, been used in rice fields in China since ancient times. International interest in *Azolla-Anabaena* systems for meeting a part of nitrogen requirement of rice is rather recent and much of it has been at the instance of the International Rice Research Institute, Philippines.

Azolla Anabaena associations are symbiotic relationships between a genus of water ferns and nitrogen fixing blue-green algae. They are found both under temperate and tropical fresh water ecosystems. The new world species, subgenus *Enazolla,* include *A. caroliniana* Wild., *A. filiculoides* Lam. (type species ; possible synonyms being *A. rubra* and *A japanicum*), *A. mexicana* Presl., and presumably *A. microphylla* Kaul-

Figure 9.2. Effect of algal inoculation on the grain yield of rice



No inoculation ; Algal inoculation.
(Source : Venkataraman, 1979)

Table 9.8 Acetylene reduction, dry matter production and doubling time of various azolla species

Species (country)	Temp.	C_2H_4 n moles/g dry wt/min.	N mg/g dry wt. per day	Dry matter increase g/g/day	Doubling time days
A. pinnata (India)	Ambient	-	5.9– 6.2	0.168–0.176	4.3– 4.5
A. pinnata (Indonesia)	Ambient (25–32°C)	600–1300	4.2– 9.0	0.134–0.290	2.7– 5.5
A. Caroliniana (Netherland)	29°C	1900–2950	9.8–14.9	0.271–0.413	2.0– 2.9
A. filiculoides (S. Africa)	25°C	300– 800	2.0– 5.4	0.057–0.155	4.8–12.5
A. mexicana (U.S.A.)	Ambient	600– 700	4.0– 4.7	0.084–0.098	10.6–19.9

Source: Becking (1979)

fuss. The old world species, subgenus *Rhizosperma,* include *A. pinnata* R. Br. (synonyms are *A. imbricata* (Roxb.) Nakai and *A. africana* Desvaux) and *A. nilotica* Decaisne (Peters *et al.,* 1979). The algal symbiont belongs to the family Nostocacace and is generally referred as *Anabaena azollae* Stras. It is not yet confirmed whether the symbiont is the same in different azolla species; no different strains have, however, been reported. Differences in the acetylene reduction activity of different species of azolla have been reported and are given in Table 9.8.

The ecosystem requirements for *Azolla* include free-floating water, sufficient light and temperature around 15°C. At a relative humidity of less than 60% *Azolla* becomes dry and fragile and complete drying will kill the plant (Becking, 1979). According to Becking (1979) the most favourable temperature for the growth of *A. pinnata* is 16–17°C; much of the *Azolla* dies when the temperature rises to 20–24°C. Ahmad (1941, 1943) observed that the growth of *A. filiculoides* decreased above 20°*C* particularly at lower light intensities. The growth was nil at 35°C. Watanabe *et al.* (1977) observed that the growth of *A. pinnata* was reduced by about 50% at 35°C (day)/27°C (night) (average 27°C). Inability of *Azolla* to grow under high temperatures is a major barrier in using *Azolla Anabaena* systems for supplying nitrogen to rice in many developing countries in Asia and Africa. However, where the temperatures during a period of two months before rice planting do not rise above 30°C, it should be possible to use *Azolla* for supplying part nitrogen to rice.

The major nutrient requirement for *Azolla* is phosphate (10-25 kg P_2O_2//ha). Addition of potassium also helps in the growth of azolla. Azolla grows better in soils having pH between 5.5 and 7 (Singh, 1979), although some growth is reported even at pH 10. Acidic soils of pH 3.0-3.5 do not permit the growth of azolla and the inoculum dies.

Using the results of acetylene reduction assays of *A.pinnata*, Becking (1979) suggested nitrogen fixation of the order of 335-670 kg N/ha. Watanabe *et al.* (1977) from IRRI Philippines measured an accumulation of 330 kg N/ha in 220 days. The mineralization of azolla nitrogen is not too slow; about 50% of nitrogen as ammonia was released in 3 weeks at 24°C (Singh, 1979). Thus, the released nitrogen can be made use by the rice crop. The Indian experience (Table 9.9) shows that incorporation of 10 MT of *azolla* per hectare is as efficient as the basal application of 30 kg N/ha.

Non-photosynthetic bacteria

The nitrogen fixing power of non-photosynthetic bacteria has been known since long and there is fairly long list of these (La Rue, 1977). But the amounts of nitrogen fixed by them are relatively small (Table 9.5) and, therefore, interest in these from the viewpoint of practical application has been much less. However, in the wake of the energy crisis there is now considerable interest in this avenue of nitrogen fixation.

Table 9.9 Effect of azolla and N fertilizer on rice yield

Treatment	Summer 1976		Winter 1977	
	Grain MT/ha	Increase over control %	Grain MT/ha	Increase over control %
Control	4.87	-	1.72	-
Incorporated *Azolla* (10–12 MT*)	5.32	9	2.42	41
Incorporated *Azolla* (20–24 MT/ha)	5.60	15	2.62	52
Unincorporated *Azolla* (10–12 MT/ha)	5.16	6	2.40	39
20 kg N/ha (basal)	5.48	12	3.19	28
40 kg N/ha (basal)	5.48	12	3.19	85
60 kg N/ha (basal)	5.82	19	3.52	104
80 kg N/ha (basal)	6.08	25	3.89	126
30 kg N/ha + Azolla (10–12 MT/ha)	5.66	16	3.46	101
50 kg N/ha + Azolla (10–12 MT/ha)	6.36	31	3.58	108
LSD (P=0.01)	0.20		0.35	

*Fresh weight
Source: Singh (1979)

Nodule forming non-legumes

Most nodulating non-leguminous plants with the capacity of fixing nitrogen are woody and, therefore, their economic application is generally restricted to forestry and general ecology of a region. Nevertheless, they do play an important role in overall human welfare. These associations have been recently discussed in detail by Becking (1977)

NEW AVENUES OF BIOLOGICAL NITROGEN FIXATION

Dobereiner *et al.* (1972) reported nitrogen fixation by *Paspalum notatum – Azotobacter paspali* association. In such an associative system no nodules are produced, but in some cases bacteria live underneath a mucilaginous sheath on the root surface. Dobereiner *et al.* (1972) suggested a fixation of about 90 kg N/ha for *P.notatum – A. pasali* association. Later they reported the occurance of a nitrogen fixing *Spirillum lipoferum* on the roots of grass *Digitaria decumbens* (Dobereiner and Day, 1976). In most of these studies acetylene reduction was used to detect nitrogenase activity.

Table 9.10. Estimates of N fixation by micro-organisms associated with some non-nodulated plants

Plant	N-fixed	Reference
	GRASSES	
Agrostis tenuis	37 g/N/ha/day	Nelson *et al* (1976)
Digitaria sanguinalis	3–10g N/ha/day	Barber & Evans (1976)
Panicum virgatum	1.3 kg N/ha/120 days	Tjapkema (1975)
Grasslands	0.6–1.5 kg N/ha/28 days	Paul *et al* (1971)
Pasture prairie	Max. 1 kg N/ha/season	Vlassak (1973)
Paspalum notatum	90 kg N/ha/yr.	Dobereiner (1972)
	FOOD CROPS	
Corn	2.4 kg N/ha/day	Von Bulow & Dobereiner (1975)
Rice	70 kg N/ha/yr.	Balandreau *et al.* (1975)
Wheat field	4.1 kg N/ha/yr	Steyn & Delwiche (1970)

Some estimates of nitrogen fixed by associative systems are given in Table 9.10. The discovery of N-fixing, organisms on roots of grasses including field crops belonging to family gramineae has led to considerable excitement and speculation about the possibility of providing part nitrogen for important food crops through associative systems. However, as the data in Table 9.10 indicate, in general, the amount of N fixed is much less as compared to *Rhizobia*. There are no doubt some exceptions where very high values have been reported. For example Barber *et al.* (1976) reported that inoculation of corn with *Azospirillum* under green house conditions fixed as much as 734 g N/ha/day.

Dommergues and Rinaudo (1979) compared legume and rice N-fixing systems and observed that while legume *Rhizobium* symbiosis required only one mole of glucose for fixing one mole of N, rice rhizosphere nitrogen fixing system required 3-4 moles of glucose for aerobic fixers and 8-10 moles for anaerobic fixers. As regards protection against oxygen excess there was no protection by the rice plant but some protection was offered by anaerobic conditions obtained in rice fields. The fate of nitrogen fixed in rice rhizosphere is not yet clearly established.

The other new avenues for biological N-fixation with an intensive research effect the world over include the following:

1. Development of new *Rhizobium* strains insensitive to soil ammonium and nitrate concentration.
2. Breeding for legume cultivars with higher photosynthetic capabilities to support more N_2 fixation.
3. Selection or development by genetic means of nitrogen fixing bacteria, which can live on the roots of cereals and fix nitrogen for the normal plant growth.
4. The transfer of *nif* genes into a harmless bacterium that is capable of invading plant cells and establishing an effective N_2 fixing system.

5. Transfer of *nif* genes from bacteria directly to higher plant cells.
6. Use of protoplast fusion methods to create new symbiotic associations between micro-organisms and higher plants.

IMPROVING THE EFFICIENCY OF FERTILIZER NITROGEN

The efficiency of utilization of fertilizer nitrogen by cereals is fairly low in tropical and sub-tropical regions of the world (Table 9.11) and this is a barrier in the application of recommended doses of nitrogen to crops such as rice, maize, sorghum and millet in these regions in spite of the availability of potentially high yielding varieties and hybrids of these crops. The seriousness of the problem needs to be examined in view of the fact that these crops currently make up 80 per cent of the total cereal production in the developing countries, where additional 399.5 million metric tons of these grains will have to be produced per year by 2000 A.D. The low efficiency of fertilizer nitrogen in these crops and regions is due to severe nitrogen losses caused by heavy rains in short spells of time and poor fertilizer and crop management practices.

Table 9.11. Recovery of fertilizer N by cereals

Crop	Source of N	Rate (kg N/ha)	Recovery (%)
Rice	Urea	50	34.3
	Sodium nitrate	40–120	19.4
	Ammonium sulphate	40–120	39.6
	Urea	50–150	28.3
	Urea	100	28.0
	Neem cake coated urea	100	47.4
	Sulphur coated urea	100	37.7
	Urea + N-Serve	100	41.7
Wheat	Ammonium sulphate	60	45.7
	Ammonium sulphate	120	52.4
	Sodium nitrate	60	45.1
	Ammonium nitrate	120	46.3
	Urea	120	35.3–46.0
	Urea	150	48.4
Maize	urea	60–180	63.1–40.3
	Urea	100–200	32.0–18.4
Sorghum	Urea	120	58.5
	Urea	50–100	32.0–25.0
	Urea	50–200	56.0–40.0
Pearl millet	Urea	40–200	31.5–19.9

Source: Prasad (1979)

From the viewpoint of crop production three processes of nitrogen loss appear to be of practical significance, namely: 1. volatilization as ammonia; 2. leaching as nitrates and 3. denitrification. These processes have attracted the attention of research workers all over the world (Bremner and Blackmer, 1978; Freney *et al.*, 1981).

Volatilization losses as ammonia can be serious when urea is surface applied in heavier doses on alkaline soils (Mikkelsen *et al.*, 1978; Vlek and Craswell, 1979). Leaching losses as nitrates particularly in rice fields could be as high as 70 per cent (Pande and Adak, 1971; Prakasa Rao and Prasad, 1980). Denitrification losses occur in rice fields after applied urea or ammonium nitrogen has nitrified. Experiments with ^{15}N have shown that as much as 14.4 per cent of applied nitrogen could be lost through denitrification from rice fields (Mahapatra *et al.*, 1980).

Fertilizer efficiency is generally calculated in terms of applied plant nutrient removed by a crop and is therefore largely influenced by the yields obtained. Also for all practical purposes the parameter kg yield (economic produce) per kg nutrient is used to denote fertilizer use efficiency in crop production. Thus all the factors that could effect the yield of economic produce would also affect the fertilizer use efficiency. These factors can be broadly classified into four groups, namely, soil factors, crop factors, environmental factors and agronomic management. Some of the factors and agronomic management practices are enumerated below:

Soil factors

1. Initial fertility
2. Texture and structure
3. pH
4. Topography
5. Drainage
6. Salinity/alkalinity

Crop factors

1. Choice of crop
2. Choice of variety – its yield potential
3. Resistance of the variety to diseases and pests
4. Resistance of the crop and its variety to soil problems such as water logging, salinity, alkalinity etc.

Environmental factors

1. Rainfall and its distribution
2. Sunny days and sunshine hours
3. Occurrence and duration of frost
4. Incidence of diseases and pests

Agronomic management practices

1. Timely sowing
2. Adequate plant population
3. Water management
4. Weed control
5. Balanced fertilization

6. Timely fertilizer application
7. Method of fertilizer application
8. Plant protection/s

A brief discussion on the effect of high yielding varieties, some of the agronomic management practices and slow-release nitrogen fertilizers and nitrification inhibitors on fertilizer nitrogen efficiency follows.

High yielding varieties

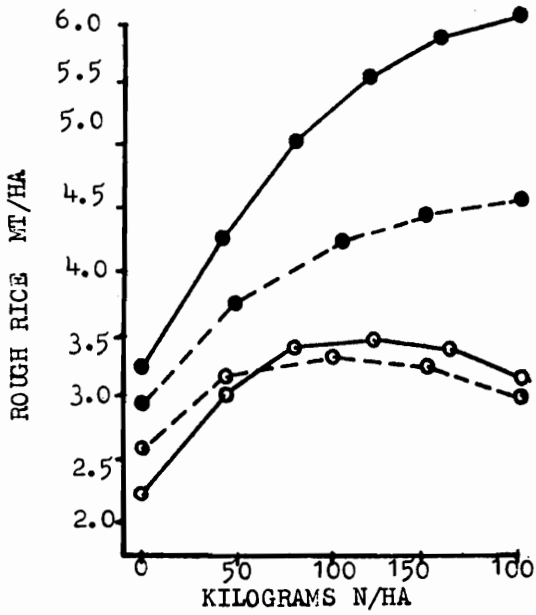
The discovery of the dwarfing gene 'Dee-Gee-Woo-Gen' in Taiwan and the introduction of Taichung Native-1 and IR-8 varieties of dwarf rice from the International Rice Research Institute, Philippines as well as the introduction of dwarf wheat varieties Sonora 64 and Lerma Rojo from CYMMIT, Mexico demonstrated for the first time in India and several other countries their high yield potential and high nitrogen responsiveness. The relative response fo dwarf and tall rice and wheat varieties to nitrogen are shown in Figures 9.3 & 9.4. Obviously the efficiency of fertilizer nitrogen is considerably improved by using the high yielding varieties. As a matter of fact, in India, the area under high yielding varieties of cereals, total cereal production in the country and fertilizer nitrogen consumption are highly correlated (Table 9.12).

Similarly a number of high yielding and nitrogen responsive hybrids/composites of corn, sorghum and millets have become available and these must replace low yielding local cultivars for improving the efficiency of fertilizer nitrogen and for augmenting the much needed food production particularly in the developing countries.

Timely sowing

Timely sowing of a crop is one of the most important agronomic factor affecting crop yields and therefore the fertilizer nitrogen efficiency. Brar and Chela (1969) observed that each day delay in sowing of wheat grown from the middle of November to the middle of December resulted in a reduction of 50 kg grain per hectare per day. At Pantnagar, India, the mean grain yield of seven dwarf wheat varieties decreased from 5.25 MT/ha for 20 November sowing to 2.70 MT/ha for 20 December sowing; amounting to a reduction of 85 kg grain/ha/day (Sharma and Lal, 1978). In this experiment a uniform dose of 140 kg N/ha was applied. While sowing on 20 November gave 37.5 kg grain per kg N, sowing on 20 December gave only 19.3 kg N per kg N. Thus using the same variety and fertilizer dose the efficiency of nitrogen was reduced by about 50% by delayed sowing. Indeed, it must be stated that the recommended date of sowing is the second and third week of November.

Figure 9.3. Response of tall and high yielding dwarf indica rices to nitrogen



_____ Amber dwarfs, _____. ____ Red dwarfs , --------Tall.

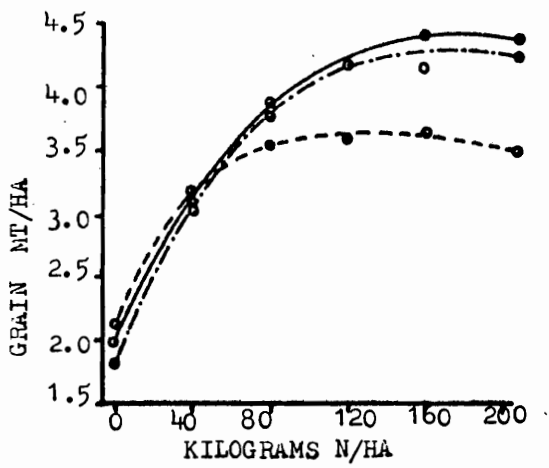


Figure 9.4. Response of tall and high yielding dwarf wheats to nitrogen

Table 9.12. Area under high yielding varieties, total cereal production and fertilizer nitrogen consumption in India

Crop-year (July–June)	Area under cereals (million ha)		Total cereal production (metric tons)	Fertilizer N consumption (million metric tons)
	Total	High yielding varieties		
1965–66	92.4	-	62.4	0.57
1967–68	98.8	6.0	82.9	1.03
1969–70	101.5	11.4	87.8	1.35
1974–75	99.0	27.3	89.8	1.76
1979–80	102.9	38.4	101.1	3.50
1983–84	106.9	52.4	138.9	5.02

Source: FAI (1984)

Plant population

Lack of an adequate plant population has been one barrier that has limited the grain yield in cereals, pulses and other crops more than any other single factor. The causes of inadequate plant population are many including low seed rates, lack of soil moisture, attack by insect pests, incidence of diseases and deficiencies of plant nutrients. The relationship between plant population and response of maize and sorghum to nitrogen fertilization clearly showed that for improving the efficiency of fertilizer nitrogen adequate plant population is a must (Srivastava and Singh, 1980).

Weed control

Herbicides are not yet used in the developing countries and removal of weeds from the crop fields takes the major share of the human drudgery on the farm. Weeds compete with crop plants for nutrients, moisture and light. They may remove as much as 22–78 kg N/ha (Mani, 1975). Weeds thus doubly affect the fertilizer nitrogen efficiency, firstly by affecting the yield of crop and secondly by feeding on applied nitrogen. Data from an experiment on corn (Table 9.13) clearly show that nitrogen efficiency was increased from 16.4 kg grain/kg N in unweeded plots to 23.2 to 29.4 kg grain/kg N when weeds were controlled manually or with the help of herbicides.

Water management

Efficient water management is important for higher crop yields and fertilizer nitrogen efficiency. Under irrigated agriculture there is always a tendency to use excess water which not only results in waste of water, a costly and precious crop production input but also could be responsible for leaching and even run-off losses of fertilizer nitrogen.

Table 9.13. Effect of weed control on nitrogen efficiency in corn

Treatment	Grain yield	Kg grain/kg plant nutrient
No weeding	32.8	16.4
Manual weeding	46.4	23.2
Chemical weed control	58.9	29.4
LSD (P:0.05)	3.7	

Source: Mani (1975)

On the other hand under dryland agriculture conditions efficiency of applied nitrogen depends on the success or failure of the crop. In many situations there is no midway; the crop is either successful or completely fails. Crop planning on the basis of stored moisture is therefore utmost important in dryland agriculture. Studies on black soils in India have shown that on shallow soils having about 100 mm stored soil moisture sorghum and maize could be grown, while on medium depth soils having about 150 mm stored soil moisture crops such as soybean and pigeon pea could be successful. On deeper soils storing about 200 mm soil moisture two crops such as maize and safflower or sorghum and gram or soybean and gram could be grown. In dryland areas one life saving irrigation can significantly increase crop yields and fertilizer nitrogen efficiency (Table 9.14).

Table 9.14. Effect of life-saving irrigation on nitrogen use efficiency measured by increase in yield of sorghum

Fertilizer treatment	Depth of irrigation		
(kgN/ha)	None	5cm	10cm
	Red Soil		
58	2300	2360	2300
120	3220	4210	5440
Response to 62 kg N/ha	920	1850	3140
	(14.8)*	(29.8)	(50.6)
	Black Soil		
58	2850	3420	
120	4990	5760	
Response to 62 kg N/ha	2140	2340	
	(34.5)	(37.7)	

Source: Kanwar (1977)
*Figures in parentheses give kg grain/kg N

Timely nitrogen application

Timely nitrogen application to crops is one factor that can considerably affect the efficiency of applied nitrogen. Experiments on timing of N application have therefore been conducted with most crops all over the world.

In wheat 23 experiments conducted at 10 locations in India showed that application of N in two splits (half at sowing and the rest half at first irrigation 3–4 weeks after sowing) was best (Bhardwaj, 1978). More splits are recommended on light textured soils particularly when high rates of N (160–200 kg N/ha) are applied (Sandhu and Gill, 1972). On medium heavy soils, however, all N may be applied at sowing.

In rice, Tanaka *et al.* (1959) observed that split application of nitrogen, one dose at transplanting and another at panicle initiation, is best for high grain yields and nitrogen efficiency. Studies in India (Prasad *et al.*, 1970) and in the Philippines (De Datta *et al.*, 1974) also suggest two to three split applications for higher efficiency. However, more split applications are needed for long duration varieties and for lighter soils.

Two to three split applications of nitrogen are also recommended for higher fertilizer nitrogen efficiency in corn, sorghum and millets.

Method of nitrogen application

Method of nitrogen application has received considerable attention in rice, where Shioiri (1941) explained the mechanism of loss of surface applied ammonium in rice soil and recommended the deep placement of fertilizers. ^{15}N-labelled fertilizers on a montmorillonitic clay showed that nitrogen utilization and grain yield were highest when the fertilizer was placed at a 10 cm depth (De Datta *et al.*, 1968). Prasad *et al.* (1970) showed that deep placement of nitrogen and use of pellets was superior to broadcast application and both these methods gave higher nitrogen efficiency (Table 9.15). Application of nitrogen as mudballs has also received considerable attention. In an experiment at IRRI (De Datta, 1978), 60 kg N/ha applied as mudballs and those obtained with 100 kg N/ha applied conventionally were comparable.

Table 9.15. Relative efficiency of different methods of nitrogen application in rice

Method of application	Grain yield		Recovery of N%	
	1967	1968	1967	1968
Broadcast	6.8	5.8	30	28
Placement in soil (6–8 cm by hand plow)	7.4	6.2	41	37
Pellets near plants	7.5	6.0	51	40
LSD (P=0.05)	0.3	0.1	6	7

Source: Prasad *et al.* (1970)

Not much advantage of placement of nitrogen has been reported in the case of upland crops except under dryland agriculture conditions or when anhydrous ammonia is used as a nitrogen carrier. Under dryland agriculture conditions for crops grown on stored moisture drilling or placement of fertilizer 10–15 cm below soil surface gives better crop stand, higher crop yields and higher fertilizer efficiency (Venkateswarlu, 1979). Placement of anhydrous ammonia in adequately moistened soil is a must for preventing volatilization losses as ammonia. (McDowell & Smith, 1958).

Slow-release fertilizers and nitrification inhibitors

Slow-release nitrogen fertilizers and nitrification inhibitors offer alternatives to the practices of split application and placement of N for increasing the efficiency of nitrogen applied to summer cereals. These materials have drawn attention of agronomists, soil scientists and fertilizer technologists the world over. The subject has been extensively reviewed by Prasad *et al.* (1971).

Slow-release nitrogen fertilizers

These materials can be broadly classified into two groups: (1) Chemical compounds with inherently slow rates of dissolution, for example, urea-form, oxamide isobutylidene diurea (IBDU); (2) Urea and other nitrogen fertilizers provided with a coating which acts as a moisture barrier, such as sulphur, shellac and neem cake coated urea.

Isobutylidene Diurea (IBDU)

IBDU as a source of N has been the subject of considerable study in Japan, where it was developed (Hamamoto, 1966). It has also been evaluated in the Philippines (IRRI, 1973), U.S.A. (Hughes, 1976) and India (Rajale and Prasad, 1975). Release of N from IBDU depends upon pH and particle size. Hughes (1976) reported that N release from IBDU was much more rapid in acid than in alkaline soils. He observed that 75 per cent of N from IBDU was released after 10 weeks with a particle size of 0.6–0.7 mm, 58 per cent in 21 weeks with 1.0–1.2 mm and 50 per cent in 32 weeks with 1.7–2.0 mm size particles.

Field experiments in Japan showed that IBDU gave 20 per cent more rice than ammonium sulphate applied in two split doses; the increase was 25 per cent when ammonium sulphate was also applied in a single basal dressing (Hamamoto, 1966). Results from the All India Co-ordinated Agronomic Experiments Scheme (AICAES, 1970, 1972) also showed IBDU to be superior to urea. In an experiment in India, IBDU produced 24 per cent more rice grain and a higher recovery (Rajale and Prasad, 1975).

Sulphur coated urea (SCU)

Of the slow release fertilizers SCU has been most widely tested (Davies, 1976). Due to slow release of N from SCU, ammonia volatilization losses are much less. On a fine sandy acid soil in Texas (USA), cumulative volatilization losses for 14 days on unlimed soil were 51.5, 22.5, 9 and 1.7 per cent from urea, ammonium sulphate, SCU-30 (per cent dissolution rate in 7 days) and SCU-20 (Matocha, 1976) Incorporation of lime with soil prior to N addition reduced ammonia loss more than 50 per cent

as compared to surface application, but mixing N with limed acid soil did not reduce ammonia loss. Prasad (1976) studied ammonia loss from SCU as compared to conventional N fertilizers at different moisture contents. Volatilization losses as ammonia were higher at 32°C than at 22°C and decreased as the moisture content was increased from 25 to 80 per cent water holding capacity. Losses were highest with urea and lowest with SCU.

SCU has been tested most for the rice crop. Engelstad *et al.* (1972), summarizing the results before 1972, observed that the response to SCU was generally good and superior to the response to urea in a single application and often to split applications at the same N rate. Results from 41 experiments in seven countries showed that on an average, SCU produced 6 kg more grain/kg N than urea (Table 9.16). In 24 dry-season and 60 wet-season trials conducted during 1975-77 under the International Network on Fertilizer Efficiency in Rice (INSFER) programme, SCU gave significantly higher yield than the best split application in 30 per cent of the experiments (IRRI, 1973).

Table 9.16. Average yield of rough rice as affected by sources of N

Source of N	Grain yield (q/ha)	Increase in yield due to N (q/ha)	Nitrogen fertilizer efficiency (kg rice/kg N)
Control	32	-	-
Urea	49	17	16
Sulphur coated urea	56	23	22

Source: Doll (1975)

In India field experiments under AICRIP (1969, 1970) showed that SCU gave 50 per cent more increase in yield than urea. Results from the All India Co-ordinated Agronomic Experiments Scheme (AICAES, 1972) also showed that in comparison with urea SCU gave 470 kg/ha more grain.

The advantages of SCU have been more obvious in soil with intermittent flooding and drying. Under such conditions in Peru, Sanchez *et al.* (1973) found that it was possible to produce the same yield with 40 per cent of the N rate in the form of SCU compared with urea. In Indonesia, Partohardjono and Fitts (1974) found that SCU was superior to three split applications of urea under intermittent flooding, while under constant flooding there was no difference between the two treatments.

Matocha (1976) found from pot culture experiments on corn that SCU was superior to urea, ammonium nitrate and ammonium sulphate. In a field experiment at Cook-Ville, Tennessee (USA), grain yield of corn as well as the relative efficiency of SCU was significantly more at lower level of N in two out of three years (Frye, 1977).

Neem cake coated urea (NCU)

Bains *et al.* (1971) showed that treatment of urea with an acetone extract of dried and crushed neem kernel increased the efficiency of urea as a nitrogenous fertilizer. This

Figure 9.5. Effect of neam cake coating of urea on the grain yield and nil return in rice-wheat rotation

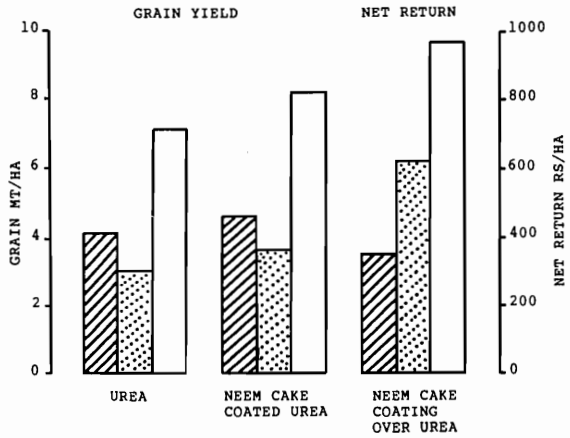


Table 9.17. Relative efficiency of USG, SCU, NCU, and urea for rice

N-Carriers	Grain (q/ha) 1977	1978	N uptake (kg/ha) 1977	1978	Recovery of applied N 1977	1978
Urea	40.2	52.1	98	103	33	39
USG	42.3	56.2	105	118	39	49
NCU	42.5	55.4	103	111	38	45
SCU	42.3	54.3	104	109	37	43
LSD (P=0.05)	2.0	2.0	5	5	NS	4

Source: Prasad and Prasad (1981)

USG – Urea super granules; NCU – Neem cake coated urea
SCU – Sulphur coated urea

treatment was superior to SCU compared well with the treatment of proven inhibitors of nitrification.

A number of field and laboratory experiments at IARI (Prasad and Prasad, 1981; Prakasa Rao and Prasad, 1980) have clearly shown the advantage of neem cake coated urea, which compared well with sulphur coated urea and urea supergranules (Table 9.17).

Nitrification Inhibitors

Since a major portion of the fertilizer N is lost from the crop fields after the nitrification of urea or ammonium N, nitrification inhibitors have been widely tested for minimizing N losses in the field. The first specific nitrification inhibitor identified was 2-chloro-6 trichloro-methyl pyridine also called N-serve (Goring, 1962). This material was searched so that nitrogen could be applied in fall for use in the spring

season, when there is rush for sale as well as the time is needed for other farm operations and sowing. A number of studies in USA and elsewhere (Hendrickson *et al.*, 1978) have shown that N-Serve effectively controls nitrification of ammonium N. Other nitrification inhibitors are AM (2-amino-4-chloro-6 methyl pyrimidine), Dicyandiamide (DCD), Thiourea, ST (2-sulphanilamide-thiazole), potassium azide, ATC (4 amino-1, 2, 4-triazole) and CL-1580 (2, 4-diamino-6-trichloromethyl- S-triazone).

The effectiveness of inhibitors in field applications is less clear. Field experiments on rice in India (Lakhdive and Prasad, 1970; Rajale and Prasad, 1975) and in Japan (IRC, 1966; Nishihara and Tsuneyoshi, 1968) showed a beneficial effect of a nitrification inhibitor, while in USA Patrick *et al.* (1968) and Turner (1977) failed to obtain any significant increase in rice yield by such treatments.

Urea supergranules

Large marble size granules of urea referred to as urea supergranules or urea briquettes are the latest nitrogen fertilizer reported to have much higher efficiency than urea. Nommik (1976) attributed the low volatilization losses of ammonia from large size urea granules to slower rates of urea hydrolysis and to the increase in the rate of downward diffusion of urea and ammonia.

Field studies in India (Prasad and Prasad, 1981) have shown USG to be a highly promising material. USG was significantly superior to urea and compared well with sulphur coated urea. In 22 per cent of the 77 trials conducted under the INSFER programme (IRRI, 1978) USG gave significantly higher yield than the best split application.

CONCLUSIONS

The available estimates on nitrogen requirement indicate that in 2000 AD about 86 million MT of nitrogen per year have to be consumed in addition to the current consumption of about 57 million MT, which means that in the coming 18 years the per hectare nitrogen consumption has to be more than doubled. This is not impossible because in India the fertilizer consumption has been more than doubled at the end of each Five Year Plan. No doubt we have to seriously consider whether we can achieve the desired level of food production without entering into the luxury of such high level nitrogen consumption per hectare as in the Netherlands, because the later could also lead to the problems of water and air pollution and nitrate toxicity.

Biological nitrogen fixation can certainly help in meeting the nitrogen needs of the world. In this regard, the following actions need to be immediately initiated in developing countries:

1. Increasing the area under grain and forage legumes.
2. Well-planned breeding programmes for developing high yielding varieties of grain legumes suitable for different agro-climatic regions are the utmost immediate necessity of the world.

3. Developing cropping systems involving legumes. Legumes fit well in multiple-relay cropping system as well as in intercropping systems.
4. Popularising the use of *Rhizobial* cultures for different species. This would necessitate developing of production oriented microbiological research centres, which can produce large amounts of required *Rhizobial* cultures for distribution to farmers. The Governments must take appropriate policy decisions so that these cultures are produced, standardized and made available to the farmers.
5. Most of the grain legumes are still grown under rainfed conditions. In many dryland areas the production can almost be doubled by just providing one life saving irrigation. Development of appropriate water harvesting techniques as well as planning of major irrigation projects would go a long way in increasing the area under grain legumes, production by them as well as associated biological nitrogen fixation.

The current thrust in biological nitrogen fixation on transferring of nitrogen fixing genes to cereals is certainly appropriate but for the period between now and 2000 AD, we have still to heavily rely on nitrogen fixation by legumes and certain other associative systems. In rice, all our efforts must be made to exploit the nitrogen fixation by blue-green algae and *Azolla-anabaena* systems.

Rice occupies about one-fourth of the area under cereals in the world and 90% of it is in Asia. The available data from a large number of experiments including those using ^{15}N suggest that hardly 50% of the applied nitrogen is utilized. Research on development of new and better fertilizers for rice is very much needed. Intensive extension efforts are also necessary to take the results of agronomic research on time and method of fertilizer application to the farmers, so that the fertilizer nitrogen applied to fields is more efficiently utilized.

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CHAPTER 10

Chemical Technology for Producing Fertilizer Nitrogen in the year 2000

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DIRECTION OF FERTILIZER NITROGEN TECHNOLOGY

DEVELOPMENTS IN THE chemical technology for producing fertilizer nitrogen will in the near future be directed towards the following objectives:

1. Optimising energy requirements for production;
2. Reducing investments through new developments in refinements of design and new materials of construction;
3. Design of large capacity single train plants for reliability of performance with high on-stream efficiency for basic production of ammonia, urea, nitric acid, ammonium nitrate, etc;
4. Technologies involving simpler process steps
5. Technologies that will permit economical production in small capacity plants suitable for small countries or certain areas of large countries;
6. More efficient technologies on use of feedstocks other than petroleum based;
7. Technologies for production of new products or new forms of existing products such as urea and ammonium nitrate;
8. Technological developments in the production of granular fertilizers to produce products of improved agronomic characteristics and, at the same time, contributing to reduced investment costs, reduced energy consumption, and reduced operating and maintenance costs;
9. More wide-spread use of liquid fertilizers, particularly in the developing countries;
10. Technologies leading to reduction/elimination of air pollution and water pollution problems.

BASIC CONCEPTS TOWARDS POSSIBLE CHANGES IN NITROGEN APPLICATION AND AGRICULTURE WHICH MIGHT INFLUENCE TECHNOLOGY

An appreciation of the state of agricultural development with a particular reference to fertilizer usage is of relevance in dealing with the subject of chemical technology for producing fertilizer nitrogen in the year 2000, more specifically in areas listed above as 7, 8 and 9. Adaptation to change in (1) Nitrogen Application Methods; (2) New Agricultural Technologies, based on Genetic Research; and (3) Cropping Patterns is going to receive close attention.

Until now, in 1981, the use of nitrogen chemical fertilizer is extensive in developed countries such as USA, Western Europe and Japan. In many of these countries, there is an intensive application of chemical fertilizer nitrogen to maximise the per unit yield of agricultural crops. There are several factors which might influence the reorientation of the use of fertilizer nitrogen by the year 2000 in the developed countries.

Fertilizer use efficiency

First, currently, the uptake by plants of applied nitrogen is only about 40-50% under most optimum conditions. Research has begun to unfold the knowledge of pathways of losses of nitrogen through volatilisation, denitrification and leaching. As a result, continuous efforts are being made to improve the forms of nitrogen fertilizers and application techniques to improve efficiency. These efforts are likely to lead to a significant improvement in the efficiency of uptake of nitrogen; in consequence, much less fertilizers might be required but in a different form than what is being currently used to obtain the same level of yields. All these aspects are discussed in greater details in Chapter 8.

Micro-nutrients

A better understanding of crop needs would lead to the development and usage of agro-chemicals such as growth promoters and growth regulators. An understanding of soil nutrients deficiency will help to eliminate the limiting factors for growth by use of micro-nutrients.

Slow release materials

New product designs must be such which will dissolve into the soil at a slow rate thereby providing a nitrogen release rate which will be commensurate with the rate of uptake of this nutrient by the plant at different stages of plant growth. New pro-

ducts might also have to be combined with suitable inhibitors which will retard such chemical reactions that contribute to loss of either applied chemical nitrogen or biologically fixed nitrogen and thereby making such nitrogen not available for plant growth.

Influence on cropping patterns

National policies in many countries are being directed towards improving agriculture to attain national self-sufficiency in foodgrains requirement. In consequence, the impact on exports of foodgrains from the developed countries of North America might be such as to re-orient agricultural cropping patterns and in consequence the need for different types of fertilizer materials.

TECHNOLOGY OF CHEMICAL NITROGEN FIXATION; PROSPECTS AND RETROSPECTS

Energy use

The world as a whole consumes only 3.5% (Hignett and Mudahar, 1981) of the total commercial energy in the entire agricultural production sector. But within this relatively small percentage of commercial energy used for agriculture, 45% is used in the form of fertilizers. Of this, 82% is required for manufacturing, packaging, transportation and application of nitrogen fertilizers. However among all these processes manufacturing alone uses 90% of this energy. Nitrogen accounts for 94% of the energy used in manufacturing all fertilizers consumed in the developing countries. The importance of energy economy in the manufacture of nitrogen fertilizers is thus evident.

Nitrogen fixation routes

Research in the early part of this century has led to three possible ways of nitrogen fixation: (1) Combination of oxygen and nitrogen in the air to produce nitrogen oxides, and thereafter converting into nitrates; (2) Combination of nitrogen with hydrogen to produce ammonia; (3) Use of chemical compounds which, under certain conditions, could fix nitrogen in the air.

All the three routes, viz. the Electric Arc/Thermal Process, the Synthetic Ammonia Process and the Cyanamide Process (fixing nitrogen on Calcium Carbide produced electro-thermally) have led to commercial processes with varying success.

Although theoretically standard free energy changes in direct oxidation (6.2 GJ/t

N) route are significantly lower than for ammonia synthesis (24.36 GJ/t N) the best possible energy efficiency obtained in fixing nitrogen has been exceedingly a poor 1% in direct oxidation by electric arc against ammonia synthesis (Honti, 1981). Development efforts in the USA have been partially successful in obtaining higher efficiency in the direct oxidation process thermally by heating the reactants to high temperatures (2000°C) to obtain a reasonable rate of reaction in the forward direction and very quickly chilling the reactants and the product to less than 600°C to freeze the equilibrium to obtain relatively small yields of nitric oxide. This inevitably results in large energy losses. Thus, the energy requirement per tonne of nitrogen is high giving a yield efficiency of 8% against 75% for ammonia synthesis that is technically possible and 60% that has been attained in industry (Honti, 1981). The energy efficiency in the cyanamide route has also been exceedingly poor. As such, ammonia synthesis has become almost exclusively the technology for production of nitrogen fertilizers. The industrial output of fixed nitrogen in 1980, which amounted to 80 million tonnes of nitrogen (N) per year is based almost exclusively on ammonia synthesis and about 71% of which is based on methane steam reforming using natural gas as the feedstock. It is likely to remain so in the year 2000. Any technological development in the area of nitrogen fixation will, therefore, be oriented towards improvement in ammonia technology.

Feedstocks for ammonia synthesis

The methane reforming process with *Natural gas* as the feedstock operating at 30-35 ata pressure has been the most energy efficient that has, until now, been available in industrial practice.

Naphtha steam reforming is somewhat less efficient (by 5-10%) than methane reforming; the higher carbon : hydrogen ratio in naphtha results in greater steam consumption and heavier carbon dioxide separation duties, since more CO_2 has to be separated than in the methane reforming process. Besides, the reforming catalyst requires feedstock desulphurisation which is even much more elaborate in the naphtha route than in methane route.

Heavier hydrocarbons or *coal* can be used by partial oxidation process routes. In both cases, energy efficiency is significantly lower. 50% more calories are required to produce the same quantity of ammonia from coal than from natural gas. Further, coal based plants involve considerably more plant and machinery contributing to higher investment costs.

Despite higher energy requirements and investment costs, there has been significant interest, in recent years, in the use of *coal for ammonia synthesis*. Technologically, it is unlikely to compete with methane steam reforming. Other considerations of economic relevance, namely national self-sufficiency, balance of payments problems, strategic considerations, national development efforts, might lead to the choice of coal as feedstock for ammonia synthesis in some parts of the world. However, renewed activities in exploration – both on-shore and off-shore – are resulting in success in new finds of natural gas and crude petroleum in many parts of the world.

These efforts are bound to continue at an accelerated pace. Natural gas available from such efforts will naturally be the preferred feedstock for producing fertilizer nitrogen than from other sources. This will be the trend towards 2000.

Technological improvements in ammonia synthesis

The stage of development in ammonia synthesis between 1950 and 1970 has brought down the energy consumption from 67 GJ/t N to 44 GJ/t N (Honti, 1981). The latter figure has been achieved with natural gas as feedstock and by using centrifugal compressor design with a high efficiency energy cycle. The ammonia plants have been designed for production of up to 1500 tonnes of ammonia per day in one train.

Technologies towards reduction in energy requirements in a further improvement of the methane steam reforming process, beyond 1980, will lead to the development of an economically viable and commercially reliable process in the near future. The following process steps are particularly significant.

Reduction in the stack gas temperature. It is possible to reduce the stack temperature to around 100°C (particularly if sulphur-free natural gas is used) but the combustion air pre-heater surface will have to be determined to evolve an economical design between savings in energy against extra investments.

Increase in steam pressure and superheat. Properties of materials are constantly being improved; this might lead to adopting pressures in the range of 135-140 ata and superheat the steam to the turbine inlet to 530°C.

Carbon dioxide removal. Low level heat is being used for regeneration in the removal of the carbon dioxide step. The use of such low level heat elsewhere and the adoption of a physical absorption system will provide significant energy savings.

Compressors and drives. Reduction in energy requirement will be attained by improved designs of compressors and drives. Significant potential savings are expected in this area.

Heat recovery in synthesis loop. There are possibilities to increase heat recovery in the synthesis loop, but increased investment costs might limit the energy savings in this area.

Absorption refrigeration. The low level heat that is available by using the physical absorption system could be used for an absorption refrigeration unit. The residual ammonia in the gas leaving the refrigeration unit will have to be lowered by mixing the make up with the recycled gas before the convertor to reduce the inlet ammonia. This could be achieved by super methanation by removing the final traces of oxygenated compounds, namely carbon monoxide, carbon dioxide and water vapour by absorption, thereby resulting in a gas of a very high purity to maintain high catalyst activity.

Purge gas recovery. The purge gas recovery by one of the processes e.g. pressure swing absorption, diffusion, selectoxo or relatively more developed cryogenic sys-

tems will improve the energy efficiency of traditional ammonia synthesis systems.

The purification train could be altered to deliver stoichiometric ratio of nitrogen and hydrogen in synthesis gas to the synthesis loop, thereby eliminating the purge and at the same time, significantly reducing reformer furnace duty. The Braun Purifier Process removes practically all the methane remaining at the primary reformer outlet by secondary reforming, using excess air; excess of nitrogen resulting in the process gas is thereafter removed as a liquid containing all other residual impurities like methane and argon and leaving stoichiometric quantities of hydrogen and nitrogen.

New designs and new materials. The improvements in design and materials are towards reducing or making more uniform the stresses that materials are exposed to under operating conditions. This knowledge might contribute to either reduction in the amount of material required or increased life. Changes in design might simplify manufacturing or reduce costs or improve quality. Improving heat transfer might permit higher operating temperatures and thus extend the working range of materials.

Properties of materials are constantly being improved to make them stronger, less susceptible to corrosion, more heat resistant, flame-resistant, etc. Engineering to incorporate these improvements in the designs will lead to reduction in sizes and weight, increased performance and improved reliability in the process.

Optimum designs. Feasibility of adoption of the options outlined above is dependent on a balance between many variables. Optimum design will be obtained which will optimise the energy requirements (rather than efforts towards minimising it to the absolute level), and adopting process simplification with new catalysts and simplified equipment through new designs and new materials of construction. Researchers are active to develop a reliable ammonia synthesis catalyst to operate at relatively low pressures. With such developments, it might become possible to eliminate the compressor and operate the ammonia synthesis loop near the methane reforming pressure.

Braun purifier technology. Methane steam reforming using natural gas as the feedstock will continue to dominate the chemical nitrogen fixation industry until 2000 and possibly beyond. Improvements in the process involved and equipment on the lines indicated above will continue to take place. The most advanced technology as of 1980 is the technology based on the Braun Purifier Process for ammonia production based on natural gas as the feedstock. Large capacity commercial plants of 1500 tonnes per day were built towards the end of seventies using this technology, which have demonstrated process and equipment performance with a high on-stream availability and yielding at least 20% reduced energy consumption than the plants generally designed and built between the period 1972-1978.

The Braun Purifier Process not only provides lower energy consumption but each of the process steps has milder duties which results in high on-stream efficiency. Duties on the primary reformer are significantly less vigorous as high residual methane in the exit gas is the basis of design which is practically totally reduced to low levels by use of excess air and after shift conversion and CO_2 removal, the cryogenic purifier step yields a gas of exceptionally high purity with a stoichiometric hydrogen

to nitrogen ratio for ammonia synthesis. The ammonia synthesis loop, therefore, could be operated with exceedingly low inerts and at low pressure about 125 ata. The equipment design in the ammonia synthesis section is also simple where two separate reactors are used to obtain the desired rate of reaction and attainment of equilibrium and for effective heat exchange. The compression duty is also simpler in view of the low final discharge pressure from the synthesis compressor. The heat recovery at high level heat and high pressure steam with necessary superheat yields high energy recovery and efficiency in the turbine drives.

World leaders in ammonia technology in Europe have, therefore, adopted this process in the early Eighties. No doubt, there will be further improvement in this process more particularly in the areas of use of physical absorption process for CO^2 removal, use of absorption refrigeration and recovery of heat as steam at higher pressures and temperatures.

There is an added advantage in this process route since adequate carbon dioxide becomes available for conversion of all the ammonia into urea despite the low carbon hydrogen ratio in the feedstock methane.

Large capacity ammonia plants. As of 1980–81, single train large capacity ammonia plants have been built generally for 1350 tonnes per day with some exceptions of 1500 tonnes per day. One or two have even higher capacity. Japanese and Soviet technologists are studying design features for a 3000 tonnes per day single train ammonia plant. In the near future and towards 2000, plants of this capacity will be built. Catalysts with higher activity and longer shelf life will become available leading to simplified process steps and the use of simple and more reliable equipment. New materials will be used in equipment design and both compressors and compressor drives would have significantly improved efficiencies and reliability.

Instrumentation for process control and "on-line" computer control for process variables to maintain optimum conditions at all times will be increasingly used. There will be more wide-spread use of temperature monitoring and recording facilities to permit control for maintenance of optimum process efficiency and continued high catalyst activity. Monitoring and recording of vibration and speed of high speed machineries will be more and more used to provide continual checks to maintain high efficiency standards during operation.

Small capacity plants. There are limited but economically significant areas in the world where the use of small capacity plants might fit in with the economy and, therefore, might become the desirable optimum choice. Research and development efforts for the design of efficient small capacity plants will become active.

Coal as feedstock. Current technologies for the use of coal as feedstock for ammonia production are not efficient. Active researches and development efforts are currently on for more efficient coal gasification processes. Coal and lignite will have specific economic significance in certain areas and improved technologies for their use will become important.

Urea

During the last decade, there has been a significant technological development in the production of urea. Large capacity urea plants with capacities of 1800 tonnes per day in single train, have been successfully developed with improved ammonia conversion efficiencies and lower energy consumption. New materials of construction and new designs and equipment and machinery have contributed to reliability in operation and high on-stream performance. Montedison of Italy, who were the first to introduce urea as a fertilizer on a commercial scale in the early 1950s, report a new development in 1981 (Pagani *et al.*, 1980), that has been proved in a demonstration unit which reduces the energy requirements by about 50% of what has been best attainable until 1980 in commercial installations. The Isobaric Double Recycle (IDR) process of Montedison uses high ammonia to carbon dioxide ratio in the reactor to obtain higher carbon dioxide conversion efficiency. This permits residual carbamates being recycled to be substantially reduced and in consequence, energy consumption in decomposition of the carbamate gets reduced. The recycle of excess ammonia is effected in two stages in the same pressure as used in the reactor itself.

Future development towards 2000 will be in the areas of new equipment designs and new materials of construction for larger single train urea plants and lower energy consumption. The prilling tower process for production of urea prills, which is being universally adopted, is likely to become obsolete and will be replaced by fluidisation granulation techniques (Bruynseels, 1981), which has already come into commercial usage.

The prilling process has several drawbacks, namely the investment is high; the physical properties of the product such as crushing strength, the prill size, the size distribution, etc. are not satisfactory; and the large volume of air required contributes to air pollution with urea particles. The feed urea solution has to be concentrated to 99% and above, which requires additional equipment and energy and presents technical problems. The fluidized granulation technology contributes to reduction in investment, reduction in energy consumption and reduction in operating and maintenance costs (Bruynseels 1981). Only 95% solution is used for fluidization, thereby reducing the energy requirements for concentration and investment for concentration unit. The air pollution problems with urea particulate matters is practically eliminated since the volume of air used is significantly lower than used in the prilling process.

Ammonium nitrate

There are two distinct developments in the ammonium nitrate technology. The first relates to reduction in energy consumption by pressure neutralization with provision for heat recovery as steam in the system. The second area of improvement is on improving the product quality. A recent process uses a coating in a special coating drum in three stages (van Hijfte, 1981). In the first stage, Alkyl amine (Octadecylamine) melt is separated on the ammonium nitrate pellets and the pellets

are provided over the entire surface with a uniform and continuous coating; the fertilizer pellets are air cooled in the second stage to 27–28°C to solidify the coat and in the third stage, a coating of thin mineral lubricating oil is applied with a high parafinic hydrocarbon content. The product so produced has significantly low moisture absorption, lower caking tendencies and lower dusting tendencies. This coat has been successfully used for pure ammonium nitrate and also for calcium ammonium nitrate production.

Addition of inhibitors

Agronomically, urea prills are unsatisfactory as loss of nitrogen through ammonia volatilization, when urea is surface applied, is significantly high. Urea when surface applied and incorporated to flooded soils, contributes to nitrogen loss, following hydrolysis of urea into volatile ammonia and takes place through enzymatic catalysis by urease. It is, therefore, necessary to inhibit the hydrolysis reaction by inhibiting the urease activity. Small addition of urease inhibitor to urea during final product formulation, has been suggested and is currently the subject of intensive research. The effect of incorporation of 1% phenylphosphorodiamidate (PPD) into urea granules has shown promise (Vlek *et al.*, 1980).

Modified urea forms

Deep placement of urea and more particularly urea super granules, i.e. large granules of urea 10–12 mm dia have indicated possibilities of obtaining higher nitrogen efficiencies from the applied nitrogen through urea. Considerable work has also been going on, on product formulation with suitable coatings to reduce rate of release of nitrogen or by developing special products. Development of nitrogen products to yield slow release properties is currently a field of active research.

In the years to come, granular urea suitably coated or modified urea, such as urea super granules with coatings and additions of inhibitors, might become increasingly available to provide a vastly superior urea product than is currently available. Such a product will contribute to higher nitrogen use efficiency and thereby require significantly lower application of nitrogen than what would otherwise be needed with present day prilled urea. There is going to be significant improvement in product urea in the years to come and present day urea prills that are being universally applied will become obsolete. The urea super granules with deep placement provides a zone of concentrated urea solution where denitrifying bacteria cannot enter and this nitrogen is left at the root zone for uptake by the plants.

Melamine as fertilizer

Melamine is a product containing 62% nitrogen and is produced from urea. Cur-

rently, it is not used as a fertilizer but is used for production of a range of plastics. Melamine production technology will be developed in future to produce large tonnages of melamine that might be used directly as fertilizers. Melamine will provide the necessary slow release characteristics with high nitrogen content and with proper placement, might become a suitable source of slow release material yielding high nitrogen recovery efficiency for plant growth.

Liquid fertilizers

Nitrogenous fertilizers in liquid forms either as clear liquids or in suspensions, are in use in the developed countries, more particularly in North America. In future, the trend in the developing countries will be to use more and more liquid fertilizers. Liquid fertilizers will require less energy and reduced investment to produce. This can be pumped through pipelines to the market areas from the production centres and there could be a significant savings in energy, materials for packing and transportation. This trend of use of liquid fertilizers will continue to develop more particularly in the developing regions of the world such as India.

Ammonia in international trade

Anhydrous ammonia has become a product in international trade. Large quantities of ammonia are currently being moved from one continent to another and this practice has become wide-spread more particularly during the last five years. This trend is going to continue more and more. Thus, ammonia production might take place in areas where natural gas is in abundance and there are no competing demands for it. Such ammonia could be transported to areas where it could be used for conversion into fertilizer products. Such products could be improved ammonium nitrate with superior handling properties and reduced fire hazards, or could be used as liquid nitrogenous fertilizers. The energy requirements for ocean transportation of ammonia per unit of nitrogen will be significantly lower than for solid fertilizers.

Air and water pollution

Future trends will show more and more emphasis on development of technologies to eliminate air and water pollution problems. The fertilizer industry is a source of pollution which destroys the environment and affects air quality and marine life through pollutants in effluents discharged in water streams. There will be more emphasis towards cleaning of air and zero discharge of liquid effluents or practically pollutant free harmless effluents.

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CHAPTER 11

Role of Phosphorus in Global Food Production

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INTRODUCTION

BY THE YEAR 2015, the world's population will be 8 billion (Borlaug, 1983). The present food production growth rates are insufficient to keep pace with growth demands especially in the poor, populous countries (Asian Development Bank, 1977; International Food Policy Research Institute, 1977; Wortman, 1980). The problem will become worse as more and more countries convert food crops into power alcohol.

SOLUTIONS TO THE FOOD DEFICIT PROBLEMS

The following solutions have been suggested: (a) Increasing production in the surplus areas, mostly developed countries; (b) Introducing large-scale mechanized crop production in the developing countries; (c) Extending the area of cultivated land; (d) Intensifying food production. The most promising method of increasing food supply in the near future is increasing the yield per ha per year on currently cultivated land in the developing countries. However, a simple strategy for enhancing the world's food supply in the immediate future is increasing the rational use of fertilizers in the developing countries (Swaminathan, 1980).

CROP RESPONSES TO FERTILIZERS

Crops respond dramatically to fertilizers on most soils. The use of nearly 100 million tons of nutrients annually proves it.

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Table 11.1. Contribution of fertilizer to grain yield increases

Region	Period	Increase in yield attributable to fertilizers (%)
World	1959–79	50
United States	1940–55	33–55
Developing countries	1948/52–1972/73	48

Adapted from IFDC/UNIDO, 1979.

Table 11.2. Recent contributions of fertilizers to crop output

Country/Region	Contribution of fertilizer (%)	Source
Japan	50	Engibous (1975)
United States	37	Free *et al.* (1976)
Developing countries	15	Pinstrup-Anderson (1976)
Thailand	10	Engibous (1975)
South and Southeast Asia	9	Herdt and Barker (1975)

Estimates of the contribution of fertilizers to agricultural production are in tables 11.1 and 11.2. Recent contributions are least for South and Southeast Asia. So is their fertilizer consumption. The per capita consumption in 1974 was 6.7 kg for developing countries and 58 kg for developed countries (IFDC/UNIDO, 1979). The corresponding per ha rates were 83 and 322 kg. Low fertilizer consumption is one major reason for the food deficits in many developing countries. Because developing countries are in the steeply ascending part of the fertilizer response curve, substantial yield increases may be possible if more fertilizer is used. To meet world food needs, the use of NPK fertilizers must increase four or five times in the next 20 years (Russell and Cooke, 1983).

According to Herdt and Barker (1975) the average response to fertilizer applied to modern varieties of rice by farmers in Asia is 10–15 kg grain per kg fertilizers. IFDC/UNIDO (1979) assumes a ratio of 10:1 for developing market economies.

Kemmler (1979) showed a linear relationship between rice yields and fertilizer used in 10 Asian countries (Table 11.3).

The results of 250,000 fertilizer trials in 40 countries revealed that average highest response was 67% and the average highest value/cost ratio was 4.8. The use of fertilizers on tropical crops is economic (Richards, 1979).

The increase in world fertilizer consumption from 14 million tons nutrients in 1950 to 92 million tons in 1976 (IFDC/UNIDO,1979) is a good indicator of the role of fer-

tilizers in feeding an exploding world population. Nitrogen accounted for 48%, phosphorus for 28.5%, potassium for 23.5% of the fertilizers consumed in 1977/78 (FAO, 1980).

Table 11.3. Rice yields and amount of fertilizer applied in 10 Asian countries

NPK (kg/ha)	Rice yield (t/ha)
0	1.5
100	3.0
200	4.5
300	6.0

Source: Kemmler, 1979.

CROP RESPONSES TO PHOSPHORUS FERTILIZERS

Phosphorus materials have been used for centuries to increase crop yields. The manurial value of bones was recognized by Chinese and Welsh farmers about 2000 years ago.

In the 19th century the use of bones as a fertilizer was widespread. The demand was so great that battle fields and graveyards of Europe were scoured for bones. By 1830 bone meal, bone dust, and bone charcoal were widely used as fertilizer. Peruvian guano then entered the European market. It was followed by superphosphate and its variants. In 1978 the world produced 125 million tons of rock phosphate (FAO, 1980), 85% of which was used as fertilizers.

Crop response to phosphate fertilizers depends on soil, weather, crop, variety, form and amount of phosphate, method of application, and the presence or absence of other fertilizers. Some of these factors will be discussed in later sections. This section illustrates the magnitude of the yield increases that have been obtained on a variety of soils and crops in diverse climates and the potential of phosphate fertilization in increasing food production.

In India, responses ranged from 4 to 16 kg grain per kg P_2O_5 at 60 kg P_2O_5/ha. Of the cereals, wetland rice gave the highest response (Roy and Kanwar, 1979). It ranged from 0.3 to 3.2 t/ha on phosphorus-deficient soils in a total of 291 tests in 1968-70. In 930 trials conducted in India during 1974–1977, irrigated, modern rice varieties showed responses of 11.3 to 28.6 kg grain per kg P_2O_5 on phosphorus-deficient soils, in the presence of nitrogen fertilizer. In similar trials with wheat, the response was 10.4 to 22.6 kg grain per kg P_2O_5. With sorghum and millet, adding 60 kg P_2O_5/ha doubled the yield response of 171 kg grain per ha obtained with 60 kg N/ha. In hundreds of similar trials with pulses and groundnuts, the nitrogen plus phosphorus treat-

Table 11.4 Phosphate fertilizer needs of some Andean countries of tropical Latin America

Country	Soil	Crop	Recommended rate (kg P_2O_5/ha)
Colombia	Andepts	Wheat, corn	100
		Potatoes	300
	Oxisols	Cowpeas, rice, corn, Pastures	50–120
	Alfisols, Entisols Inceptisols	Rice	40
		Cassava	90
Ecuador	Andepts	Potatoes	240
		Corn	180
		Wheat	150
Peru	Ultisols	Corn	50
Brazil	Oxisols	Corn	160
Colombia	Andepts	Beans	400
Colombia	Oxisols	*Brachiaria decumbens*	50–100

Source: Leon and Fenster, 1979

ment significantly outyielded the nitrogen treatment. Because more than 46% of the districts of India are phosphorus deficient, and 51% are moderately deficient (Ghosh and Hasan, 1979), the potential of phosphate fertilizers for increasing food production in India is high.

Leon and Fenster (1979) noted striking responses to phosphate fertilizer on the acid, phosphorus-deficient Ultisols and Oxisols of Colombia and Brazil and Andepts of the Andean countries. Van Raij (1979) observed similar responses on the acid soils of Brazil. The magnitude of the phosphate fertilizer rates needed for economic responses (Table 11.4) dramatizes the phosphorus hunger of crops on the soils of the Andean countries of tropical Latin America.

Kang and Juo (1979) reported that, although phosphorus is important in food production in humid West Africa, the dominant soil orders – Alfisols, Ultisols, and Entisols – have low phosphorus requirements. But in the savannas of Nigeria phosphorus is one of the two major nutrients limiting crop yields (Mokwunye, 1979). In 92% of trials in three savanna zones, sorghum responded postively to phosphate fertilizer. The optimum economic rate for sorghum was 25 kg P_2O_5/ha for the old varieties compared with 100 kg P_2O_5/ha for the modern semi-dwarfs.

In West Asia and North Africa where the soils are eroded and poor in organic carbon and available phosphorus, applications of phosphate increased yields in most of the region's crops (Saxena, 1979).

Wetland rice responds well to fertilizer phosphate. In 54 forms-and-levels-of-phosphorus experiments, conducted with adequate nitrogen and potassium, in nine tropical countries, in 1977-79, responses to 40 kg P_2O_5/ha as superphosphate ranged from 0 to 5.5 t/ha (International Rice Research Institute, 1980). The mean response was 0.9 t/ha or 25.7%.

Cassava has a high phosphorus requirement. The fresh weight of tubers increased from 6 t/ha with no phosphate fertilizer to over 20 t/ha at 200 kg P_2O_5/ha (Cock and Howeler, 1977).

Although tropical legumes have a lower phosphorus requirement than temperate legumes, phosphorus deficiency is the most important factor limiting legume production in the tropics (Kretschmer, 1978; Russell, 1978). All important tropical legumes respond positively to phosphorus but there are varietal differences in responsiveness. Only superphosphate is usually needed for high productivity of legume-based tropical pastures (Hutton, 1970). Application of phosphate benefitted establishment, nodulation, persistence, and productivity of legumes (Kezya, 1977). Because some tropical legumes can fix as much as 440 kg N/ha/year and yield up to 900 kg N/ha/year (Whitney, 1975), the role of phosphorus in maintaining and improving the nitrogen fertility of soils needs exploitation in view of the impending high cost of nitrogen fertilizers.

Examples of crop responses to phosphorus fertilizer in the United States are in Table 11.5. Nelson (1980) reported the following yield responses in kg to 1 kg P: peanuts (20), rice (25), and sugar (20). Ozanne (1980) has discussed mathematical models relating crop response to applied phosphorus.

Table 11.5. Crop responses to phosphorus fertilizers in the United States

	Treatment (lb/acre)			Yield	Unit
	N	P_2O_5	K_2O		
Wheat	0	0	0	34	bu/ac
	80	0	0	51	
	80	80	0	64	
Corn	0	0	0	73	bu/ac
	0	27	0	122	
	0	82	0	148	
Alfalfa	0	0	0	1.2	t/ha
	0	45	0	3.9	
	0	90	0	5.2	

Adapted from Ellington, 1978.

Table 11.6. Synergistic effect of nitrogen and phosphorus on corn yield

N (lb/ac)	P_2O_5 (lb/ac)	Yield (bu/ac)
0	0	41
0	160	58
200	0	50
200	160	123

Source: Wagner, 1979.

Crop responses to phosphorus can be increased by supplying other nutrients, such as nitrogen and potassium, in adequate amounts, or correcting toxicities by liming (Tables 11.6, 11.7, 11.8).

Increasing the use of phosphate fertilizers is a simple and reliable method of enhancing food production, especially in the tropical countries, where soils are phosphorus-deficient, and use of phosphorus fertilizers is inadequate (Dabin, 1980).

Table 11.7. Synergistic effect of phosphorus and potassium on corn yield

P_2O_5 (lb/ac)	K_2O (lb/ac)	Yield (bu/ac)
0	0	42
120	0	45
0	120	117
120	120	142

Source: Wagner, 1979.

Table 11.8. Effects of phosphate and lime on soybean yield on an Oxisol

P_2O_5 (kg/ha)	Soybean yield (t/ha)	
	No lime	6.6 t lime/ha
0	1.2	2.0
300	1.8	2.4

Source: van Raij, 1979.

PLANT PHOSPHORUS

The previous section described the effectiveness of phosphorus fertilizers in increasing food production. To appreciate this role of phosphorus and exploit it, a review of the tremendous importance of phosphorus in plant metabolism and the effects of phosphorus on plant performance is necessary.

Every living cell needs phosphorus for growth, respiration, and reproduction because phosphorus is a constituent of several compounds vital to these processes (Metzler, 1977). Some of them are listed below.

Deoxyribonucleic acid (DNA) carries the genetic code or the basic blueprint for life processes. Ribonucleic acid (RNA) regulates protein synthesis. Adenosine triphosphate (ATP) collects and stores energy from photosynthesis and respiration,

provides energy for synthesis or protein, starch, and sucrose, as well as for nitrogen fixation and accumulation of ions in cells against concentration gradients. Nicotinamide-adenine dinucleotide (NAD^+) and nicotinamide-adenine dinucleotide phosphate ($NADP^+$) and their reduced forms NADH and NADPH are electron transfer agents in photosynthesis, fermentation, and respiration. Sugar phosphates participate in the synthesis of sugars from carbon dioxide in photosynthesis and in the breakdown of sugars during respiration. Phospholipids are components of cell membranes which regulate entry and exit of solutes. And phytin acts as a phosphorus reserve for the emerging seedling.

Phosphorus is involved in so many vital processes in plants that a deficiency of phosphorus severely retards shoot and root growth, depresses tillering in cereals, delays maturity, and drastically reduces the yield of grain, fruits, roots, and tubers, grasses, and legumes. Irreversible damage is done long before the foliar symptoms – purplish, reddish, or orange discolorations of the older leaves – appear. Mild deficiency may go undetected until final yield is measured and the plants analyzed. Because phosphorus deficiency damage is irreversible, it must be avoided from the very beginning of plant growth.

A phosphorus content of less than 0.1% in the dry matter of plants indicates phosphorus deficiency (Mengel and Kirkby, 1978). An adequate supply of phosphorus from the beginning ensures seedling vigor, healthy plants with tolerance for physical and biotic environmental stresses, high yields, and quality produce.

The water stress tolerance of plants with a good supply of phosphorus has been attributed to a good root system, reduced transpiration, shading, increased water use efficiency, and maintenance of the flow of phosphorus from the soil into the roots in spite of retarded diffusion and absorption, induced by moisture stress (Nelson, 1978). Ignazi (1977) stresses "the need for a policy of planned phosphorus enrichment of soils to make crops less sensitive to climatic uncertainty."

Champagnol (1979) reported that phosphate applications produced positive growth responses on saline soils in 34 of 37 crops studied and speculated on the role of phospholipids and phosphorylated compounds in salt tolerance.

Additional phosphate in the soil helps plants to resist adverse effects of low temperature on the concentration of available phosphate, uptake of nutrients, and growth (Wallingford, 1978).

Griffith (1978) cited experiments indicating that phosphate fertilizer reduced disease incidence in corn, soybean, wheat, barley, and sugar cane.

Crop quality is measured by color, appearance, taste, chemical composition, and handling and storage properties. According to Munson (1978), phosphate fertilizers increased the phosphorus content of forage and grain, the sugar content of sugar beets, the oil content of corn, the specific gravity of potatoes, the plumpness of small grains, and the percentage of good soybeans.

PHOSPHORUS AS A SOURCE OF NITROGEN

Nitrogen is the key to crop productivity. The world consumption of 48 million tons of fertilizer nitrogen in 1977/78 is proof of its value in modern crop production. But nitrogen fertilizers will be more expensive as oil and natural gas get dearer, and the main sufferers will be the developing countries without oil or gas resources. The time may come when biologically fixed nitrogen will be the main source of nitrogen for crops.

Biological nitrogen fixation is the conversion by living organisms of nitrogen gas into forms that plants can use. It is brought about mainly by free-living heterotrophic bacteria, blue-green algae, symbiotic bacteria, and bacteria living in association with roots or leaves. The free-living bacteria include photosynthetic bacteria and aerobic, anaerobic, and facultatively anaerobic bacteria. About 125 strains of blue-green algae fix nitrogen (Stewart *et al.*, 1979). Symbiotic organisms include *Rhizobia* that live in association with legumes and *Azolla-Anabaena* associations consisting of a water fern and nitrogen-fixing blue-green algae.

All those organisms have one common biochemical feature: they use adenosine triphosphate – derived from photophosphorylation or oxidative phosphorylation – to reduce nitrogen to ammonia with the help of nitrogenase (Arnon and Yoch, 1974; Mulder and Brotonegoro, 1974; Stewart, 1974). Thus phosphorus is intimately involved in biological nitrogen fixation. A good phosphorus supply should increase nitrogen fixation. There is ample evidence for that.

According to Mulder and Brotonegoro (1974) *Azotobacter chroococcum*, an aerobic free-living nitrogen-fixing bacterium, needs and contains large amounts of phosphorus. Dobereiner (1974) reported that phosphorus fertilizer increased tenfold the number of *Azotobacter* in the rhizosphere of tropical grasses. Ruinen (1974) listed available phosphorus as one requirement for the growth and performance of phyllosphere nitrogen-fixing microbes.

Although nitrogen-fixing blue-green algae can extract phosphorus from waters very low in phosphorus (Stewart, 1974) they benefit by increased availability of phosphorus. Blue-green algae accumulate phosphorus and store it as polyphosphates for use in times of deficiency.

Matsuguchi (1979) found that the growth of nitrogen-fixing blue-green algae and nonsulfur, purple photosynthetic bacteria was better in a soil with a higher pH and more available phosphorus than in acid soils. He observed, also, that phosphorus and lime improved the growth of heterotrophic and phototrophic nitrogen fixers and increased their acetylene reduction activity on a strongly acid soil, but a single application of either did not. Stewart *et al.*, (1979) reported that phosphate increased rice yield in the presence of nitrogen-fixing cyanobacteria and surmised that phosphate application may reduce the need for fertilizer nitrogen. In wetland rice fields phosphate fertilizer enhances algal growth and nitrogen fixation as measured by acetylene reduction (Roger and Reynaud, 1979).

Azolla has been used in China for centuries to manure rice fields. Chu (1979) reported that it is grown on 1.3 million ha in China. Azolla grows best in soils with a high content of available phosphorus. In phosphorus-deficient soils, phosphate fer-

tilizer improves the growth of azolla. Applying 13.5 kg P_2O_5/ha increased azolla yield 164%. Chu concluded that fertilizing azolla with phosphate is a method of obtaining a large amount of nitrogen with a little phosphate fertilizer. According to Tuan and Thuyet (1979), superphosphate is the best fertilizer for azolla. In India, phosphate fertilizer enhanced the growth of azolla and nitrogen fixation (Singh, 1979). Applying 15 kg P_2O_5/ha increased the fresh weight of azolla from 2.2 t/ha to 14.5 t/ha and the amount of nitrogen fixed from 5 to 33 kg N/ha. Over 4 kg N was fixed per kg of P applied with a phosphorus utilization efficiency of 37% (International Rice Research Institute, 1979).

Phosphorus is necessary for photosynthesis, nitrogen fixation, root growth, and nodulation in legumes. In the tropics, phosphorus deficiency and soil acidity are the major limiting factors for legume growth and nitrogen fixation (Whitney, 1975). Application of phosphate benefits establishment, persistence, nodulation, and yield of legumes (Whitney, 1975). Tropical legumes fix up to 440 kg N/ha/year. According to Hutton (1970) maintenance of a phosphate-responsive legume is the cheapest way to provide nitrogen for pasture and grazing animals in the tropics. Kerya (1977) reported that applying superphosphate at the rate of 39 kg P/ha/year increased the total nitrogen content of a pasture by 222 kg/ha/year.

Table 11.9 shows the potential some tropical plants and organisms have for increasing soil nitrogen content.

Because of its beneficial effect on all nitrogen-fixing organisms, phosphorus has tremendous potential as an indirect source of nitrogen.

Table 11.9. Nitrogen-fixing potential of some tropical organisms

	Nitrogen fixed kg/ha/yr	
Azolla filiculoides	500	Becking (1979)
Blue-green algae	30[1]	Roger and Kulasoorziya (1980)
Free-living savanna bacteria	40	Odu (1977)
Azotobacter paspali	93	Odu (1977)
Tropical grasses	100	Greenland (1977)
Tropical forage legumes	440	Whitney (1975)

[1]Per crop of wetland rice

SOIL PHOSPHORUS

Practically the only natural source of phosphorus for plants is the soil. And on the content, nature, and reactions of phosphorus compounds in soils depend crop performance and response to phosphorus fertilizers.

Table 11.10. Total phosphorus content of some soils

Description	P (%)	Source
Australian soils	0.02–.05	Black (1968)
Indian soils	0.01–.5	Mukkerjee et al. (1979)
U.S. soils	0.0 –.17	Parker (1953)
Peat soils (temperate)	0.04–.18	Brady (1974)
Peat soils (tropical)	0.05–.09	Suhardjo & Widjaja–Adhi (1976)
Paddy soils (tropical Asia)	0.00–.24	Kawaguchi & Kyuma (1977)
Paddy soils (Japan)	0.03–.38	Kawaguchi & Kyuma (1977)

The total phosphorus content of soils varies widely (Table 11.10). Oxisols, Ultisols, Alfisols, and many Vertisols contain less than 0.02% total phosphorus (Sanchez, 1976). Of the total phosphorus in mineral soils, 20–80% is in the organic form (Stevenson, 1982). In highly weathered soils up to 80% of the total phosphorus may be organic (Sanchez, 1976). Erosion of such soils will thus lead to a heavy loss of soil phosphorus.

Although the total phosphorus content of a soil is not a good measure of plant-available phosphorus, it has some practical significance in crop production. Kawaguchi and Kyuma (1977) regarded paddy soils containing less than 0.017% P as phosphorus deficient, and attributed phosphorus deficiency in wetland rice in South-east Asia to a low content of total soil phosphorus. In Australia, where the soils are low in total phosphorus (Table 11.10), crop production is limited over enormous areas by phosphorus supply (Russell, 1973). But 60% of agricultural land in countries with intensive agriculture (mainly Western Europe and the U.S.A.) have reached a normal or high level of soil phosphorus through fertilization (Ainsaux, 1977). Continuous cropping of soils low in total phosphorus without phosphate fertilizer may lead to a gradual depletion of the element and decline in crop yield.

Phosphorus is present in soils almost entirely as orthophosphate. It occurs in the soil solution as $H_2PO_4^{-1}$ and HPO_4^{-2} ions and as organic substances. Solid phase phosphorus consists of: the phosphates of calcium, iron, and aluminum; phosphates absorbed on solid particles or occluded in them; and phosphorus in humus and inositol phosphates. The distribution of the inorganic forms and the fate of fertilizer phosphate is governed largely by soil pH, nature and content of clay, and the water regime.

Aluminum and iron phosphates dominate in strongly acid soils and occur as variscite ($AGPO_4.2H_2O$), strengite ($FePO_4.2H_2O$) or mixtures of the two, or as adsorption products of phosphate on iron and aluminum oxides and clays. Acid soils fix phosphates strongly because they contain exchangeable aluminum, iron and aluminum oxides, and 1:1 clays. Thus Oxisols and Ultisols fix large amounts of phosphorus. Andepts have a high phosphorus fixing capacity because of their high allophane content. Soils with high phosphorus fixing capacities need large amounts of fertilizer phosphate to increase the availability of phosphate to crops.

In neutral and alkaline soils, phosphate is present temporarily as di-, tri- and octa-calcium phosphates, and permanently as apatites. The solubility of calcium phosphates in the soil solution decreases as pH increases. Thus, water-soluble phosphate fertilizers applied to such soils will convert gradually to apatites.

Waterlogging increases the concentration of water-soluble phosphorus and available phosphorus (Ponnamperuma, 1972). Thus the phosphorus fertilizer requirement of wetland rice is less than that of dryland crops (Mitsui, 1960).

Phosphorus in soils can be divided into three fractions according to plant availability: soil-solution phosphate, phosphate that rapidly equilibrates with the soil solution (labile phosphate), and insoluble phosphates that equilibrate slowly with the other two fractions (nonlabile phosphate) (Larsen, 1967).

Water-soluble phosphate is the immediate source of phosphorus for plants, but its concentration is low, ranging from 0.0003 ppm in some phosphorus-deficient tropical soils to 3 ppm for soils well suplied with phosphorus (Russell, 1973). Most crops need about 0.3 ppm P in the soil solution for good yields. Good soil management should aim at maintaining an adequate level of phosphorus in the soil solution. As plants absorb phosphorus from the soil solution, it is replenished from the labile pool. The release of nonlabile phosphorus is too slow to meet the needs of a growing crop. Thus water-soluble phosphorus and part of the labile phosphorus constitute the plant available phosphorus in soils.

Methods used for measuring plant-available phosphorus vary with the country, soil, and crop (Kamprath and Watson, 1980). They include: extraction with water, organic acids, acidic buffer solutions, strong acids, and alkalis; isotopic dilution; determining the phosphate potential of the soil solution, and quantity/intensity relationships; electro-ultrafiltration; pot experiments; and field experiments. The methods most widely used worldwide are the Bray P_1 extraction (0.025 *N* HC1 + 0.03 *N* NH_4F) for acid and neutral soils and the Olsen extraction (0.5 *M* $NaHCO_3$ at pH 8.5) for alkaline soils. For wetland rice soils, Olsen's method gives good results, regardless of pH (Chang, 1978).

Andepts, Oxisols, Spodosols, Rendolls, sodic soils, high-pH Vertisols and some Aridosols are low in available phosphorus (Dudal, 1976)). So are acid sulfate soils (van Breemen and Pons, 1978). More than 60% of the rice soils of Thailand, Malaysia and Cambodia are phosphorus deficient (Kawaguchi and Kyuma, 1968, 1969). In India, 46% of districts are low in available phosphorus (Ghosh and Hasan, 1979) on the basis of over 8 million soil tests. Goswami (1975) observed that the black, red, coastal alluvial, and laterite soils of southern India and the red and yellow soils of Orissa and Madhya Pradesh are phosphorus deficient.

Available phosphorus values are of little use unless they are calibrated and correlated with final responses of different crops on different soils and in different climatic zones. Where such work has been done, soil tests are valuable in making phosphate fertilizer recommendations.

PHOSPHORUS NEEDS OF CROPS

The phosphorus needs of crops vary with the growth stage, species, variety, and yield target.

Young plants need more phosphorus than mature plants because phosphorus is required for cell division, cell expansion, and energy transfers associated with growth. Thus plants absorb more phosphorus per unit weight of dry matter and respond better to fertilizer phosphate early in the season than late.

Crops producing large amounts of organic matter such as sugarcane, cassava, potatoes, sugar beets, maize, and productive pastures, and also legumes need more phosphorus than barley, wheat, and rice. Tropical legumes have a lower phosphorus requirement than temperate legumes and among them *Stylosanthes spp.* have a very low phosphorus requirement (Kretschmer, 1978). Marked genotypic differences in apparent phosphorus needs exist in rice (Ponnamperuma, 1982). Sweet potatoes have a low phosphorus requirement (Plucknett, 1978).

At a yield level of about 1t/ha, phosphorus uptake by cereals and grain legumes is less than 10 kg P/ha. When yields are raised, cereals remove 14 to 35 kg P/ha (Sanchez, 1976).

As the crop yields per ha per year are increased by breeding, pest control, soil and water management, multiple cropping, and the use of nitrogen fertilizers, the demands of crops for soil phosphorus will increase. Few soils in the tropics can meet such demands without fertilizer phosphorus.

PHOSPHORUS FERTILIZERS

Although bones were used for centuries as fertilizer, the modern phosphate fertilizer industry began in the 1840s with the manufacture of superphosphate by treating phosphate rock with sulfuric acid. In some later processes, sulfuric acid was replaced by phosphoric acid or nitric acid, and an array of water-soluble phosphate fertilizers was made. Other phosphate fertilizers were obtained as by-products of the steel industry, or by calcining, fusing, or grinding phosphate rock.

Ordinary, normal, or single superphosphate (SSP) is manufactured by treating finely ground rock phosphate with sulfuric acid. It is a mixture of monocalcium phosphate and calcium sulfate, and contains 20 to 23% total P_2O_5 of which over 90% is available. Phosphate-rock grade determines the ease of manufacture and quality of the product. The world production in 1972 was estimated to be 7.9 million tons or 35% of the total P_2O_5 fertilizer production but is expected to decline because of the demand for higher analysis fertilizers (IFDC/UNIDO, 1979). Because of the simplicity of the manufacturing process and the low capital cost, SSP is popular in developing countries. It is an excellent phosphate fertilizer for all crops and a source of sulfur

for crops on sulfur-deficient soils. Its main drawback is the low phosphorus content.

Triple superphosphate (TSP) is the most concentrated straight phosphate fertilizer in the market. It is made by the action of phosphoric acid on phosphate rock. The process needs expensive and sophisticated equipment, and has a high energy demand. TSP consists almost entirely of monocalcium phosphate and contains 44 to 52% P_2O_5 almost all of which is available to plants. TSP supplies 15 to 20% of the world's phosphate fertilizer (IFDC/UNIDO, 1979). TSP is an excellent phosphate fertilizer and is suitable for transportation over long distances.

Ammonium phosphates are water-soluble fertilizers with a high plant food content. They are made by reacting ammonia with phosphoric acid alone or mixed with sulfuric acid. Monoammonium phosphate (11% N, 48% P_2O_5) and diammonium phosphate (18% N, 46% P_2O_5) are popular because of their high analysis and good physical properties (IFDC/UNIDO, 1979).

Nitrophosphates are products of the action of nitric acid on phosphate rock. Advantages of the process are that even unreactive igneous apatites dissolve in nitric acid and the nitric acid used itself has fertilizer value. The P_2O_5 content is about 15% and the water solubility is 25 to 60%. Nitrophosphates give the best results on acid soils. The world capacity for nitrophosphate production, which was 3.5 million tons P_2O_5 in 1975, is expected to increase to 4.5 million tons in 1985 (IFDC/TVA, 1979). A partially acidulated phosphate rock fertilizer which requires 70% less H_3PO_4 than for TSP was shown to be as efficient as TSP (Garbouchev, 1981). Heat-treated phosphate fertilizers include basic slag, Rhenania phosphate, and fused calcium magnesium phosphate.

Basic slag is a by-product of the steel industry. It contains 10 to 20% P_2O_5. Its fertilizer value depends on the P_2O_5 content, citric solubility, and fineness of grinding. Basic slag is good for acid soils. World production of basic slag, which is currently about 0.5 million t/year, is decreasing (IFDC/UNIDO, 1979).

Rhenania phosphate is made by calcining phosphate rock with sodium carbonate and silica. The product contains 28 to 30% P_2O_5 and has a high citrate solubility. It is a good source of phosphorus for acid soils and for crops that benefit by silica application. It has given good results in acid tropical soils.

Fused calcium magnesium phosphate (CMP) is made by fusing a mixture of phosphate rock and magnesium silicate in an electric furnace, quenching, and grinding the product to a fine powder. CMP contains 20% P_2O_5 with a citric acid solubility exceeding 90%. About 500,000 tons of the fertilizer are manufactured annually in Japan. CMP is better than superphosphate on acid soils.

Ground rock phosphates are the cheapest source of fertilizer phosphate. Their manufacture from phosphate rock is capital-saving, simple, and inexpensive. Besides, it is energy saving: its mining, beneficiation, and grinding uses only one sixth of the energy required for TSP (Stangel, 1976). World consumption in 1976 was 1.2 million tons P_2O_5, about 5% of phosphate fertilizer consumption (IFDC/UNIDO, 1979). The P_2O_5 content varies from 25 to 39% and the citric solubility from 14 to 65%. But because rock phosphates vary widely in their fertilizer value, they are not popular in the intensive farming systems of temperate agriculture (Russell, 1973).

Because ground rock phosphates are inexpensive, are easy to manufacture, are moderately high in P_2O_5 content, and are effective on the phosphorus-deficient acid soils of the humid tropics, increasing the use of ground rock phosphate may be a simple method of enhancing food production in tropical countries.

PRODUCTION AND CONSUMPTION OF PHOSPHATE FERTILIZERS

World production of phosphate fertilizer in 1981/82 was 32 million tons P_2O_5 and consumption, 31 million tons. The distribution among the three major regions are in Table 11.11. Both production and consumption were least and the deficits highest in the developing market economies. The low consumption per ha in developing countries (Table 11.12) indicate the vast potential for phosphate fertilizer use in these regions.

Table 11.11. Phosphate fertilizer production and consumption in 1981/82 by region

Region	Millions of tons P_2O_5	
	Production	Consumption
Developed market economies	15.2	12.7
Developing market economies	4.8	6.1
Centrally planned economies	11.9	12.1
World	31.9	30.9

Adapted from Food and Agriculture Organization of the United Nations, 1983.

Table 11.12. Phosphate fertilizer consumption per ha of arable land and perennial crops in different regions, 1977

Region	Consumption/ha (kg P_2O_5)
Africa	4.3
Asia	9.2
Europe	59.1
North and Central America	22.2
Oceania	24.0
South America	14.3
USSR	17.5
World	17.8

Adapted from Sheldrich and Stier, 1979.

World phosphate fertilizer production capacity was estimated as 41 million tons P_2O_5 in 1978/79, 49 million tons in 1982/83, and nearly 90 million tons in 2000/01 (Table 11.13). Projected growth rates are in Table 11.14 and the projected demands in Table 11.15.

The figures show that, although for the world as a whole capacity will exceed demand during the next two decades, the developing countries will experience deficits and will have to continue importing phosphate fertilizers till 2000. The increase in imports in this decade will occur in spite of increased production capacity.

Because more than half the world's people live in Asia, where the population growth rate is high and food production is inadequate to meet the demands of population growth, and severe food shortages in the 1990s are forecast, phosphate supply and demand in Asia are of special interest.

Table 11.13. Forecast of phosphate fertilizer production capacity

Region	Millions of tons P_20_5		
	1978/79	1982/83	2000/01
Developed countries	33.0	35.7	62.1
Developing countries	8.4	13.4	27.8
World	41.4	49.1	89.9

Source: United Nations Industrial Development Organization (UNIDO), 1978.

Table 11.14. Fertilizer capacity growth rate

Region	1978/1982	1982/2000
Developed countries	1.98	3.13
Developing countries	12.33	4.12
World	4.34	3.42

Source: UNIDO, 1978

Table 11.15. Projected phosphate fertilizer demand

	Millions of tons P_20_5			
	1979	*1983*	*1988*	*2001*
Developed countries	22.1	27.2	30.7	48.3
Developing countries	7.4	10.3	14.5	27.9
World	29.5	37.5	45.2	76.2

Source: IFDC/UNIDO, 1979.

Asia lacks the capacity to meet its phosphate fertilizer needs. That is due to inadequate resources of phosphate rock, scarcity of sulfur, and insufficient manufacturing capacity. Most of Asia's plants are small units producing less than 200 tons P_2O_5 per day. New plants being installed will have higher capacities. That will bring down the cost of phosphate fertilizer according to the National Fertilizer Development Center (NFDC) (1975). In 1973 Asia imported 626,000 tons P_2O_5 (NFDC, 1975).

Even with increased production capacity, Asia faces a deficit of 350,000 tons (NFDC, 1975). The forecasts for four regions (Table 11.16) indicate that, in spite of increased production, the phosphate fertilizer deficit is increasing in all four Asian regions except the Northeast (Japan, South Korea, Taiwan). The forecast for the Peoples' Republic of China is a supply-demand equilibrium in 1980 at 1.8 million tons.

Table 11.16. Forecast of phosphate fertilizer supply and demand in four Asian regions

Year	Thousands of tons P_2O_5							
	Middle[1/]		Southeast[2/]		Asean[3/]		Northeast[4/]	
	Demand	Supply	Demand	Supply	Demand	Supply	Demand	Supply
1974	795	349	51	0	196	45	950	1005
1975	882	423	56	0	218	45	969	1022
1976	972	506	60	0	241	52	988	1045
1977	988	667	64	0	264	59	1005	1129
1978	1164	708	69	0	291	70	1021	1198
1979	1265	685	73	0	318	70	1035	1282
1980	1369	820	78	0	347	70	1047	1405

1/ Middle: Afganistan, Pakistan, India, Nepal, Bangladesh, Sri Lanka.
2/ Southeast: Burma, Laos, South Viet Nam, Kampuchea.
3/ Asean: Thailand, Malaysia, Indonesia, Philippines.
4/ Northeast: Japan, South Korea, Taiwan.
Adapted from National Fertilizer Development Center, 1975.

As one of the world's largest fertilizer consuming nations and as a developing country, India is of special interest in the supply-demand context.

Table 11.17 shows production, consumption, and phosphate fertilizer imports. Production lagged behind consumption during 1974–82 and caused a deficit of 343,000 tons in 1981–82. Imports bridge the gap between production and consumption.

The fertilizer consumption trends in India in recent years (Fertilizer Association of India, 1979a) illustrate the influence of the factors that affect fertilizer consumption in developing countries. The sharp increase in fertilizer consumption in 1966–67 over the previous year and its continuation till 1973 reflected the impact of the new fertilizer-responsive wheat and rice varieties. The average-compound growth rate per year for the 7-year period since the introduction of the high yielding varieties was 22.6%. World shortages and high prices in 1973–74 caused a drop in growth rate to 1.6%. The period 1974–76 saw a sharp differential decrease in phosphate consump-

tion due to high prices. Because that led to imbalanced fertilization, the government reduced the price of SSP. During the period 1976–79, a combination of good weather, low prices, and increased use of the high yielding varieties, improved irrigation facilities, and a vigorous extension programme brought about a dramatic increase in fertilizer consumption. But because all the sulfur and 67% of the phosphate rock needed for the manufacture of phosphate fertilizer is imported, India's phosphate fertilizer consumption depends largely on external forces.

Table 11.17. Indian production, consumption, and imports of phosphate fertilizers

	Thousands of tons P_2O_5		
Year	Production	Consumption	Imports
1974–75	331	471	286
1975–76	320	467	361
1976–77	478	635	23
1977–78	670	867	164
1978–79	776	1102	244
1979–80	763	1151	237
1980–81	842	1214	452
1981–82	950	1322	343

Adapted from Fertilizer News, July 1982

WORLD RESOURCES OF PHOSPHATE ROCK

The three key ingredients of phosphate fertilizer manufacture are phosphate rock, sulfur, and energy. The future of phosphate fertilizers depends on the availability of those ingredients in sufficient amounts and at reasonable prices.

The only source of phosphorus for the manufacture of phosphate fertilizer is phosphate rock. Projected production in 2000 is 300 million tons (Hignett *et al.*, 1977).

Commercial phosphate rock is prepared by mining, beneficiating, and grinding naturally occurring phosphate deposits. The suitability of phosphate rock as raw material for fertilizer manufacture depends on the following factors:

1. origin
2. chemical composition of the phosphate
3. nature and content of accessory materials
4. P_2O_5 content
5. size of the deposit
6. location

Igneous and metamorphic phosphates are hard and coarsely crystalline. They require finer grinding and longer reaction time than sedimentary phosphates which

are usually soft and are microcrystalline.

The primary phosphorus source of most commercial phosphate rocks is fluorapatite. Pure fluorapatite has the formula $Ca_{10}F_2(PO_4)_6$. Fluorapatite in phosphate rock varies widely in composition. Some phosphate is invariably replaced by carbonate and some fluoride by hydroxyl. The greater the substitution of carbonate for phosphate and of hydroxyl for fluorine, the greater the reactivity of the phosphate rock.

Carbonates of calcium and magnesium increase sulfuric acid consumption. Iron and aluminum oxides reduce the grade of superphosphate. Chloride increases corrosion of equipment. Organic matter causes foaming. Tolerance limits appropriate for each manufacturing process have been set up for those impurities.

Although the P_2O_5 content of the ore is important, ores containing less than 10% P_2O_5 are exploited where beneficiation is easy. The deposit needs to be large enough to last 15 to 20 years. Smaller deposits can be used if the manufacturing process is suitable. World resources are estimated as 144,000 billion tons of phosphate rock of 30% P_2O_5 grade. Their distribution is shown in Table 11.18.

Table 11.18. World phosphate reserves

Region	Reserves (billions of tons)
Africa	67.2
Asia	17.3
Europe (including USSR)	7.5
Middle East	4.9
North America	36.8
Oceania	2.1
South and Central America	8.5
World	144.3

Adapted from Hignett *et al.*, 1977.

Although known world reserves are adequate for 400 years (Hignett *et al.*, 1977), South and Southeast Asia and Europe lack sufficient reserves. In these regions exploration is necessary to identify even small deposits. World production figures of phosphate rock in 1978 are in Table 11.19. Regions such as Europe, where phosphate fertilizer demand is high and South America and Asia where the need is high, did not produce enough phosphate rock. The largest exporters are Africa and North America. The main importing regions are Europe and South America.

Although world phosphate rock reserves are adequate for many centuries, phosphate rock has been in short supply in the world market. Consequently prices have risen. Phosphate rock delivered in Asian ports is estimated to cost $80 to $100 per ton (NFDC, 1975).

Most phosphate fertilizers are made by the acid process, which requires sulfur. And most Asian countries depend on imported sulfur. Canadian sulfur prices rose from $44 a ton in January 1979 to $100 a ton in October 1979 (FAO,1980).

The high cost of phosphate rock, sulfur, and energy will raise the price of phos-

Table 11.19. Phosphate rock production, 1978

Region	Production (million of tons)
Africa	32.4
Asia	11.9
Oceania	4.1
South America	1.2
USA	50.0
USSR	24.8
World	124.4

Source: FAO, 1980.

phate fertilizers. To ease the burden, which will be heaviest in Asian developing countries, strategies need to be devised to conserve and recycle natural sources of phosphorus and increase the efficiency of phosphate fertilizers.

Conserving and recycling phosphorus

Phosphorus is essential for life, and no element can take its place. Unlike nitrogen, it is nonrenewable. So every effort must be made to conserve and utilize efficiently soil and fertilizer phosphorus. Phosphorus is lost from the soil system by erosion, leaching, and crop removal. In nature, or under subsistence agriculture, those losses are minimal. Intensification of agriculture, urbanization, and population growth have increased those losses. The phosphates removed from the land surface accumulate as river and ocean sediments, assisted by plants and animals. Thousands of years later, those sediments may rise above sea level and serve as sources of phosphorus. But people living in the next few millenia will not be the beneficiaries of that phosphorus cycle in nature.

Because up to 80% of top-soil phosphorus is in soil organic matter, erosion constitutes a serious loss of phosphorus from cultivated soils. Goswami and Sarkar (1974) have reviewed the data on nutrient losses from soils. The United States loses 5 lb P/acre/year, or 60% of the phosphate applied as fertilizer. The annual loss in India is over 91 million ha of erodible soils is 3.8 million tons of P. The main factors determining phosphorus loss by erosion are land form, erodibility, cropping system, and time and method of phosphate application. Use of silt as manure, as is done in China (FAO, 1977), returns to the soil part of the phosphorus removed by erosion.

Because erosion is a serious problem in the humid tropics and it is likely to become more severe as intensified crop production expands, Greenland and Lal (1977) have stressed the need for research and action to save our soils.

Losses of phosphorus from normal soils by leaching is less than 2 kg P/ha/year because both native phosphorus compounds and those formed by interaction of phosphate fertilizers with soil are insoluble in water. But in waterlogged soils, sand soils, and peat soils, phosphate is mobile and liable to loss from the system by leaching.

Crop removal probably is the most important source of phosphorus loss from soils in intensive agriculture systems. Table 11.20 lists phosphorus removed by some crops. The amount depends on the crop and its yield. Bananas remove the least and cassava the most. In cereals, leaving the straw in the field will return about 25% of the phosphorus taken up by the crop, thus helping to reduce the drain on soil phosphorus. In India, agricultural crops removed 2.1 million tons of P_2O_5 in 1970. It corresponds to 2.5 times the current application as fertilizer (Roy and Kanwar, 1979).

Table 11.20. Phosphorus removed by some crops

Crops	Parts	Yield (t/ha)	P removed (kg/ha)
Wheat	Grain and straw	10.0	27
Rice	Grain and straw	16.0	37
Corn	Grain and straw	8.0	18
Potatoes	Tubers	44	14
Sweet potatoes	Roots	16.5	8
Cassava	Roots	30	40
Bananas	Bunches	10.0	2
Sugarcane	Tops	200	29

Adapted from Sanchez, 1976.

Much of the phosphorus that is removed from the land ends up as manure, night soil, urban wastes, or sewage sludge. If economic methods of reusing these materials are avilable, the heavy drain of phosphorus from the land to the ocean can be minimized while providing crops with nitrogen, phosphorus and potassium. Unfortunately, most of these materials are low in phosphorus. One method of conserving and recycling phosphorus is returning to the land as much as possible of the element removed by crops and farm animals. This practice is widely used in China where the main source of plant nutrients for rice is farm manure (International Rice Research Institute, 1978).

The anticipated increase in fertilizer prices has stimulated interest in the use of crop residues, farm manures, night soil, and urban wastes as sources of plant nutrients. Because this subject is discussed in the other sections, and because phosphorus is the least important of the major elements supplied by the above manures, this section will review briefly the merits and demerits of organic wastes as sources of phosphorus for food crops.

Table 11.21 and 11.22 show the composition of some crop residues and farm manures. The great drawback is the low phosphorus content of the materials. Unless human and animal labor is used to return crop residues and farm manures, the energy cost may exceed the value of the nutrients (Biswas, 1979). In a large country like India, the total amount of plant nutrients available from organic wastes is prodigious. According to Joshi (1974), the figures are: 2.3 million tons of N, 0.6 million tons of P_2O_5, and 1.2 million tons of N_2O, annually.

Table 11.21. Nutrient content of some crop residues

Residue	N (%)	P (%)	K (%)
Rice straw	0.44	0.06	0.88
Corn straw	0.92	0.15	0.95
Wheat straw	0.76	0.10	1.2
Sorghum straw	0.81	0.05	0.16

Computed from Sanchez, 1976.

Table 11.22. Nutrient content of some organic manures

Material	N (%)	P_2O_5 (%)	K_2O (%)
Farmyard manure	0.5–1.5	0.4–0.8	0.5–1.9
Compost (rural)	0.4–0.8	O.3–0.6	0.7–1.0
Compost (urban)	1.0–2.0	1.0	1.5
Green manures	0.5–0.7	0.1–0.2	0.6–0.8
Settled sludge (dry)	2.0–2.5	1.0–1.2	0.4–0.5
Activated sludge (dry)	5.0–6.5	3.0–3.5	0.5–0.7
Night soil	1.2–1.3	0.8–1.0	0.4–0.5
Pig manure[1/]	0.60	0.40	0.44

Source: The Fertilizer Association of India, 1979b.
[1/]FAO, 1977.

Organic wastes listed in Table 11.22 have good manurial value. Part of the nitrogen is available immediately and the rest gradually. The phosphorus in organic manures is as good as that in superphosphate. Besides, bulky organic manures increase the availability of soil phosphorus. The potassium is immediately available to plants.

The feasibility of using organic manures depend on the following criteria:

1. nutrient content
2. demand as fee or fuel
3. labor and transportation costs
4. health hazards
5. aesthetics
6. the presence of toxic substances in urban wastes

After due consideration of the above factors, the FAO (1977) recommended that organic materials should be used in large quantities to recycle nutrients and reduce the consumption of mineral fertilizers.

Kemmler (1980) has reviewed recycling in some Asian countries. In China the amounts of N, P_2O_5, and K_2O applied in organic forms are 64, 39, and 74 kg/ha, respectively. In Japan, farmers applied 3.2 tons/ha compost and 0.6 t/ha straw to their rice fields. Nutrients supplied by rural and urban composts, in India, in 1975, averaged 7 kg N/ha, 5 kg P_2O_5/ha, and 10 kg K_2O/ha. Recycling is feasible but insufficient to meet crop demands.

Efficient use of phosphorus fertilizers

The efficiency of utilization of phosphate fertilizer by crops is low, being 5 to 10% in the year of application (Russell, 1973). The fertilizer crisis of the early seventies stimulated further thinking and research on the efficient use of fertilizers and generated a large volume of literature on the subject.

The main strategies proposed for the efficient use of fertilizers include:

1. Computation of optimum fertilizer needs based on soil tests, crop, site characteristics, weather, and economic returns (Colwell, Ramamoorthy *et al.*, 1974; Kamprath and Watson, 1980; Swaminathan, 1980);
2. Research on placement, times of application, and adsorption by the soil (Barber, 1977);
3. National and international fertilizer tests to evaulate the best amount, kind, and method of application of fertilizers (Roy *et al.*, 1978; Increasing Productivity Under Tight Supplies, 1976; International Rice Research Institute, 1980);
4. Balanced fertilization (Kick, 1974; Roy and Kanwar, 1979; Kang and Juo, 1979);
5. Selecting species and breeding cultivars that are efficient users of soil and fertilizer phosphorus (Ikehashi and Ponnamperuma, 1978; Cock and Howeler, 1978; Kreschmer, Clark *et al.*, 1978; Ponnamperuma, 1982);
6. Use of fertilizer-responsive, disease and insect resistant varieties with tolerance for adverse soil and climatic conditions (International Rice Research Institute, 1975);
7. Applying lime and silica to acid soils to decrease phosphorus fixation (Sanchez, 1976);
8. Use of organic manures to increase the availability of phosphorus (FAO 1977);

In practice, phosphorus fertilizer efficiency can be increased by:

1. avoiding its use where soil tests indicate no probable economic response;
2. selecting the form of phosphate fertilizer best suited to the soil and the crop;
3. applying phosphate early and at the best point in the rotation;
4. minimizing fixation by band placement or spraying;
5. correcting soil toxicities and deficiencies of nitrogen, potassium, sulfur, and micronutrients;
6. using phosphorus efficient species and cultivars;
7. minimizing pest damage by using resistant varieties;
8. growing varieties with tolerance for adverse environmental factors;
9. applying lime, silica, and organic manures where necessary; and
10. adopting good cultural practices.

Population growth is outstripping food production in most developing countries, especially the populous countries where both food and arable land are scarce. The simplest and quickest method of minimizing the huge food deficits expected in the next decade is to use more fertilizer.

Phosphorus is a key fertilizer element because it plays a vital role in plant metabolism and nitrogen fixation. Most soils in the developing countries are deficient in phosphorus, and the inadequate use of phosphate fertilizer is one cause of their low productivity.

Phosphorus fertilizers are made by treating phosphate rock with acids or by heating it with other minerals. Of the array of phosphate fertilizers manufactured, single super phosphate is the best for developing countries because its manufacture is simple and inexpensive and needs no high technology.

Although current world production of phosphate rock is adequate and world reserves are sufficient for several centuries, most countries of Asia, South America, and Europe lack indigenous sources of phosphate rock. So it is imported at increasing cost from North America and North Africa. India, one of the world's largest consumers of fertilizers, imports 67% of her rock phosphate and all the sulfur used for the manufacture of phosphate fertilizer. There is a need for more exploration of local phosphate rock deposits and their exploitation in such countries.

Because phosphorus is a nonrenewable resource, and is indispensable for life, steps need to be taken to conserve it. The drain on the earth's phosphorus reserves can be minimized by controlling soil erosion, recycling wastes, and using phosphate fertilizers efficiently.

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CHAPTER 12
Needs and Resources of Potassium

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INTRODUCTION

POTASSIUM IS AN essential element for all living organisms because it influences several important metabolic processes. Although potassium does not form a structural part of any plant organ, it is essential for a number of enzyme systems involved in plant metabolism and translocation of photosynthates. According to Beringer (1978), K^+ is an activator or cofactor for more than 60 enzymes including starch synthetase, acetyl-CoA synthetase and nitrate reductase. In addition, the synthesis of functional polyribosomes and their binding of amino acids and the formation of peptide bonds require K^+.

The mobility of K^+ through membranes is a fundamental principle in the generation and transfer of metabolic energy, ATP. The stimulating effect of K^+ on photosynthesis, phloem-loading and phloem-transport as well as in the synthesis of high-molecular weight substances within the storage organs is dependent upon involvement of K^+ in energy metabolism of the plant.

The high mobility of K^+ through membranes explains the participation of K^+ in stomatal regulation and osmoregulation. These processes are the basis for the tolerance of plants against water stress, frost and salinity. Sinha (1978) has pointed out that drought and salinity tolerant varieties of wheat accumulate more potassium than the susceptible varieties, and sorghum varieties which accumulate large amounts of potassium are more tolerant of salinity. The length of cotton fibre is associated with accumulation of K^+ and malate in the developing fibre. The plants receiving large amounts of potassium retain more leaf area and greater potential of nitrate assimilation. Also the plants well supplied with potassium have higher stomatal resistance during water stress.

Potassium helps control of diseases by enabling plants develop leaves with strong epidermal walls and thick cuticle preventing entry of the germinating spores from the leaf surface. Potassium reduces moisture on leaf surface, necessary for spore germination by checking transpiration and restricting the accumulation of free amino acids and sugary tissues. Perrenoud (1977) has summarized the effects of potassium on

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plant health. According to him, potassium generally reduces the damage which crops suffer through pest and disease, and this includes a host of fungal diseases, insects and mites. The improvements in resistence due to potassium are of the order of 10 to 50%; These effects appear to be related to soil K status.

NEEDS OF POTASSIUM IN CROP PRODUCTION

There are two ways of looking at the crop needs of potassium, one to determine the amount of this nutrient which plants remove from the soil and the other to compute the amounts of the nutrient needed for external application in order to enable the soils to raise crops with requisite yields.

Table 12.1. Average uptake of K

	(Kg K/Tonne)			
Crop	*Grain*		*Straw*	*Reference*
Cereals				
Wheat	5.0		10.0	Rejado, P.Q., 1978
		(29.9)		National Commission on Agri. 1976.
Rice	5.0		20.0	Rejado, P.Q., 1978
		(47.2)		National Commission on Agri. 1976.
Oats	6.0		14.0	Rejado, P.Q., 1978
Rye	5.0		10.0	Rejado, P.Q., 1978
Maize	7.0		13.0	Rejado, P.Q., 1978
		(32.4)		National Commission on Agri., 1976.
Oil seeds				
Rape (2.5 tonnes/ha yield)	10		73	Trocme, S. (1976–77)
Soya (3.5 tonnes/ha yield)	12		27	Trocme, S. (1976–77)
Tuber Crops	*Aerial*		*Storage Organs*	
Potato	3.6		2.2	von Boguslawski, E. & von Gierke, K., 1961.
			3.9	Grewal & Sharma, 1978. National Commission on Agri. 1976.
		(6.8)		
Sugarbeet	3.2–4.3		0.6–0.7	von Boguslawski & Gierke, 1961.
Cassava			0.9–1.2	Obigbesan, G.O., 1977.

Yam	-	1.2–1.8	Obigbesan *et al.*, 1976.
Cocoyam	2.2–4.1	1.2–1.8	de la Pena & Plucknett, 1972.
Fruit Crops			
Grape	9.0		Subramanian & Iyengar, 1978.
Plantation Crops			
Pineapple	6.3		Subramanian & Iyengar, 1978.
Banana – Robusta	20.2		Subramanian & Iyengar, 1978.
– Poovan	33.4		Subramanian & Iyengar, 1978.
Papaya	3.3		Subramanian & Iyengar, 1978.
Tea	(22.4)		National Commission, on Agri., 1976.
Coffee	(16.7)		National Commission on Agri., 1976.
Rubber	7.2		Nelliat, E.V., 1978.
Fibre Crops			
Cotton (per bale)	(117.9)		National Commission on Agri., 1976.
Jute (per bale)	(22.4)		National Commission on Agri., 1976.
Fodder Crops(Dry matter yield)			
Panicum	18.5		Gill & Singh, 1978.
Cynodon	16.9		Gill & Singh, 1978.
Stylosanthes	22.6		Gill & Singh, 1978.
Centrosema	21.1		Gill & Singh, 1978.

The figures indicate the average removal of K by different plant parts on the basis of Kg K/tonnes of grain, tubers, leaves, lint, etc. The figures in parentheses represent the removal in the harvested plant parts above ground level.

Plants differ in their composition (Table 12.1). Crops like banana, tea and coffee remove much more potassium than cereals such as wheat, rice, oats, rye and maize. Oilseed crops – rape mustard and soybean – are intermediate. Straws of cereal and oilseed crops retain much more potassium than the grain. However, because crops differ widely in their yield per unit of land area, elemental composition of crop plants is not directly related to the total amount of the nutrients removed by them during a crop season. Estimates of K^+ removal by different crops are given in Table 12.2. Accordingly, crops like potato, sugarcane, cassava, pineapple and banana remove more potassium during a crop season than wheat, rice, cotton, tea and coffee. Nutrient removal by crops during a crop season, per se, is not a reliable index of their needs for external supplies of potassium. Duration of a crop, its rooting pattern, yield potential and conditions of growth are the factors which, besides nutrient supplying capacity of a soil, determine the actual needs for fertilizer potassium by a crop or a group of crops grown in a particular agroclimatic region. Generally, short duration crops like potato depend upon fertilizer potassium much more than long duration crops like sugarcane. Crops with a fibrous root system take up nutrients proportion-

Table 12.2. Potassium removal by crops

Crop	*Yield/Ha*	*Potassium Removal (Kg K/ha)*
Cereal		
Wheat	6.0 tons	145
Rice	6.0 tons	150
Maize	8.4 tons	190
Sorghum	2.2 tons	100
Root & Tuber Crops		
Sugar Beet	45 tons	250
Potato	40 tons	260
Cassava	40 tons	290
Oil crops		
Groundnut	2.0 tons	90
Soybeans	3.0 tons	140
Fiber		
Cotton	1.5 tons	110
Jute	20 tons	130
Forage		
Grass	12 tons hay	300
Alfalfa	9 tons hay	140

Source: Sheldrick and Stier, 1978.

ately more from the surface soil than from the lower layers. The crops with a tap root system obtain most of their potassium from lower deposits in soil. Nutrient removal by crops is pretty much a function of the magnitude of their yields. Regions of high crop yields or progressive farms within regions of low or moderate crop yields will need much more fertilizer inlcuding potassium than otherwise. Farm areas which experience stress of one kind or the other, drought, water-logging, salinity or frost, need potassium relatively more than the areas which suffer no such problem. Highly leached soils like laterites and acid soils, soils of low intrinsic productivity like red soils and loose sandy soils within other soil groups need external supplies of potassium to a larger extent than the others.

The development of fertilizer consumption in the world is a twentieth century phenomenon, although mineral fertilizers have been available for more than a century. Growth in fertilizer use has more or less paralleled the development of science and technology, the advances in medical sciences and rise in human population during this period. The last 2 or 3 decades have witnessed a truly phenomenal increase in fertilizer consumption. According to Von Peter (1979), all the developing countries, with three quarters of the world population, used in 1950 only 731,000 tonnes NPK. This was about England's consumption at that time and about what Pakistan uses today. The 1977–78 world consumption of fertilizers and potassium, is given in Table 12.3 according to broad geographical regions. It shows a profound increase of fertilizer use in developing countries. The annual rate of growth in fertilizer use in the developing and the developed countries is shown in Figure 12.1. It highlights the observation that (because of the very poor base of fertilizer usage in the developing countries), the annual fertilizer growth rate in the developing countries was 13–15%

against 5–9% per annum in the developed countries. The FAO, UNIDO, World Bank estimates (Table 12.4) forecast that annual growth of fertilizer consumption will continue to differ greatly between the developed and the developing countries.

Table 12.3. World NPK consumption (t) and NPK ratio in 1977–78

	N	P	K	N :	P :	K
West Europe	8754869	5596593	5166025	100:	64:	59
East Europe	11690459	8130331	8589038	100:	70:	73
North America	9687163	5197811	5275364	100:	53:	54
Latin America	2576294	2231533	1390468	100:	87:	54
Asia	13492889	5035587	2267138	100:	37:	17
Africa	1323077	894491	379862	100:	68:	29
World Total	47768009	28279446	23313623	100:	59:	49

Source: von Peter, 1979.

Figure 12.1. Fertilizer growth rates in developed and developing countries (1950–75)

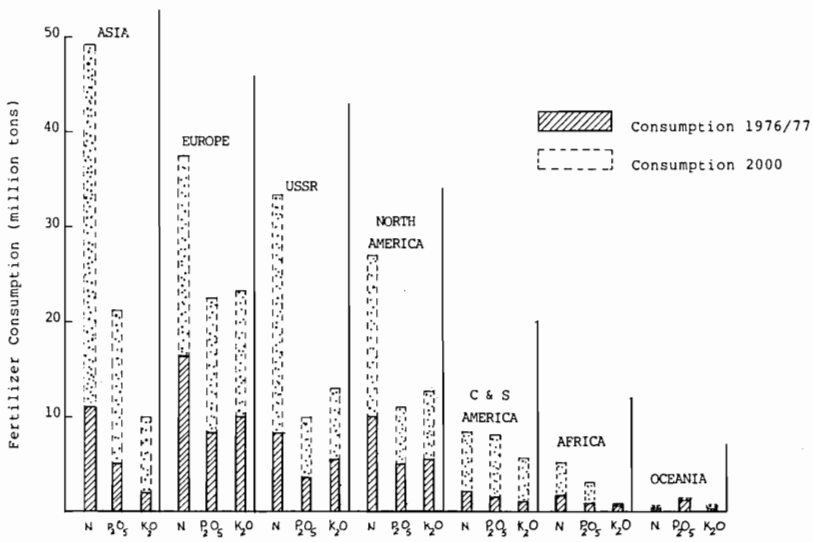
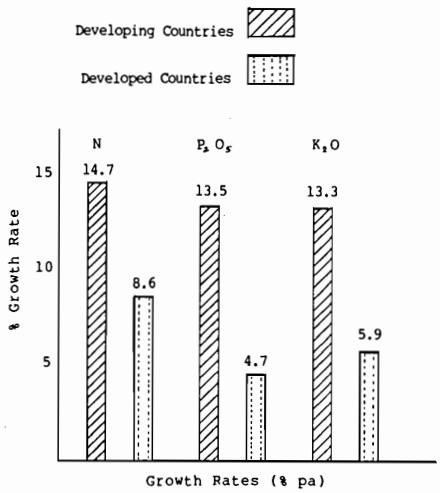


Table 12.4. Expected annual growth rates for NPK (1977/78 – 1988/89)

	%		
	N	P	K
World	6.3	5.7	6.0
Developing countries	11.2	10.8	10.6
Developed countries	4.4	1.9	3.7

Source: FAO, UNIDO, World Bank, 1979.
Working Group on fertilizers, June.

Figure 12.2. Regional fertilizer consumption 1976/77 and estimate 2000



The population in the developed countries has now more or less stabilized but population in the developing countries is still increasing at a fast rate. The pressures of growing populations will spur the developing nations to mount vigorous programmes of increasing crop production, involving an increased usage of fertilizers, including potassium (Figure 12.2 and Table 12.5). These estimates are based on the demographic projections and the following assumptions:

(a) Food, fibre (and fuel) needs will at least increase in proportion to the rise in population.
(b) 50 percent of the increase in crop yields will accrue from the increased usage of fertilizers (the balance 50 percent will come from wider adoption of other ingredients of modern agricultural technology and more efficient recycling of rural and urban wastes).

(c) Crop output: fertilizer input ratio will be around 10:1 and
(d) N:P:K ratio in the fertilizer mix will remain unchanged.

Table 12.5(a). World population estimates for 1980 & 2000 (millions)

	1980	2000	Growth rates 1980-2000 %
World	4415	6199	1.7
Developed countries	1163	1325	0.7
Developing countries	3252	4874	2.0
Africa	370	668	3.0
Asia	2519	3605	2.7
Latin America	363	601	2.5

Source: Agriculture – Towards 2000, FAO, Rome, 1981.

RESOURCES OF FERTILIZER POTASSIUM

Against this backdrop of fertilizer and potassium needs, it may be worthwhile to look into the situation of world potassium resources. Sheldrick and Stier (1978) have recently surveyed the world potash situation. The potassium salts were discovered around 1840 in Strassfurt, Germany, where rock salts were being mined. About 17 years later, after Liebig propounded his famous theory of mineral nutrition of plants, the use of potassium salts as fertilizer material began to be explored. Commercial potash production commenced in 1861 when the first factory was erected there to produce potassium chloride. By 1863, the number of plants had swelled to 14 and included other potash salts such as potassium sulphate. In 1924, Germany and France formed a cartel with a division of 70:30 of the export market. At about that time Poland (1920), Spain (1926), U.S.A. (1931), Palestine (1931) and the USSR (1932), also commenced production. Canada started developing its vast resources, in the early 1960's which led to a major change in the world potash industry. By 1970, Canada had developed its production capacity to 7.5 million tonnes K_2O per annum, which was greater than any other country. USSR is now the second largest producer with vast reserves and potential for continuing large-scale expansion. At present, about 30% of the world production is in North America, in Canada and the USA, about 65% is produced in Europe in Germany, France, Spain, Italy and the USSR. The remaining 5% of the world potash supply is obtained from scattered sources such as Israel, Chile and Congo. Production has started in the UK and Australia, and has also been reported recently in the People's Republic of China. Pertinent information on the geology of potash deposits and world potash reserves and capacity is summarized below.

Table 12.5(b) Additional amount of potassium needed in 2000 A.D. (million tonnes K_2O)

Crops	World Total	Developed Countries	Developing Countries	Africa	Asia	Latin America
Total Cereals	4.741	2.355	2.386	0.357	1.475	0.554
Wheat	0.913	0.44	0.473	0.047	0.321	0.105
Rice	0.976	0.021	0.955	0.045	0.805	0.105
Maize	0.967	0.446	0.521	0.125	0.145	0.251
Sorghum	0.224	0.043	0.181	0.044	0.075	0.062
Millet	0.105	0.002	0.103	0.051	0.049	0.003
Total Pulses	0.182	0.025	0.157	0.033	0.09	0.034
Soya Bean	0.331	0.129	0.202	0.001	0.044	0.157
Total oil crops	0.153	0.037	0.116	0.021	0.045	0.05
Potatoes	0.154	0.093	0.061	0.006	0.021	0.034
Sugarcane	0.279	0.029	0.25	0.029	0.061	0.16
Seed Cotton	0.183	0.053	0.13	0.028	0.057	0.045
Jute	0.01	-	0.01	-	0.009	0.001
Coffee	0.286	0.027	0.259	0.12	0.011	0.128
Tea	0.028	0.002	0.026	0.004	0.02	0.002
Total	6.452	2.752	3.7	0.65	1.882	1.168

Geology of potash deposits

Potassium is widely distributed in the earth's crust, where it is the seventh most abundant element. Although it is widely present in igneous rocks, yet economic recovery of potash is almost entirely limited to the soluble salts which occur in sedimentary deposits formed by the evaporation of ancient seas. The most common ores and their properties are given in Table 12.6. The production of potassium chloride from sylvinite is by far the largest and the most common potash mining operation.

Table 12.6. Common ores of potassium; their composition & occurrence

Name	Formula	% K_2O	Location
Sylvinite	$KCl + NaCl$	10–35	Canada, USA, USSR, Germany, France
Carnallite	$KCl.MgCl_2 6H_2O + NaCl$	10–16	Germany, Congo, Brazil.
Langbeinite	$K_2SO_4.2MgSO_4 + NaCl$	7-12	USA, USSR.
Kainite	$4KCl.4MgSO_4 11H_2O + NaCl$	13–18	Italy
Hartsalz	$KCl + NaCl + CaSO_4 (MgSO_4H_2O)$	10–20	Germany

Source: Sheldrick and Stier, 1978.

World potash reserves

The world possesses very large reserves and resources of potash – enough to last for centuries to come. Although there is a general agreement on the relative importance of various potash locations, there is difference in the estimates of reserves and resources.

Based on 1976 mine prices, reserves have been estimated at 13 billion tonnes plus other resources of about 140 billion tonnes. The largest deposits are in Canada and the USSR, but sufficiently large deposits also exist in the USA, Europe, Asia and South America.

However, only under optimum conditions, the potash mines and refining facilities are expected to reach their nominal production capacity. Optimum conditions do not prevail for all production units at all times. Accordingly, allowance should be made for the unexpected breakdown, lack of spare parts and cannibalization on production capacity, strikes etc. for sub-optimal capacity utilization, assuming no constraint of demand. A brief account of the resources, and their capacity utilization is given below and summarized in Table 12.7.

Table 12.7. Potash resources, reserves and capacity

Location	(Million Tonnes K_2O) *Total Resources*[1/]	*Reserves*[2/]	*1976*	*Capacity Incremental (1976–85)*
Canada	67,000	9,000	7.55	0.99
USSR	45,000	2,000	8.75	6.25
Germany, GDR	7,200	900	3.15	0.60
Germany, FRG	4,800	500	3.00	0.10
Israel and Jordan	1,200	220	0.75	0.15
			-	0.40
USA	5,000	180	2.83	-
France	270	90	2.20	-
Spain	200	60	0.70	0.30
United Kingdom	230	50	-	0.55
Thailand[3/]	9,000	n.a.	-	-
Brazil[3/]	300	n.a.	0.95	0.20
Congo[3/]	200	n.a.	-	-
China	-	-	-	0.30
Total	140,400	13,000		

[1/]*Recoverable potash at current market prices.*
[2/]*Total reserves but including potash that could be recovered with existing technology at a future date and assuming acceptable market prices.*
[3/]*Reserves not currently being exploited.*

Source: Sheldrick and Stier, 1978.

North America

Canada: Very extensive Elk point Basin Devonian potash deposits exist in three main evaporites, mainly in Saskatchewan, but these also extend south into the USA and west into Alberta and east into Manitoba. The beds are 2–4 m thick, almost horizontal, and about 1000 m underground easily mined (cheap to exploit) and contain 20–30% K_2O as sylvinite.

These are the world's largest known potash reserves, estimated at 9.0 billion tonnes K_2O. Canada's rated potash capacity in 1970 totalled 7.55 million tonnes K_2O per annum and was expected to rise by 1985 to 8.54 million tonnes.

United States of America: Most of the mineable potash occurs in the Carlsbad area of New Mexico in the form of sylvinite and two mixed beds containing langbeinite and kainite and are in the form of 1–3 meter thick beds. The mined ore contains 16–22% K_2O and mining is usually done at 100–500 m underground. Significant quantities of potash exist in the form of natural brines and are recovered commercially from the Great Salt Lake and Bonneville Salt Flats in Utah and from Searles Lake in California. The brines of the Great Salt Lake in Utah have a salt content of about 27% and resources of about 100 million tonnes K_2O. The total capacity of U.S.A. is estimated at 2.8 million tonnes K_2O per annum, and reserves are estimated at 180 million tonnes K_2O.

Central and South America

Potash deposits are present in Mexico, Brazil, Peru and Chile. The deposits in Brazil are known to contain large quantities of carnallite and also sylvinite. The plans to exploit this deposit are to eventually produce 0.6 million tonnes K_2O per annum. Annual production in Chile is 20,000 tonnes K_2O.

Africa

There are potash reserves in the Congo, Ethiopia and Morocco. The potash in the Congo was being mined as sylvinite with the possibility also of mining carnallite.

Europe

There are large potash deposits in several parts of Europe, most of which are being exploited commercially.

France: Sylvinite has been mined for many years in the Alsace Region of France, with total reserves estimated at 90 million tonnes K_2O and an ore concentration of 15–20% K_2O. The mining is carried out about 900 m underground, into 1.5–5 m thick seam. The room and pillar mining is gradually to be replaced by more efficient long wall mining. This plan limits production to 3 mines which can maintain potash output at about 2.2 million tonnes K_2 per annum.

Germany: A large deposit extends across both the GDR and the FRG. There are five mineable potash beds comprising a mixture of different potash ores. The thickness of the potash beds is generally 1.5–3.5 m but at places may reach 30 m. In the Werra Fulda Valley on the border with GDR, mining is at 500 m underground through room and pillar methods. Total reserves of the FRG deposits are about 500 million tonnes K_2O and the capacity of their mines in operation is 3 million tonnes K_2O per year.

In Werra Fulda Valley of the German Democratic Republic, mining of the mainly carnallite ore containing 12–15%, K_2O is done at 800 m underground, using room and pillar methods. The South Harza mines are at a depth between 400 m and 1000 m. The ore is mainly Hartsalz averaging 12–15%, but due to difficult roof conditions, only 30–35% of the ore is recovered. The Zielitz mine on the North German plain, 700–800 m underground works a sylvinite bed, 6–9 m thick and averaging 15% K_2O. Potash reserves in East Germany are given at 900 million tonnes K_2O. The capacity is now estimated at 3.15 million tonnes K_2O, expanding to 3.75 million tonnes by early 1980's.

England: Large evaporites of sylvinite are found on the northeast coast of England, 1100 m underground. The ore which averages 27% K_2O is extracted through room and pillar methods and recoverable reserves are estimated at 50 million tonnes K_2O, with a capacity of 0.6 million tonnes K_2O per annum.

Spain: Both carnallite and sylvinite deposits are mined 400-800 m underground in Navarre and Catalonia, where total reserves are estimated at 60 million tonnes K_2O.

Carnallite has 11–12% K_2O, and sylvinite 12–17% K_2O. The potash seams are generally 1–15 m thick. The Spanish potash capacity is estimated at 1 million tonnes K_2O.
Italy: The potash deposits, which are in Sicily, comprise mainly of kainite, 12–18% K_2O, and are mined at 300– 800 m underground. The main product is potassium sulphate. The potash beds are 2–30 m thick. Reserves are estimated around 23 million tonnes K_2O. Present capacity is 250,000 tonnes K_2O per annum.
USSR: The Soviet Union has probably one of the most extensive reserves of high grade potash ores in the world. There are three principal areas of potash deposition: in the Upper Kama Basin, West of the Urals; in the Pripyat Depression in Byelorussia, and in the Western Ukraine. In the region west of Urals, permian sylvinite deposits predominate, with some carnallite. Most of the potash is mined from the Red-II layer, consisting of 4 sylvinite seams 4.5 – 5 m thick, interbedded with 3-6 m thick halite beds. Some sylvinite and carnallite is also mined from the combined AB layers, of which the A-layer is 1–1.5 m thick. The average K_2O content of red-II potash seams is 15–20%, whereas the A-layer varies from 20–27% K_2O. Mining is done 250–500 m underground.

In Byelorussia, an upper 4 m thick sylvinite and a lower 3 m thick bed of alternating sylvinite and halite are being exploited at a depth of 250-500 m in the old mines and at 900 m in new mines. The K_2O content is 16–20% K_2O.

The West Ukraine potash beds contain mainly sylvinite and kainite with 8–19% K_2O and are mined at 200–300 m underground.

USSR recoverable reserves are estimated at 2 billion tonnes K_2O, and total potash resources about 45 billion tonnes K_2O, second only to those in Canada. In 1975 capacity was 8.75 million tonnes K_2O which is expected to increase to about 13 million tonnes by 1984/85.

Asia

Israel: The Dead sea between Jordan and Israel is rich in potash minerals. It is estimated to contain a total of 1200 million tonnes K_2O, of which 220 million tonnes constitute recoverable reserves. The 1975/76 productions capacity of 0.75 million tonnes is expected to expand to 0.90 million tonnes towards the mid-1980's. Israel is currently recovering potash on a commercial basis. Jordan hopes to commence operations soon.
China: Little is known about the details of potash deposits in China other than the fact that potash is being recovered from Lake Chaerhhan in northwest China and also from deposits in West Central China.
Thailand: Large deposits of carnallite have been discovered in the northeastern part of the country near the border with Laos, but there are as yet no known plans for production.
India: The Geological Survey of India expect huge deposits of potassium in the Thar desert of Rajasthan, but no firm estimates are available.

Australia

Commercial deposits of potash, mainly as langbeinite, are present in Lake McLeod in Western Australia.

NON-CONVENTIONAL SOURCES OF FERTILIZER POTASSIUM

Although the world possesses very large reserves and resources of potash, most countries in Asia and Africa totally depend on external supplies to meet their requirements. Ghosh (1976) has described the following alternative sources of fertilizer potassium which might partly substitute the conventional forms.

Sea & lake water

Sea water contains about 0.03 percent K. Accordingly, one cubic kilometer has about 0.3 million tonnes of potassium. The Central Salt and Marine Chemical Research Institute, Bhavanagar in Gujarat (India) has developed processes for manufacturing potassium chloride, potassium sulphate and potassium schoenite from mixed salt obtained by solar evaporation of bittern, the waste material from salt works. Datar (1966) estimated that approximately 0.1 million tonnes of potassium schoenite could be annually manufactured from the salt works in Andhra Pradesh, Gujarat, Madras, Maharashtra and Orissa. Dhar *et al.* (1978) have discussed the possibilities of manufacturing potassium schoenite of fertilizer grade from Tsokar lake brine of Ladakh in Jammu & Kashmir. However, the costs of transportation over long distances may not be conducive to its economic viability.

The excavations from dry beds around salt lakes and lagoons and sedimentary deposits of mixed salts are directly used in some countries after little or no processing. These contain 12–35% K_2O. These low salt mixtures mainly suit local consumption due to the high transportation costs involved.

Doubts have been expressed in certain quarters about indiscriminate use of schoenite because of its high magnesium content and possible deterioration of the micro structure of soil due to excessive entrance of magnesium in the exchange complex.

Furnace dust

A considerable amount of potassium which is volatilized off from the furnace settles on the flue duct. Blast furnace dust may contain more than 14% K_2O. Cement kiln dust is also a promising source of potassium. Fly ash from coal burning power

generating sets also has 1.6 – 5.8% K_2O, but is likely to contain toxic amounts (18.50 ppm) of boron (Holliday *et al*, 1958).

Distillery wastes

Distillery wastes contain 1.1–1.5 percent K_2O. The extraction of potash as potassium sulphate involves huge investments, high operational costs and greater energy inputs. As such, spent waste can be used for irrigation purposes. The main problem in its widespread utilization centres around the availability of sufficient cropped area in the vicinity, reduction of BOD to the permissible limit and the absence of toxic elements.

Organic matter recycling

Farmers everywhere are aware of the beneficial effects of farm yard manure applied to agricultural crops. Until the use of chemical fertilizer started in agriculture nearly 140 years ago, farm yard manure was nearly the sole source of replenishing the soil fertility depleted by human or natural factors. In some of the developing countries, like India, a part of the potentially available dung is used for fuel. Bhumbla (1974) has estimated the total potential of the nutrients from dung, urine and agricultural wastes in India. According to N, P_2O_5 and K_2O content may be taken as 0.2, 0.10 and 0.15 percent respectively, in the dung, 0.6, 0.1 and 0.5% in the urine and 0.4, 0.1 and 0.4% in the farm wastes. The estimates are given inTable 12.8. Again, on the assumption that availability of N, P_2O_5 and K_2O in dung/agricultural wastes will be 30,60 and 75% of that in the inorganic fertilizers (about 50% N in urine), his estimates of available nutrients are given in Table 12.9. Proceeding further on the assumption that about 25 percent of the potentially available dung is used for fuel and the increase in efficiency by proper storage etc. may account for another 10 percent, the increased availability of nutrients will be approximately 0.27 million tonnes N, 0.17 million tonnes P_2O_5 and 0.13 million tonnes K_2O. To make this possible, more stress will have to be laid on developing alternate source of fuel. Bhumbla (1974) considered that the urban compost, because of the cost and transport difficulties, will be used only in the areas near the towns by vegetable producers or for the production of fodder for animals.

There is no denying the fact, however, that in view of the mounting costs of agricultural inputs, no effort should be spared in preserving all wastes and recycling them in agriculture.

Table 12.8. Total nutrients in dung, urine and farm wastes

Source	Quantity (million tonnes)	N	P_2O_5	K_2O
Dung	630	1.26	0.63	0.94
Urine	100	0.60	0.10	0.50
Farm Wastes	85	0.34	0.09	0.34
	Total	2.20	0.82	1.78

Source: Bhumbla, 1974.

Table 12.9. Available nutrients in dung, urine and agricultural wastes (million tonnes)

Source	*N*	*P_2O_5*	*K_2O*
Dung	*0.378*	*0.378*	*0.70*
Urine	*0.300*	*0.060*	*0.37*
Farm wastes	*0.102*	*0.054*	*0.25*
Total	*0.780*	*0.492*	*1.32*

Source: Bhumbla, 1974.

EPILOGUE

Meeting the increasing demands for food, forage, fibre and fuel will be a pressing challenge before the world community during the years ahead. This will require larger production of biomass over a shrinking land area. The ingredients of improved agricultural technology available to achieve this goal include usage of more and more plant nutrients, from whatever source, and with increased efficiency. Fertilizer potassium requirements will increase with the growing emphasis on producing high yields. The world reserves and resources of potassium appear sufficient for several centuries but the increasing energy costs will necessitate the development of indigenous potassium resources whereever possible and efficient recycling of wastes in agriculture, to meet the future needs.

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CHAPTER 13

Salt-Affected Soils: Problems and Prospects in Developing Countries

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INTRODUCTION

ACCUMULATION OF EXCESS salts in the root zone resulting in a partial or complete loss of soil productivity is a world wide phenomenon. The problems of soil salinity are most wide spread in the arid and semi-arid regions but salt affected soils also occur in the humid climate, especially in the coastal areas. Buringh (1979) calculated from various available data that we are losing at least 10 ha of arable land each minute; five because of soil erosion, three because of soil salinization, one because of other soil degradation processes and one due to non agricultural uses. These figures look frightening but clearly indicate the magnitude of the problems that must be tackled to supplement efforts for meeting the future global food needs. It is generally agreed that the food needs of increasing population will be met by directing the efforts of all concerned towards improving the level of management of soils already under cultivation, and bringing under plough the potentially arable soils which are presently uncultivated for growing food crops.

Soil salinity is a major impediment in achieving increased crop yields by either of the above approaches. It is in realization of this that the United Nations Conference on Desertification held in Nairobi in 1977 adopted the following recommendation: "It is recommended that urgent measures be taken to combat desertification in irrigated lands by preventing and controlling water logging, salinization and alakalinization; by modifying farming techniques to increase productivity in a regular and sustained way; by developing new irrigation and drainage schemes where appropriate, always using an integrated approach; and through improvement of the social and economic conditions of people dependent upon irrigation agriculture" (United Nations, 1977).

EXTENT OF THE PROBLEM

Table 13.1 gives an estimate of the world's potentially arable land resources and is based on a study made by the U.S. President's Science Advisory Committee (U.S. Report, 1967). The table also includes the continent-wide area affected by salinity as shown in the FAO/UNESCO Soil Map of the World. The term potentially arable land

Table 13.1. *Total land, arable land and salt-affected soils in continents*

Continents	Total land area*	Cultivated land*	% of land area cultivated	Potential arable land*	Ratio of cultifated to potential arable land ‰	Area affected by Salinity**
Africa	3010	158	5.2	734	22	80.5
Asia	2740	519	18.9	627	83	145.8
Australia & New Zealand	820	32	3.9	153	21	357.3
Europe	480	154	32.1	174	88	3.5
North America	2110	239	11.3	465	51	15.8
South America	1750	77	4.4	661	11	131.2
USSR	2240	227	10.6	356	64	218.0
Total	13,150	1,406	10.6	3,190	44	952.1

Source: The World Food Problem, A report of the President's Science Advisory Committee, Vol II Report of the Panel on the World Food Supply (U.S.A.).

* *Areas are given in million of hectares.*
** *Data based on FAO/UNESCO Soil Map.*

was defined as land, including soils considered to be cultivable and acceptably productive of food crops. Data in Table 13.1 show that only 10.6 percent of the total land area of the world is cultivated at present and that about 24.2 percent of the total land area is considered cultivable or is potentially arable. This means that there is even more land available to be reclaimed in future than is cultivated at the present time in the world as a whole. Largest areas of potentially arable land not now used for crops lie in Africa, chiefly south of the Sahara and in South America. In the continents of Europe and Asia more than 80 percent of the potentially arable land is already being cultivated. The data further show that soils affected by salinity constitute about 7 percent of the total land area and about 30 percent of the potentially arable lands. Although all the salt affected soils will not qualify to be classified as potentially arable, it is apparent that a large fraction of the world's presently cultivated and potentially arable lands are affected with a salinity problem to varying degrees. While the extent of salt affected soils is relatively small in relation to potentially arable land in the continents of Europe and north America, salinity problems pose the greatest threat to increased food production in the continent of Asia where a major fraction of the potentially arable lands is already under cultivation and salinity is a serious limitation in both realizing increased yields from the presently cultivated areas and in bringing the presently uncultivated lands under cultivation.

Problems of salinity are spreading. According to FAO data nearly 50 percent of the irrigated lands have some degree of salinity problem. Every year several hundreds of

thousands of hectares of irrigated land are abandoned as a result of salinization. For example, (El Gabaly, 1977) in Pakistan, out of a total of 15 million hectares of irrigated land about 11 million hectares suffer from salinity, waterlogging or both to varying degrees with a pronounced reduction in the yield of most crops. The area annually damaged by salinity and waterlogging is estimated at 40,000 ha. In Iraq the area under irrigation is about 3.6 million ha, of which more than 50% suffers from salinization and water logging particularly in the middle and lower Rafidain plain. In Egypt about one million ha suffer from salinity problems with a loss in crop production estimated at 30 percent of the potential. More than 50% of irrigated land in the Euphrates valley of Syria is seriously affected by salinity resulting in an estimated annual loss of 300 million U.S. dollars. In India the salt affected soils are estimated at 7 million hectare and the problem is increasing particularly in arid areas which are now being brought under irrigation. The problem is also widespread in most countries of south America and Africa but reliable estimates of the extent of the problem are not available due to inadequate scientific surveys.

Nature of salt-affected soils

Salt affected soils occuring in different parts of the world can be broadly classified into the following two categories (Szabolcs, 1974; Bhumbla and Abrol, 1978).

Saline soils

These are soils which contain excess neutral soluble salts, chiefly chlorides and sulphates of sodium, calcium and magnesium to affect plant growth adversely. Plant growth in saline soils is adversely affected, primarily, due to osmotic effects of excess salts on availability of soil water but the toxic effects of specific ions such as chloride, sulphate, boron and others are often additional factors determining plant growth relationships in saline soils.

Alkali soils

These soils, also termed sodic soils, contain measurable to appreciable quantities of sodium salts capable of alkaline hydrolysis e.g. sodium carbonate. Plant growth in alkali soils is adversely affected, primarily due to the adverse effect of excess exchangeable sodium and accompanying high pH on soil physical and physico-chemical properties, including availability and transformations of essential plant nutrients. The toxic effect of specific ions such as sodium, boron and others is often an additional factor determining plant growth in alkali soils.

Although, in nature, various sodium salts do not occur absolutely separately, in most cases either the neutral sodium salts or the salts capable of alkaline hydrolysis exert a dominant influence on soil forming processes and properties. The two types of salt affected soils also tend to occur in distinct geographical and geochemical zones and require different approaches to their management and reclamation (Abrol and Bhumbla, 1978). The processes of the formation of saline and alkali soils are respectively called salinization and alkalinization. Both saline and alkali soils occur extensively throughout the world and reduce soil productivity.

PROCESSES LEADING TO SALINIZATION

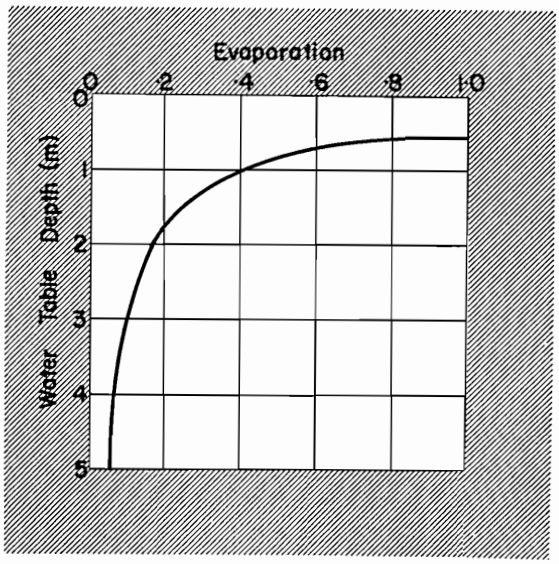
The processes leading to formation of salt-affected soils can be broadly classified as primary and, secondary. Salt affected soils of primary origin are formed as a result of the longterm influence of natural processes leading to an accumulation of salts in a region. Accumulation of salts may be the result of periodic or one time submergence of soils under the sea water or a gradual accumulation of products of weathering into the naturally undrained basins. Vast areas of lake bed soils in the north of Egypt (El Gabaly, 1977) and more than 2 million hectares of saline soils of the *Rann of Kutch* on the western coast of India are examples of saline soils lying barren due to the influence of sea water salinity. Similarly, accumulation of products of weathering in naturally undrained basins followed by repeated drying and wetting cycles would result in the formation of highly sodic soils (Kovda, 1977). Extensive areas of soils lying barren due to high salinity or high sodicity in the soil profile in different parts of the world can be reclaimed and profitably brought under cultivation if appropriate technologies are made available.

Secondary salinization and alkalinization processes owe their origin in one form or another to human intervention resulting in the accumulation of salts in the root zone of crops rendering soils partially or completely unproductive. The chief factors responsible follows.

Introduction of irrigation

In subhumid and semi arid regions, irrigation is the most effective means of stabilizing agricultural production and in the vast arid regions irrigation is the basis of food and fibre for the human population and the very existence of people is dependent on the availability of irrigation. The problems of resource degradation are also the most serious in the arid regions because in such soils, plants and landscape exist in a state of delicate equilibrium. The physical and biological environment is so fragile and unstable that any perturbation, however small, may cause permanent damage to the soil productivity. Thus before the introduction of irrigation into an area, there exists a water balance between the rainfall on the one hand and stream flow, ground water table and evaporation and transpiration on the other. This balance is disturbed when additional quantities of water are artificially spread on the land for growing agricultural crops, introducing additional factors of ground water recharge from seepage from canals, distributaries and field channels most of which are unlined, from the irrigation waters let on to the fields over and above the quantities actually utilized by the crops etc. As a result of these the ground water table rises. Consequent upon the introduction of canal irrigation in an area the ground water table rises, sometimes as much as 2-3 m in a year. There are numerous instances, throughout the world, where the water table has risen within 10 years from about 20-30 m below soil surface to less than 2m. Once the ground water table is close to the soil surface appreciable upward movement of the ground water due to evaporation from the soil surface takes place and results in the accumulation of salts in the root zone. A schematic relationship bet-

Figure 13.1. Relationship between depth of ground water and evaporation from soil surface



ween the depth of ground water and evaporation from the soil surface is shown in Figure 13.1. This relationship is extremely significant and shows that there is a critical depth of water table above which there is a sharp increase in the evaporation rate and consequent soil salinization. In general, the critical depth of the water table ranges between 1.5 to 3 m depending on the soil characteristics, root zone of crops, salt content of the ground water etc. Thus to ensure a salt free root zone, evaporation from the ground water must be prevented from keeping the ground water table below the critical depth. Provision of adequate drainage measures is the only way to control the ground water table. Although much has been written on the theory and principles of field drainage, yet the fact remains that most of the irrigation projects in developing countries are threatened due to problems of salinization due to inadequate or lack of appropriate drainage measures. As early as 1928 the report of 'Royal Commission on Agriculture in India' stated, "It would appear that many of the troubles which have arisen in the irrigated tracts of India in regard to waterlogging and formation of salty lands have been due to failure to properly correlate a new irrigation system with the natural drainage of the tract. *We have little doubt that the lesson has been learnt* and that, where this is not already the practice, a careful drainage survey which could include estimates for drainage construction will, in future, form an integral part of all new irrigation projects". While the need for a well planned drainage system as an essential component of any irrigation project has been emphasized in all writing and on all forums, in practice this aspect has been grossly neglected. As a consequence even today the problems of salinity continue to be a serious impediment in realizing the planned agricultural production from areas brought under irrigation by investing huge sums of money in most developing countries. The Indian situation represents

the problem as obtaining in other developing countries.

Faulty irrigation schemes

Introduction of irrigation is often considered a solution to the all pressing problems of the arid and semi arid regions. However, there are numerous examples to show that ill conceived or poorly implemented irrigation schemes have caused soil degradation rendering them lost to production.

According to an FAO study there has been a galloping inflation in the cost of land and water development resources. Thus the development cost of surface irrigation, including storage dams, drainage and on-farm works per hectare increased from U.S.$500 to 2,000 in 1970/71 to U.S.$3000 to 5000 in 1974/75 and to an average of U.S.$8,000 in 1977. This figure is further likely to escalate in the future as the easier and simpler projects are completed leaving the increasingly difficult projects. Because of the high costs involved to make the irrigation projects operational, there has been a tendency to find only the money required for the rapid establishment of irrigation facilities in order to grow marketable crops quickly and to defer or omit drainage works in the hope that either they will not be required or that the necessary funds will be found when the project is producing a profit. Unfortunately the cost of providing drainage and reclamation when the problems of waterlogging and salinity have already appeared are much more in addition to the huge losses already incurred through partial or complete loss of production of many areas. For any lasting success, all irrigation projects need sound drainage networks considering soil, climatic, geohydrological and geochemical factors, besides the socioeconomic and political considerations of the region. The drainage network should be put into operation at the same time as the water supply from canals and a great saving cost will ultimately result to the project. The time gap between the start and completion of a major irrigation project may normally extend to 10 years and often more increased costs during this period invariably result in spending the entire project money on the construction of storage works, main and secondary canals and leaving little or no money for investment for on-farm irrigation development including construction of water courses etc. The farmers of the area have had no experience with irrigated agriculture and the projects rarely make provision for programmes to educate the farmers in efficient irrigation practices. Again farmers, although the ultimate beneficiaries, are at no stage involved in the management of irrigation projects either at planning or at execution phases. Active involvement of farmers in local irrigation management is essential since it is the farmers that are the key to successful irrigation development and the benefits from irrigation programmes depend on the success with which farmers use the water for production. Therefore establishment of water management committees including government officials and farmers may be useful in getting better returns from irrigation projects.

Spreading water over a wide area, which is often done for political reasons, is yet another factor that leads to speeding up the rate of soil salinization without eliminating the rising ground water table. This is so because insufficient water is available to meet both the crop water requirements and the water needs to meet the leaching requirements for the control of salts in the root zone. Heavy irrigation, considering

the water requirements in an intensive cropping agriculture along with provision of adequate drainage will be more conducive to the control of salts in the root zone.

Deforestation

Human interference resulting in indiscriminate and large scale deforestation in recent years is an important factor that has resulted in altering the water balance of large areas, in many cases leading to serious salinization problems in both irrigated and unirrigated areas. Unfortunately this fact has not been realized seriously and this is the reason for the lack of systematic studies to evaluate the magnitude of the problem in many developing countries. Australian work has shown that reduced evapotranspiration which is common when the native forests are converted to agriculture involving non-irrigated annual crops, may result in a build of the water table. In one study it was estimated that the increased recharge to groundwater due to a change from native woodland and forest to dry farming ranged from 23 to 430 mm per year (Peck, 1975). Such alteration in ground water balance disturbs the distribution of salts and has resulted in widespread salinization problems in many parts of the world. One source of salt is in the soil and the weathering mantle, but the main source is the saline aquifers, the levels of which have risen as a result of increased accession of water regionally. The solution to the problem appears complex but must include rational land use aimed at partly restoring the original hydrological balance together with site treatments which must be chosen in accordance with the local conditions.

Use of salty waters

In many parts of the world saline groundwater is the only available source of irrigation. Prolonged use of such waters the in absence of adequate leaching can result in an excessive build up of salts in the root zone resulting in impoverished growth and yield of most crop plants.

Management practices

Adoption of proper management practices at the field level is extremely important for the control of salts in the root zone. Practices that are conducive to secondary salinization include:

Poor levelling

Even slight variations in the microrelief lead to salt accumulation in the raised spots and better leaching in the depressions which explains the spotted nature of salinity often observed in poorly levelled but otherwise normal fields. The effect of poor levelling is more pronounced in the presence of shallow saline ground waters. In some newly reclaimed lands severe levelling may expose sub-soil layers rich in salts, leading to rapid salinization.

Fallowing
This is generally practised when the quantity of irrigation water available is not sufficient to meet the crop water requirements of the entire area. Considerable quantity of salts may accumulate at the soil surface by evaporation particularly in the presence of shallow saline water table during the fallow period between two crops. Salinization may be severe if the intercrop period is long and the evaporation demand high.
Cropping pattern
The cropping pattern in an area influences soil salinization chiefly by affecting the water regime of soils. Crops like rice or berseem (Egyptian clover) which require frequent irrigations, tend to maintain a net downward flux of water and salts thereby keeping the root zone relatively salt free. Crops with a long growing duration and those that require less frequent irrigations e.g. barley or cotton will favour the accumulation of salts in the root zone.
Irrigation method
Adoption of inappropriate irrigation methods may accentuate salinity problems in the root zone. When salinity of the irrigation water/soil is high, furrow irrigated row crops often fail to produce satisfactory stands due to accumulation of salts in the seed row which prevents germination. However properly shaped beds or adoption of the border method of irrigation can minimize salt accumulation around the seed and in the root zone.

These are only a few of the examples of how poor management at the field level can accentuate the salinity problem and reduce the returns from the otherwise productive fields.

Social and human factors

Land fragmentation and associated differences in cropping and management help in the spread of secondary salinization. Differences in cropping pattern and irrigation regimes between adjacent farmers will cause migration of salts from high to low spots, from crop areas with more frequent irrigations to those with less frequency and from relatively wet soils to the relatively dry soils. The land tenure system has also an important role in the spread of salinity; thus many cultivators in the developing countries including India and Pakistan are share tenants who are often moved around by the landlords to different plots each year. As a result, they have little interest in protecting the soil from degradation due to salinity or other factors. On the other hand long term tenancy or private ownership of land will offer incentives for conservation measures including control of salinization. Similarly a stable government will have a special interest in long term measures aimed at control of salinity problems.

Existing water laws and the water pricing system is still another factor determining the efficiency of on-farm water use. In most developing countries irrigation is supplied free of charge although in some countries taxes are levied to mobilize resources for financing irrigation work. The farmers who operate their own pumps or buy water from pumps owned by others must pay for the amount of water they use. The water use efficiency of such farmers is, therefore, much higher than the farmers

who do not pay for water. This has resulted in farmers using excessive quantities of water over and above the quantities required to meet the crop consumptive use causing problems of water logging and salinization. Although, there are likely to be many repercussions but a change in this policy to pricing will help in increasing water use efficiency and control of salinity.

CONTROL OF SOIL SALINITY – THE ROLE OF APPROPRIATE TECHNOLOGIES

Extreme pressure on land resources and the ever growing needs of food production for the growing population require that salt-affected soils are restored to their original producitivity and effective steps are taken to prevent desertification of new areas being brought under irrigation at huge costs. To accomplish this, there is need to develop appropriate technologies suited for a particular region or a country. By the term 'technology' is meant the whole range of management practices that go into farm production in such areas. This includes the method of land preparation, best suited crops, varieties and cropping sequences, their fertilization and best suited cultural practices including planting techniques, best suited irrigation, drainage and on farm water management practices, need of amendments etc. And the term 'appropriate' implies that the technologies must be relevant and be adaptable down to the farmer's level. It is often maintained that the basic principles of reclamation and management of salt affected soils are well understood. This is largely true, but when it comes to the applicability at field level, the adoption of technologies developed elsewhere, say in a developed country, may be difficult without overall economic development and the elevation of the level of education of the people. Thus what might be possible for a farmer in the arid California of U.S.A. or in Australia by way of water management might be completely out of reach for the cultivator in the arid Rajasthan in India. Thus in theory it is now well established that a greater efficiency of water use and salt leaching can be accomplished by the adoption of the sprinkler method of irrigation, but for economic reasons it might be impossible to adopt this method over wide areas in most developing countries. And even if the economics permitted this, the adoption by illiterate farmers of such sophisticated water control equipment will present tremendous difficulties by way of operation and maintenance. As an example of the latter, in the past one decade or so, billions of dollars have been invested in providing most modern subsurface drainage systems in Iraq with the aim of restoring the productivity of lands gone out of cultivation due to salinization. In the previous years, Iraq has had no experience with such a drainage system and the farmers who are largely illiterate are yet to be convinced of the usefulness of these technologies. A well designed and operated drainage system can greatly increase the productivity of irrigated agriculture but only if it is effective right down to the farmer's fields. The individual farmer must understand the importance of

drainage. His full co-operation is necessary to maintain the field ditches and interceptor drains to ensure the functioning of costly drainage systems. In absence of this and in the absence of overall elevation of the education of the farmers it is doubtful that the provision of sophisticated drainage measures will help in achieving the desired objective of increased food production from these areas (Allahwerdi, 1979).

The farmer labouring in the irrigated fields is the most important link in the chain of production. Since he may be traditionbound and lack the benefit of education, he must be converted into a resourceful cultivator and an efficient irrigator. To fructify the efforts and ingenuity of scientists and extension working, a steady progress in irrigation methods and water use efficiency the farmer must be kept informed of new ideas. It is further important that technical advances made in the research laboratories be adequately tested under local field conditions and the necessary modifications made to suit the needs and capabilities of the local farmer before he is induced to use them. In order, therefore, that the technologies for reclamation of salt affected soils and for prevention of spread of salinity problems are effective and can lead to a continuous improvement in food production, it is essential that:

1. The relevent farming technologies for such areas are developed to meet the realistic goals considering the social, economic and political setting on the one hand and the tradition and level of the farmers on the other;
2. Adequate physical infrastructure is created for the transfer of tested technologies from 'Lab to Land', and
3. There is a continuous effort to improve upon the technologies as more scientific knowledge and experience is gained and as the economic conditions become more favourable.

As the available technologies improve, increasingly difficult to reclaim salt affected soils will be brought under cultivation. In the next section it will be shown how the alkali soils of the Indo-Gangetic plains in India which were considered completely unproductive a decade ago, are turning productive today with the availability of appropriate technologies. Similarly appropriate water use technologies for the newly irrigated areas based on an intimate understanding of soil plant-water system on the one hand and geochemical and geohydrological settings on the other will provide a basis for prediction of various hazards and help in taking timely measures for prevention of soil deterioration.

In many of the newly irrigated areas the efficiency of water use is generally low. Data from India on water conveyance and application efficiency are presented in Table 13.2 to illustrate a universal problem in most developing countries. The overall irrigation efficiency of about 30 percent is very low. The water seepage in conveyance amounts to 40 to 50 percent and the distribution losses at field level are about 25 percent. The experience in Pakistan is no different. The problem of improving the 'on farm' water use efficiency is complex. Knowledge of water requirements of field crops, water application and irrigation scheduling criteria, design and operation of irrigation networks and related soil plant factors are critical for the effective water use and control of groundwater level. Inadequate training of farmers is one of the chief reasons for poor 'on farm' water use efficiency. Nonetheless, mission oriented research efforts aimed at continuously improving our water management capabilities

Table 13.2. Efficiency of irrigation: losses in canals of northern India

Water Loss	Per cent
In main canals and branches	15–20
In major and minor distributaries	6–8
In field channels	20–22
In the field during application	25–27
Utilization by crops in the form of evapotranspiration	28–30

Source: Gopinath, 1976

and elevating the level of education of farmers will ultimately result in achieving the desired goals. No investments in development of appropriate technologies will be too high. New technologies must be tailored to meet the local conditions and this can be best accomplished by a team of scientists who are aware of the constraints operative at the farmers' level. That is, relevent researches are taken up by a team of scientists who can appreciate the social, cultural and political aspects of the country and guide team efforts towards best solutions under the realities with which the farmers work. Research programmes of the necessary magnitude must be organised so as to continuously provide support to the field programmes aimed at improving the existing methodologies of reclamation and on farm water management practices.

SODIC SOILS OF INDIA AND THEIR RECLAMATION – A CASE STUDY

Spread and formation

An estimated 2.5 million hectares of land is severely affected by high sodicity and is lying barren for decades in the otherwise most productive Indo-Gangetic plains of northern India. Sodic soils are generally confined to areas with a mean annual rainfall between 550 and 1000 mm. The soils occur interspersed with normal soils and may occupy, sometimes, several hundred hectares at a stretch. The soils usually occupy a somewhat lower elevation in the otherwise flat terrain. During the rainy season, July to September, rain water accumulates in the low lying areas. Weathering of aluminosilicate minerals provides a steady supply of alkali bicarbonate which accumulates in the undrained basins. In the ensuing dry season the soil solution is concentrated resulting in high soil pH through increased adsorption of sodium on the soil exchange complex. The displaced calcium precipitates and over the years the soils have reached the extreme state of deterioration (Bhumbla, 1977). The introduction of canal irrigation in these areas and other developmental activities have accen-

tuated the problem by restricting surface drainage and the rise in ground water table resulting in reduced natural leaching. A rise in ground water table in the regions where the ground waters have a high proportion of sodium relative to divalent cation and/or high residual alkalinity further results in accumulation of sodium in the root zone. In other cases ground-waters of high sodic content when used for irrigation have resulted in the extension of sodic soils.

Socio-economic impact

The occurrence of large areas of sodic soils has an adverse effect on the economic conditions of the farmer. While highly sodic soils are lying barren and produce no crops, vast areas produce only a fraction of the potential yield due to varying levels of soil sodicity. Although losses of potential crop production from these soils have been realized, rarely has concern been expressed for the indirect adverse impact of these soils on society. Being poorly permeable, sodic soils absorb little or no rain resulting in almost complete loss of excellent quality rain water from these areas. Also in areas with extensive sodic soils the problem of floods from small and medium intensity monsoon rains is accentuated causing uncalculable damage to the growing crops and property in the affected areas. Large amounts of runoff also carry huge quantities of rich nutrients from surface soil. No effort has been made to assign a monetary value to these losses. Similarly it is a common observation that expenditure on the maintenance of public structures including roads, bridges etc. is much higher in sodic soil infested areas as also the incidence of some human diseases. Sodic soil areas are either village common lands or belong to the lower strata of society who cannot afford to make the required monetary investments unless immediate returns are ensured. Urgent need for increased food production and for conservation of our resources calls for economic and speedy methods for the improvement and utilization of these soils.

Reclamation technology

Although efforts to understand the nature of these soils and devise methods for their improvement had been made for the past more than 50 years, a real break-through in developing an appropriate technology came about with the setting up of the Central Soil Salinity Research Institute, Karnal, India, where the team of scientists consisting of specialists in Soils and Plant Sciences, Agronomy, Engineering and Economics made a concerted effort to find solutions to strategic questions and came up with a series of recommendations for bringing these soils under cultivation. Major contributions from these researches are summed up below:

Drainage

Drainage of sodic soils presents special problems. It has been experimentally shown (Dhruvanarayana, 1979) that sub-surface tile drains are ineffective in lowering the ground water table due to poor water transmission properties of these soils. On the

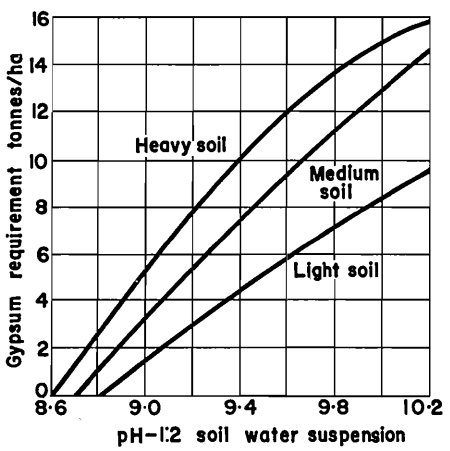
other hand vertical drainage through pumping and utilizing the pumped water for irrigation appears a practical method for lowering the ground water table in these areas since the ground water quality in sodic soil areas is generally good. Also the conditions for successful vertical drainage viz. presence of favourable aquifer properties within 10–20 m are met with in most areas having sodic soil problems. This, therefore, appears to be an ideally suited drainage measure for the control of the ground water table.

Management of monsoon rains averaging 600–700 mm during July to September is yet another problem in sodic soil areas. Within a short span the crops experience excess moisture conditions at one time and near drought conditions at the other. To overcome this and to conserve the excellent quality rain water a three tier system of water management involving rain water storage in the crop land, shallow dugout ponds and provision of surface drains was recommended (Dhruvanarayana, 1979).

Amendments

While the need for application of amendments for sodic soil reclamation is well recognized there is little experimental information on the minimum quantities required and the method of application etc. For soils containing appreciable quantities of soluble sodium carbonate, as the sodic soils of the Indo-Gangetic plains, it was shown that the existing laboratory methods over estimate the gypsum requirements of the soils. Based on these studies a more realistic procedure for determining the gypsum requirement of soils was suggested (Abrol *et al.*, 1975). It was also obsrved that there was a good relationship between pH of these soils and the soil sodicity (Gupta *et al.*, 1981). Based on these observations a graphical relationship between soil pH and the gypsum requirement of soils (Figure 13.2) was established to help in advisory work since pH is a relatively easily determined soil parameter. These studies also brought out that the existing diagnostic criteria for sodic soils need to be reviewed and suggestions in this regard were made by Abrol *et al.* (1980).

Figure 13.2. Relationship between pH and the gypsum requirement of soils

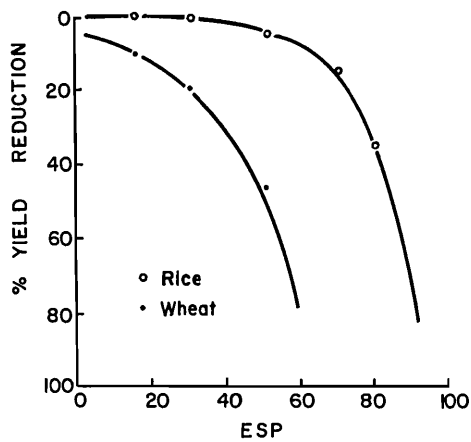


For obtaining best results from limited quantities of gypsum, field studies showed that mixing gypsum in only shallow depths, 0–10 cm, was most effective. Similarly laboratory and field studies showed that gypsum passed through a 2 mm sieve was sufficiently fine for use as an amendment when rice was grown as first crop in these soils.

Crops in sodic soils

Proper choice of crops during reclamation is important. Growing crops tolerant to high sodicity can ensure reasonable returns during the difficult initial phases of reclamation. In Table 13.3 important crops are listed according to their relative tolerance to soil sodicity. These results are based on several field greenhouse studies (Abrol and Bhumbla, 1979). Relative tolerance of rice and wheat in Figure 13.3 shows that at an ESP of 55, while the yield of rice was reduced by only about 10 percent, wheat failed to grow indicating a high tolerance of rice to sodic conditions. The high tolerance of rice to sodicity arises due to its ability to withstand waterlogging and, in fact, the need for a layer of water on the field throughout the growing season. Low permeability of sodic soils is a further advantage because losses of water due to deep percolation are restricted although in most cases sufficient to leach soluble salts resulting from exchange of sodium. These factors make rice an ideal crop during the reclamation of sodic soils. In fact, the rice crop enhances the reclamation process (Chhabra and Abrol, 1977) by mobilizing the native insoluble calcium carbonate mainly as a result of increased hydrolysis and carbon dioxide liberation by plant roots.

Figure 13.3. Relative tolerance of rice and wheat



Management practices

Adoption of best suited cultural and crop management practices is essential for obtaining maximum returns from the input to sodic soils.

Planting

Planting techniques can be often modified to overcome unfavourable soil conditions for germination or crop establishment. A significant increase in rice yield was obtained when 4 or 6 seedlings were transplanted per hill instead of the usually recommended 1 or 2 seedlings per hill in normal soil. In another study it was found

Table 13.3. Relative tolerance of some crops and grasses to exhangeable sodium

Tolerant*	Semi-tolerant	Sensitive
Karnal grass (*Diplachne fusca*)	Wheat (*Triticum vulgare*)	Cowpeas (*Vigna sinensis*)
Rhodes grass (*Chloris gayana*)	Barley (*Hordeum vulgare*)	Gram (*Cicer arietinum*)
Para grass (*Brachiaria mutica*)	Oats (*Avena sativa*)	Groundnut (*Arachis hypogaea*)
Bermuda grass (*Cynodon dectylon*)	Raya (*Brassica juncea*)	Lentil (*Lena esculenta*)
Rice (*Ryza sativa*)	Senji (*Molilotus parviflora*)	Mash (*Phasiolus mungo*)
Sugarbeet (*Beta vulgaris*)	Berseem (*Trifolium alexandrinum*)	Mung (*Phasiolus aureus*)
	Sugarcane (*Saccharum officinarum*)	Peas (*Pisum sativum*)
	Bajra (*Pennsetum typhoides*)	Maize (*Zea mays*)
	Cotton (*Gossypium hirsultum*)	Cotton, at germination (*Gossypium hirsutum*)

*Note – Crop yields are seriously affected if the ESP is more than about 55, 35 and 10 in respect of tolerant, semi-tolerant and sensitive crops, respectively. Tolerance in each column decreases from top to bottom. The grasses listed are highly tolerant and some like Karnal grass grow well even in soils of ESP – 80 to 90.

that planting somewhat older rice seedlings proved better than planting the usually recommended 30 day-old-seedlings.

Nutrients

Low organic matter content and high pH imparts inherent poor fertility to sodic soils. Poor air-water relations and high pH further influence the transformations and availability of applied fertilizers. A number of field studies have shown that crops in sodic soils respond to higher levels of applied nitrogen than the crops grown in normal soils. Amongst sources, ammonium sulphate proved to be a better source of nitrogen than urea (Nitant and Dargan, 1974). In conclusion of these studies, it is recommended that crops grown in sodic soils be fertilized with 20–25 percent more N than the recommended rates for normal soils.

Our studies have revealed that sodic soils contain high amounts of extractable phosphorus and that a significant fraction of this is leached to lower depths following application of an amendment and ponding of water. Field studies have further shown that crops like rice and wheat grown in rotation are not likely to respond to applied phosphorus for the initial 3–4 years. Similarly it has been shown that these crops do not respond to applied potassium because of sufficient release of potassium from the soil minerals (Pal and Mondal, 1980). In view of these results, crop fertilization with P and K is not recommended, at least in the initial 3–4 years of reclamation. This can result in considerable saving to the farmers.

Among the micronutrients, zinc deficiency is most common in sodic soils. For obtaining optimum yields application of zinc as zinc sulphate at the rate of 20–25 kg per ha is recommended (Takkar and Singh, 1978).

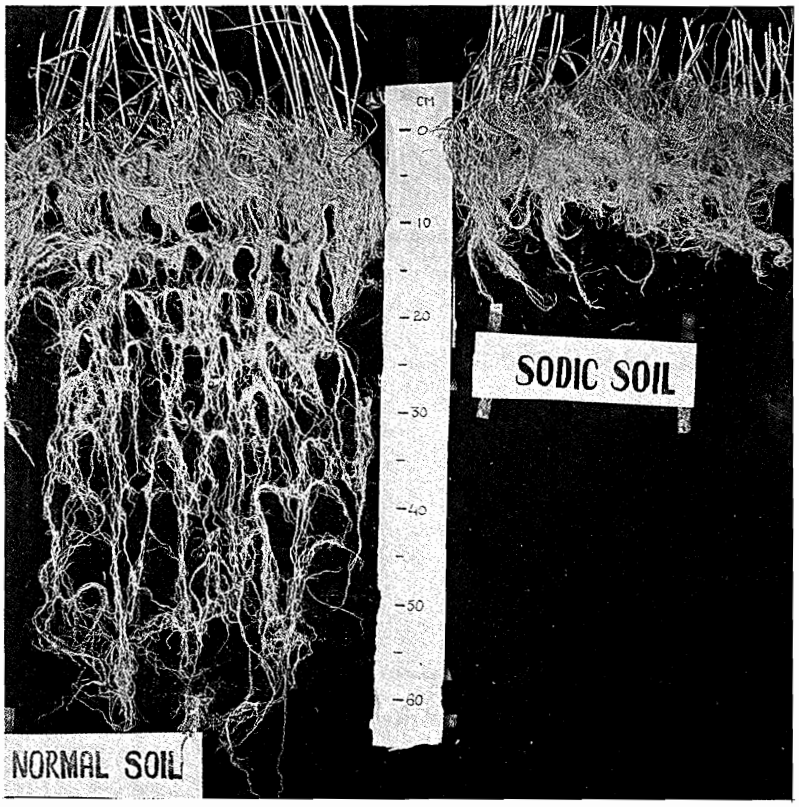
Irrigation

For crops other than rice, irrigation management presents major difficulties in obtaining optimum yields from sodic soils. Low infiltration rate and poor hydraulic conductivity result in reduced profile water storage and the availability of stored moisture to growing plants (Acharya and Abrol, 1978). Further root penetration in these soils is restricted (Figure 13.4) due to dense/high ESP sub soils layer (Abrol and Acharya, 1975). These limitations require that the crops grown in sodic soils are irrigated more frequently and with smaller quantities of water at each irrigation in comparison to the crops grown in non-sodic soils. Ability to deliver small amounts of water at a time with sprinkler system appears to offer a practical way to manage high frequency irrigation needs of sodic soils although at the present level of development there is little possibility for its adoption by farmers in the developing countries.

THE TEST OF TECHNOLOGY

The farming community is the ultimate user of the results of research. Having obtained success in the experimental field it was necessary to test the technology on the farmers' fields. Towards this end, an operational research project was initiated in

Figure 13.4. Restriction of root-penetration due to high ESP sub-soil layer



a group of villages having a severe problem of soil sodicity with the following objectives:

- test and demonstrate the technology for reclamation on the farmer's fields;
- evaluate the economics of reclamation;
- identify constraints in the transfer of technology, and
- act as a feed-back system for the researchers.

Results relating to crop yields, soil properties and on economics of reclamation were presented by Mehta *et al.* (1980). Results of this study showed that if the increase in land value is not considered as a real benefit, the reclamation cost could be recovered in about 3 years and that the farmers of reclaimed sodic soils have a sound repaying capacity. For these reasons reclamation of sodic soils was considered economically feasible and sound. It needs to be pointed out here that the above calculations do not include other benefits like employment generation, economic stabilization and regional development which will occur when large scale reclamation is taken up. Similarly benefits, that must be considered in any policy formulation on the large scale reclamation of sodic soils include improvement in soil properties which result in the conservation of rainwater and reduction in runoff causing flooding of low lying areas.

The country's need for increased food production and the economic feasibility of reclamation of sodic soils, demand that large scale reclamation is taken up. Since it is not possible for the poor farmers to take up reclamation on their own, the need for credit on easy terms appears absolutely essential. This requires the involvement of organized credit institutions and sound education and extension programmes to ensure adequate technical backing for the successful implementation of reclamation projects.

TECHNOLOGY TRANSFER

Convinced of the economic feasibility and the credit worthiness of sodic soil reclamation, the state governments have set up Land Reclamation and Development Corporations with the responsibility to assist farmers in taking up reclamation. The Corporation helps the farmers in getting loans repayable in easy instalments, procurement of inputs such as gypsum, fertilizers, installation of tubewells, land levelling etc. To make the programmes further acceptable a subsidy is provided on the cost of gypsum. Training programmes are organized for the field staff to educate the farmers on the essentials of the technology. In the past 4 years nearly 200,000 ha of sodic soils have been brought under cultivation in the states of Haryana, Punjab and Uttar Pradesh and it is proposed to reclaim additional 1 million ha in the next 10 years. This will result in increasing food production by about 6 million tonnes valued at approximately 1 billion U.S. dollars annually, at the present level of technology. This is substantial considering the regional and the overall development needs.

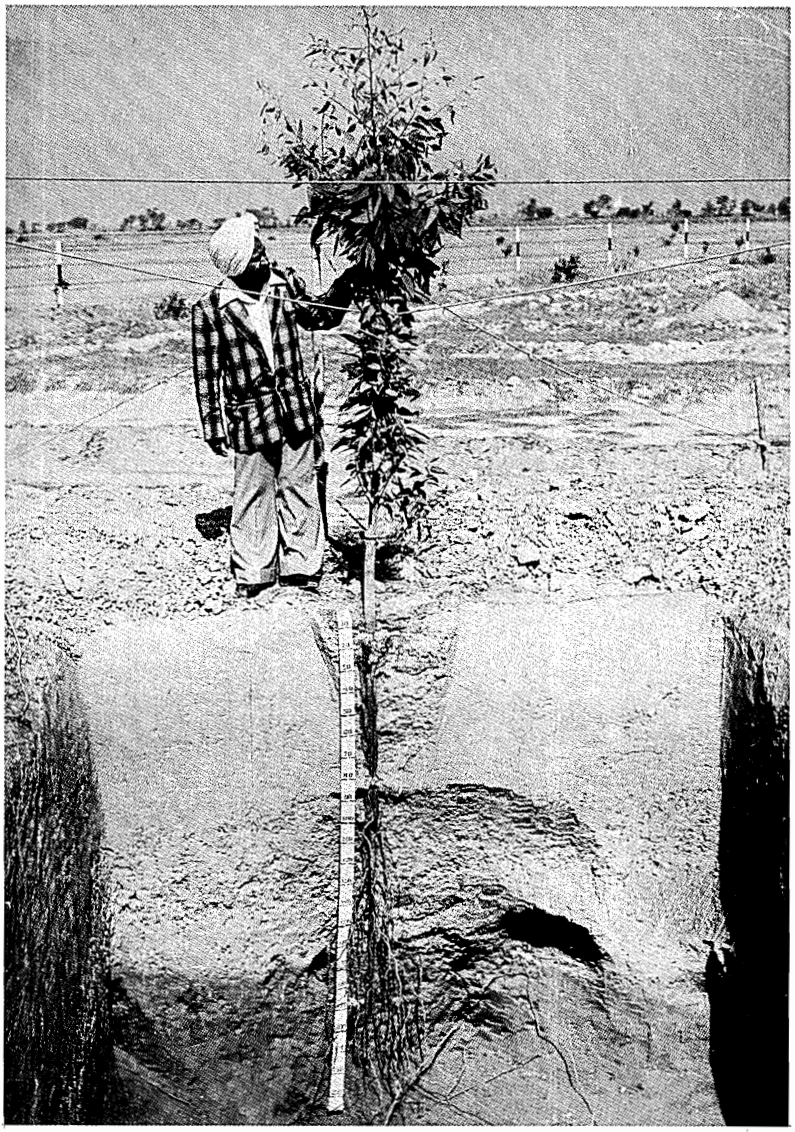
THE ALTERNATE TECHNOLOGY

A large fraction of sodic soils forms a part of the village common lands meant for community purposes including grazing grounds for cattle. Since these lands do not belong to an individual it will not be advisable to reclaim these lands for growing food crops. Agro-forestry appears a promising alternate land use for these marginal lands considering the ever increasing requirements and cost of fuel wood, need for forage for milch cattle and for environmental conservation. Availability of fuel wood will also result in greater availability of animal wastes for use as manure releasing pressure on the already scarce chemical fertilizers. In view of this efforts were made to identify grasses and cultural practices for growing trees in highly sodic soils.

Grasses in sodic soils

Field and greenhouse studies have shown that karnal grass (*Diplachne fusca*), rhodes

Figure 13.5. Roots nearly by-passing the sodicity problem and proliferating in the zone of continuous moisture availability



grass (*Chloris gayana*), para grass (*Brachiaria mutica*) and bermuda grass (*Cynodon dactylon*) are highly tolerant of sodic soil conditions and can be successfully grown in sodic soils (Ashok Kumar and Abrol, 1979). Karnal grass grows extremely well even when no amendment is applied. Karnal grass and para grass are also highly tolerant of ponded water conditions, typically obtained in sodic soil areas during the rainy sea-

son. Growth of grasses results in continuous soil improvement due to the biological action of grass roots. Thus growing tolerant grasses will not only provide the much needed forage for the cattle population but also improve the soil resulting in increased absorption of rainwater, reduced runoff and losses due to erosion.

Trees in sodic soils

Earlier attempts to grow trees in highly sodic soils were largely a failure. Field experiments by Yadav *et al.* (1975), however showed that species like *Eucalyptus hybrid, Prosopis duliflora* and *Acacia nilotica* can be grown in highly sodic soils if the seedlings are planted in 90 x 90 cm pits after the pit soil has been treated with gypsum and farm yard manure. Recent studies (Sandhu and Abrol, 1981) have shown that if tree seedlings are planted in auger holes, 15 cm diameter and 180 cm deep filled with a mixture of original soil, 3–4 kg gypsum and 7–8 kg farm yard manure, the seedlings made excellent growth and there was 100 percent survival of planted seedlings. In this technique a favourable environment is created for root growth and penetration. The roots, thus, nearly by pass the sodicity problem and proliferate in the zone of continuous moisture availability (Figure 13.5). By this technique a large number of auger holes, 8 to 9, can be made by a person in a day and it is also possible to dig the holes mechanically with an auger attached to a tractor. The technique holds promise for large scale adoption of afforestation programmes in sodic soil areas. It is hoped that continuous research efforts in this direction coupled with education and extension programmes will provide the necessary impetus for organizing the much needed agro-forestry programmes in these marginal lands.

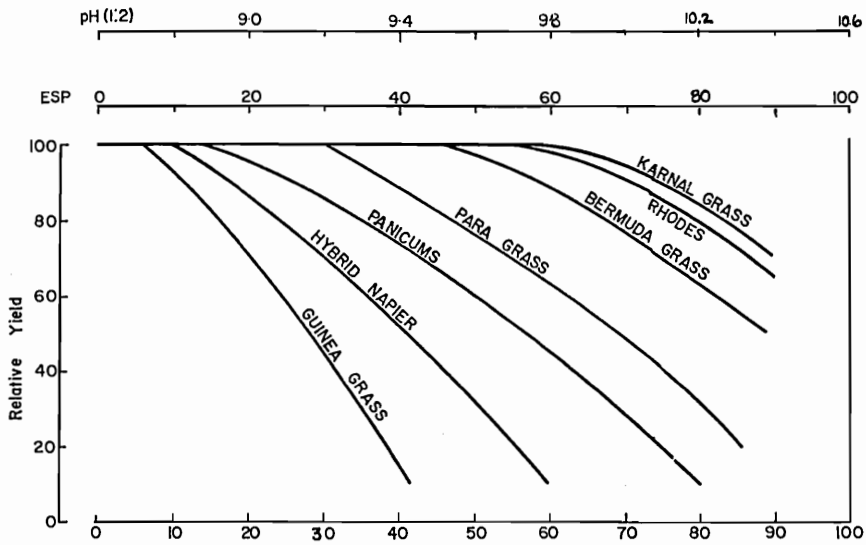
CONCLUSIONS

Salt-affected soils occur extensively, chiefly in arid and semi-arid regions, throughout the world, and are a serious impediment in obtaining increased yields from presently cultivated soils as also in bringing potentially arable lands under cultivation. Several hundred thousand hectares of cultivated soils are going out of cultivation due to salinization and alkalinization. The problem is most serious in developing countries where a major fraction of the potentially arable lands is already under cultivation. The major factors leading to the formation of salt affected soils include the introduction of irrigation into arid areas, faulty irrigation schemes, large scale deforestation, use of salty waters for irrigation and inappropriate on farm soil, water and crop management practices, including some arising out of prevailing social and human factors. Any attempt towards improvement of salt affected soils and prevention of the spread of the problem must depend heavily on the development of appropriate farming technologies of such areas which must be realistic considering the social and economic setting on the one hand and the tradition and level of education of the farmers on the other hand. For technologies to be effective, there is a need for adequate infrastructure for transfer of technologies from Lab to Land and to educate the farm-

Figure 13.6. Karnal grass (Diplachne fusca [No 1]), *a highly tolerant grain to sodic conditions*

ing community on the need and benefits of improved technologies. A case study of how appropriate technologies are helping in the reclamation and utilization of large areas of alkali soils in the Indo-Gangetic plains of India is presented. A continuous effort to improve upon and to search alternatives to the existing technologies as more scientific knowledge and experience is gained and as economic conditions become

Figure 13.7. Relative tolerance of some grasses to sodic conditions



more favourable, will lead to bringing into cultivation hitherto considered 'difficult to reclaim' salt-affected soils and in providing better 'on farm water management' for effective control of salinity in the future.

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CHAPTER 14
Salt-Affected Soils: Problems and Prospects in Developed Countries

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INTRODUCTION

THE DEVELOPED COUNTRIES cover only little more than one third of the globe's surface, still one fourth of the world's population live there and possess almost half of the arable land of the earth. The rational utilization of this land is decisive for the entire human population at present as well as in the near future.

In the developed countries both extensive and intensive agriculture are practiced. Most of these countries are situated in the northern and southern temperate or subtropical regions which contain productive croplands. Part of the soils of developed countries can be found under the cold climate where the vegetation period is rather short.

In spite of the fact that double or treble cropping is climatically more feasible in the developing countries than in the developed ones, it is the latter which produce the bulk of food as it is demonstrated in Figure 14.1. As far as grain is concerned they grow 50% while more than 65% of meat and nearly 80% of milk are produced in the developed countries.

The resources of food production are enormous in the developed world as well as in the developing countries. And the agriculture of developed countries has its strengths as well as its weaknesses. To the former ones may be assigned the great amount of well-kept arable land and, in many cases a precipitation rate sufficient for producing high yields. In these countries younger or older soils will probably remain fertile for a long period in the future under a high level technology of cultivation, fertilization and irrigation.

The climatic conditions in many developed countries heavily reduce the period of vegetation which can only be partly counter-balanced by well-keeping the soil, developing green-house production and ecological effects, microbiological activity, mulching, etc. In developed countries traditional agriculture mostly has a high technological level lending to a high capacity production system. The introduction of up-to-date machinery and increasing doses of mineral fertilizers, pesticides and her-

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bicides are capable to meet the growing demand for quantity and quality of agricultural production. The control of physical, chemical and biological soil properties are the strengths of developed countries which enable them to produce remarkably high quantities of food.

In the developed countries agriculture is highly efficient in the use of labour because the high level of mechanization and chemization is combined with the high skill of labourers.

At the same time, in the developed world agriculture is facing difficult problems.

High inputs are inevitable for ensuring high production and quality of products. At the same time, the oil crisis has increased the costs of inputs. These factors step up the food crisis and lead to a vicious circle, which we have been witnessing since 1973. In addition, the farm labour costs are increasing which influence the cost of the output of agriculture.

Figure 14.1. Food production in the developed and in the developing countries

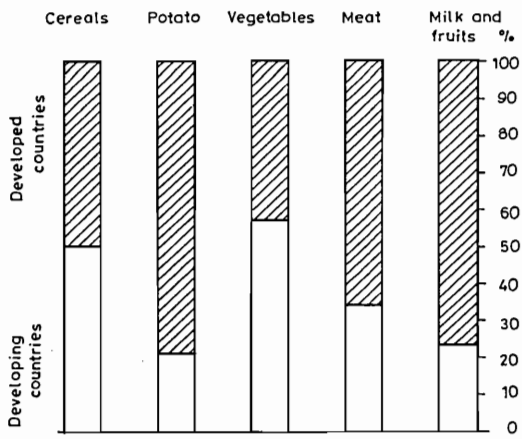


Table 14.1. Cropland use in the USA from 1949 to 1974

	1949	1959	1969	1974
	in millions of hectares			
Harvested	142	128	116	130
Cultivated summer fallow	11	13	17	11
Idle cropland	9	13	21	11
Total	162	154	154	152

The "old-fashioned" agriculture, which is in many respects similar to some recent systems of agriculture in developing countries, was a more closed system from the point of view of mass and energy flow than the present highly productive system of the developed countries. In the past only a small part of mass and energy input came from outside the farm. The animals and the farmers provided the labour force, the farmyard manure was the main plant nutrient, and crop rotation and other methods were substituted for the present day chemical plant protection.

In our time, when all these inputs must be bought from outside, the agricultural system has become open, with all the hazards of this situation.

The demand for food will continue to increase in the future. The demographic explosion will make it imperative for a long time to grow more agricultural products both in the developing and the developed countries. One can predict that the demand for producing more food will be a rather long term phenomenon in the developed countries because they would require enough food for their increasing population and also to extend help to needy countries in the third world.

The extension of croplands is one way to increasing food production and this is only possible in some of the developed countries. Many of these countries have a very high percentage of agricultural land in relation to their total land surface. To mention only a few in Europe: Hungary, the Netherlands, or Belgium have practically no reserve lands.

In other countries, for other reasons, the extension of croplands does not seem practical. In Table 14.1 some patterns of cropland use in the USA are demonstrated from 1949 to 1974. It is clear that the area of croplands in the US has not changed much and has rather diminished during the last decades.

THE PROBLEM OF SOIL SALINITY AND ALKALINITY

According to the above discussion pointing to the necessity of producing more from the same land, the quality and well-keeping of arable lands have paramount importance both in developed and in developing countries. There are factors, harmful for soil fertility, which destroy or diminish the yields of crops. The number of such factors is rather many and includes erosion, acidification, contamination with poisonous herbicides, with radioactive fission products, floods and others. The international organizations FAO and UNEP are intensively working on a world cadastre of the degradation and deterioration of soils by harmful processes.

One of the most dangerous processes, which occurs on all continents and threatens the productivity of soils, is the salinization and alkalization of soils and waters. In both the developed and the developing countries, the area of saline and alkaline soils is increasing. Irrigated lands and their environment share the potential of increasing such soils in the absence of appropriate land management policies.

Saline and alkali soils in the developed countries

Salt-affected soils can be found in many developed countries on our continents. The extent of the various saline and alkali soils in these countries is shown in Table 14.2.

From Table 14.2 it is clear that salinization and alkalinization pose serious problems in many developed countries. In some places saline and alkali soils constitute vast areas while in other cases they occur in patches in combination with fertile soils.

The great diversity of different types and sub-types of salt-affected soils require different means and methods of reclamation.

Table 14.2. Distribution of saline and alkali soils in some developed countries (in thousand hectares)

Country	Solonchaks	Saline phase	Solonetzes	Alkaline phase	Total
Canada		264	6,974		7,238
USA		5,927	2,590		8,517
USSR	20,592	57,443	50,444	89,566	219,139
Australia	16,567	702	38,111	301,860	357,240
Bulgaria	30		20		50
Czechoslovakia	13		7	85	105
France	175		75		250
Hungary	60	600	320	650	1,630
Roumania	140		110		250
Spain					840

A brief characterization of saline and alkali soils

It is generally accepted that water soluble salts, particularly the sodium salts, are responsible for the low fertility of salt-affected soils. Soils whose content of salts or their ions interfere with the growth of the majority of crops are termed saline or alkali soils.

In the course of the development of soil science and soil classification, two main groups of such soils have been distinguished:

1. Soils affected by neutral sodium salts, mainly sodium chloride and sodium sulphate,
2. Soils affected by sodium salts capable of alkaline hydrolysis, mainly $NaHCO_3$, Na_2CO_3 and Na_2SiO_3.

Soils belonging to the first group have mainly been named saline, and those of the second group are alkali soils. These two main types differ not only in their chemical character but also in their geographical and geochemical distribution, as well as in their physical, chemical, physico-chemical and biological properties. The methods used for their reclamation and agricultural utilization are also different.

Although it is evident that in nature the various sodium salts do not occur absolutely separately in soils, in most cases either the neutral sodium salts or the ones capable of alkaline hydrolysis exercise a dominating influence on the soil-forming processes and soil properties.

On the various continents, under the very wide range of environmental conditions, the general levels of the salinity or alkalinity of parent materials and ground waters may sharply differ. The salinity or alkalinity tolerance of local crops varies widely, too. The potential salinity or alkalinity of an area depends, to a considerable extent, on the cropping system used there. It is more than obvious that in all these respects only very vague limit values can be given on a world-wide scale. Therefore it is necessary that – while keeping the basic principles in mind – a certain flexibility be employed in the definition of salinity and/or alkalinity limit values characterizing the salt-affected soils of a given territory, that is, the local conditions should also be taken into consideration.

Saline soils

On most continents saline soils are the dominant type of salt-affected soils. In Europe, however, the situation is different; here the alkali type prevails.

In saline soils the dominating salts, mainly NaCl and Na_2SO_4, reach sometimes one or more per cent of the soil material, particularly in surface layers, but usually we speak of saline soils where the above mentioned value is above 0.5%. In many countries the electrical conductivity (E.C.) value is used for the measuring of salinity, and if this exceeds 4-6, saline phase or saline soil is diagnosed. Without going into particulars about the determination methods of salinity, this soil type is briefly characterized.

The maximum salt accumulation may be found at different depths in the soil profiles but very often it occurs in the top layer or near the surface. The saline soils have developed in most of the arid regions of the world. The few exceptions to this rule are caused by the salinity of local ground water or soil forming substrata (Figure 14.2).

Seasonal changes affected by the climate and, particularly, by irrigation and drainage, may occur in the salt contents of saline soils, as well as in the distribution of salts in the different layers of the soil profile. The possibility of such changes should always be taken into consideration when the soils are described as well as during the sampling and analytical procedures.

In Figure 14.3 the salt distribution in a saline soil from the Caspian Lowland is demonstrated.

Figure 14.3. Salt profile of a saline soil from the Caspian lowland (chloride-sulphate-solonchak)

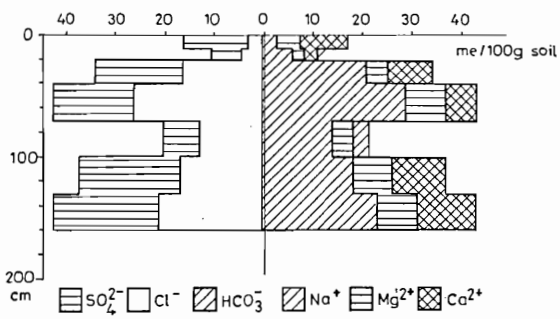
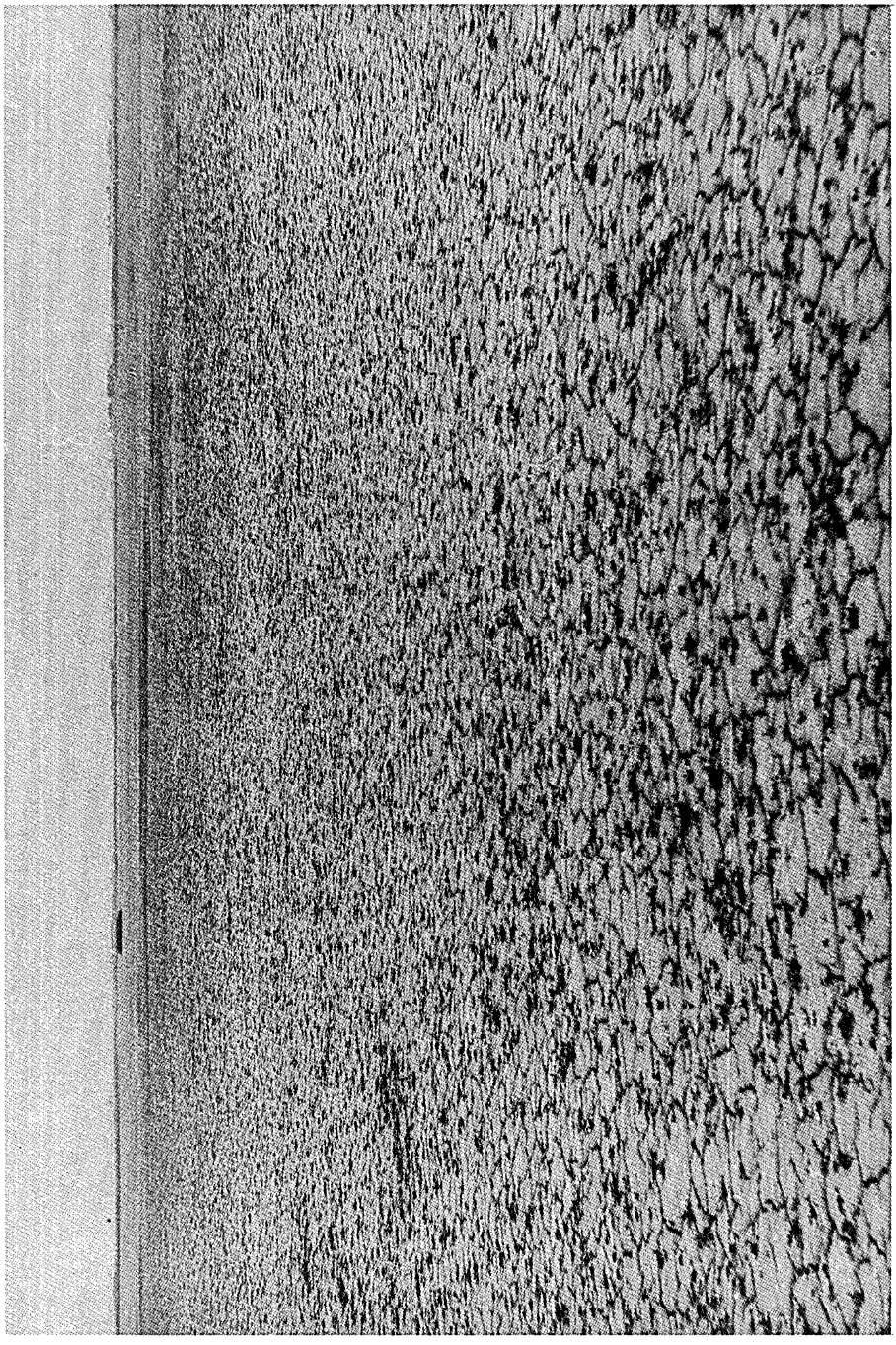


Figure 14.2. Saline soil surface



These profile descriptions show some morphological features of the different saline soils in Europe. As regards the morphology of saline soils in general, they have several common characteristics but differ also considerably.

The basic morphological feature of saline soils is the lack of a structural B horizon. Although several morphological systems use the letter "B", in those cases it never signifies a horizon distinguishable from the A horizon by its well-developed structural formation. Consequently, the profiles of saline soils are rather monotonous, from the surface down to the parent material. In few cases, when saline soils have formed under bog conditions, the top layers are humous, but usually, when they have developed under arid conditions, these soils are very poor in humous substances being lower than 1%. A low plant nutrient content, mainly N and P_2O_2, is also characteristic of most saline soils.

The high salinity determines practically all physical and chemical properties of saline soils. Consequently, when these properties are evaluated, the salt content of such soils and its influence should first of all be taken into consideration.

Many classification systems employ the term "chloride and/or sulphate solonchak" for saline soils (e.g., Figure 14.3).

Alkali soils

In alkali soils the presence of Na salts capable of alkaline hydrolysis determines the soil properties. Due to their effect either the high alkalinity of the soil solution hinders plant growth, or the alkalinity renders the physical soil properties disadvantageous for the water supply to plants. Evidently, often both of these processes exert their harmful influence, though in alkali soils without structural B horizon the former, and in alkali soils with structural B horizon the latter dominates.

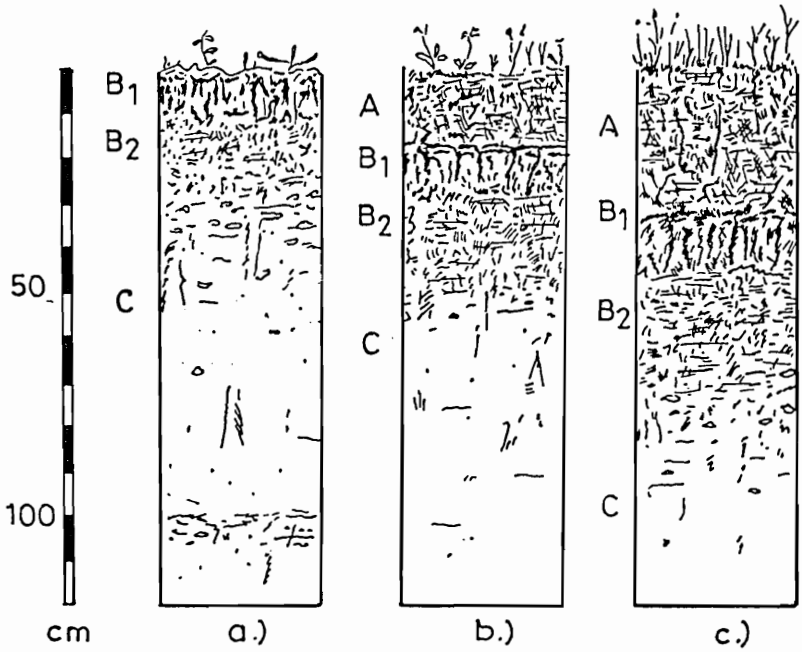
As a rule, in alkali soils without structural B horizon a considerably high concentration of sodium salts capable of alkaline hydrolysis – mainly sodium carbonate – may be found. Of all these salts which commonly occur in soils, sodium carbonate has the most harmful effect on both soils and plants. Thus this subclass represents salt-affected soils which have very disadvantageous properties for agriculture. The fertility of such soils, if any, is very low. Not only the alkalinity but, in most cases, also the salinity of these soils is rather high. This is why in many classification systems they are denominated "alkali-saline" or "saline-alkali" soils. Although sometimes neutral sodium salts may predominate among the water-soluble substances in these soils, nevertheless in most cases the dominant role is played by sodium carbonate owing to its high alkalinity.

While in soils belonging to class A (saline soils) high salt concentration occurs mainly under arid conditions and only in a few cases can such soils be found in other climatic zones. Soil salinity caused by sodium carbonate occurs in arid, moderate, or even in humid climates as well. This phenomenon can be explained by the differences in the geochemical and bio-geochemical processes involved in the accumulation in soils of neutral sodium salts and sodium salts capable of alkaline hydrolysis. Accordingly, the occurrence of saline soils is characteristic mainly of deserts, semi-deserts and very dry steppe regions, whereas alkali soils without structural B horizon may be found in various climatic zones.

In Figure 14.5 schematic profiles of alkali soils with structural B horizon (solonetz) are shown.

Figure 14.4. Saline soils (Hungarian Plain)

Figure 14.5. Schematic profiles of alkali soils with structural B horizon (solonetz)



These soils always have a structural B horizon in their profiles, which, as a rule, has a well-developed structure, mainly columnar. It can be easily distinguished from the horizon above (A horizon), which is less compact and whose structure is less developed. The B horizon determines the genetic type of these soils, their main physical, chemical, physico-chemical and biological properties, as well as their fertility together with the possibilities of their agricultural utilization.

A structural B horizon always differs markedly from the A horizon not only in morphology, colour and structure, but also in its physical, chemical, physico-chemical and biological properties.

METHODS AND RESULTS OF RECLAIMING SALINE AND ALKALI SOILS IN THE DEVELOPED COUNTRIES

As it was discussed above, a wide range of different saline and alkali soils can be found in the developed countries. Consequently the methods of their reclamation must always be specific, in accordance with the given natural conditions, improvement possibilities and economical endowments, and always based on cost benefit analysis.

The reclamation method of a saline or alkali soil must be decided upon after considering the climatic conditions.

Saline and alkali soils in different places and under different conditions have different characteristics parallel with their common features. These characteristics must be taken into consideration when elaborating the methods for their reclamation.

The main characteristic properties of saline and alkali soils are described in Table 14.3.

From the detailed characteristics given in Table 14.3, the following can be inferred:

1. In saline soils, the high content of sodium salt often shifts the pH value towards the alkaline reaction. However, this value as a rule does not surpass 8.3, except in some particular cases. On the other hand, in many saline soils, especially, when a considerable amount of $CaSO_4$ and CaC_2 are present, the pH value may be lower than the neutral level.

   In alkali soils with structural B horizon (solonetz soils), carbonates are frequently missing and, as a consequence, the pH is below 8.3, particularly in the surface layer or near the surface of the soil. In the B horizon of these soils the ESP value is high and, as a rule, exceeds the value of 15. However, in some places, it is somewhat less than ESP 15 whereas in other cases, the value surpasses this percentage, mainly in solonetz soils.
2. In saline soils, the sulphate and chloride anions dominate whereas in alkali soils bicarbonate and carbonate anions prevail. It must be noted that in extremely arid regions nitrates may play a dominant role among the anions of the electrolyte.

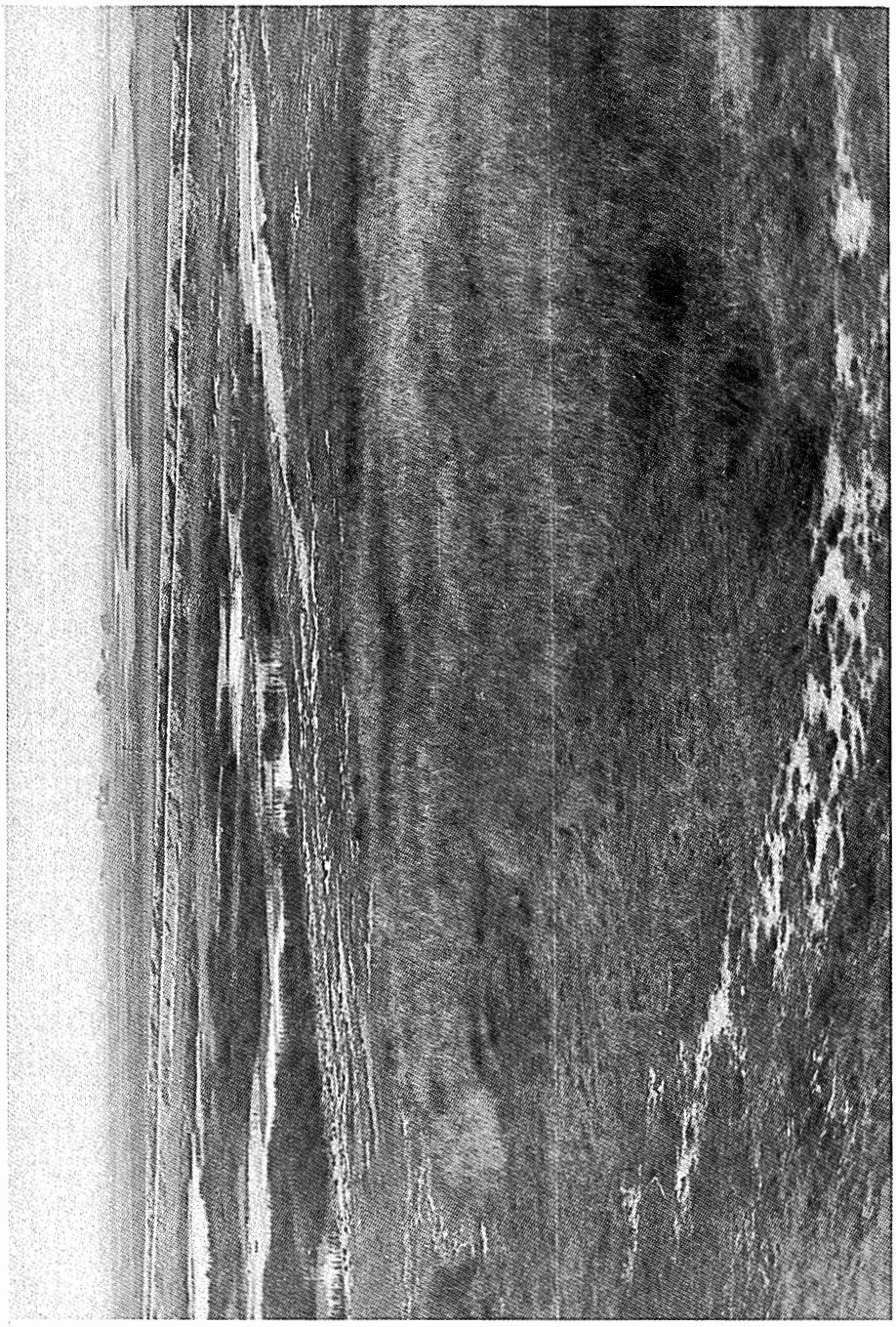
   In general, alkali soils without a structural horizon always contain free alkali carbonates while alkali soils with a structural B horizon do not have free carbonates in all cases. Thus we may distinguish carbonate-free and soda-containing solonetz soils.
3. The main effects of electrolytes on particles, especially on soil colloids in saline-soils, is coagulation. Consequently, in these soils the water-transmission properties, such as the infiltration rate and hydraulic conductivity are more favourable than in alkali soils, in which the alkali-hydrolysing electrolytes exercise a dispersive effect. These differences are the basis of different reactions of alkali and saline soils to drainage and irrigation.
4. In saline soils, the high osmotic pressure of the soil solution, as a result of high electrolyte content, constitutes the main harmful effect on plants. On the other hand, in alkali soils it is the poor physical and water-movement properties of the soil which most frequently impede the growth of plants. The toxic effect of different ions may be felt in both cases, particularly under waterlogged conditions. It should be noted that sometimes the high electrolyte content also exercises a toxic effect. For example, the relative toxicity of six salts occurring in salt-affected soils is roughly as follows:

   $$MgSO_4: CaC_2, NA_2SO_4\ NaC: NaHCO_3: Na_2CO_3 = 1 : 1: 2: 3: 3: 10$$
5. In arid regions, mainly saline soils can be encountered whereas in a moderate climate, the alkali soils dominate among the salt-affected soils. This is a general

Table 14.3. The characteristics of saline and alkali soils

Characteristics	Saline soils	Alkali soils
pH	<8.3	>8.3 somewhere along the profile, or high ESP<15 in horizon B
Chemistry of soil solution	Dominated by SO_4 and Cl anions	Dominated mainly by HCO_3 or CO_3 anions or both
Effect of electrolytes on soil particles	Flocculation	Dispersion
Main adverse/or toxic/effects on plants	High osmotic pressure of soil solution	Alkalinity of soil solution
Geographical distribution	Associated mainly with arid and semi-arid areas	Associated mainly with semi-arid and semi-humid areas
First aim of reclamation	Removal of excess electrolytes through leaching	Lowering or neutralizing the high pH through chemical amelioration

Figure 14.6. Saline soils in irrigated areas



rule, but possibly saline soils may be found in some moderate areas also, if the soil-forming factors such as the high electrolyte contents of the sediments and underground waters, lead to the development of soil salinity. Likewise, the alkalinity of soils may occur exceptionally in desert and semi-desert regions as a consequence of high carbonate contents of sediments and waters.

6. Different approaches should be adopted in the utilization and improvement of saline and alkali soils. The first step of reclamation should be to control the dominant adverse properties. In the agricultural utilization of saline soils, high electrolyte content is the main obstacle to increasing soil fertility and, therefore, the establishment of drainage and leaching systems are the preconditions of effective amelioration.

Reclamation of Saline Soils

In the course of reclaiming saline soils, excess salinity has to be removed, or at least diminished. For this purpose leaching and drainage are two basic methods. The only practical way, according to our present knowledge, for removing excess soluble salts from the soil is by washing them out. Obviously provisions must be made for disposing of the water in order to prevent re-salinization.

Drainage draws the water off, thereby improving saline soils. A proper drainage system for saline soils must be designed in most developed countries to desalinize not only the top soil layer but also the upper subsoil and water-bearing horizons. It will regulate both the water and salt balances of the soil and subsoil.

In the developed countries various types of drainage are used: vertical, deep-horizontal, shallow horizontal, etc. Vertical drainage has given good results in certain soil conditions, particularly when the deep horizons are highly permeable. However, shallow horizontal drainage is still widely used in spite of the fact that it is not always successful.

In the arid parts of the developed countries the reclamation of saline soils is practised mainly in two regions.

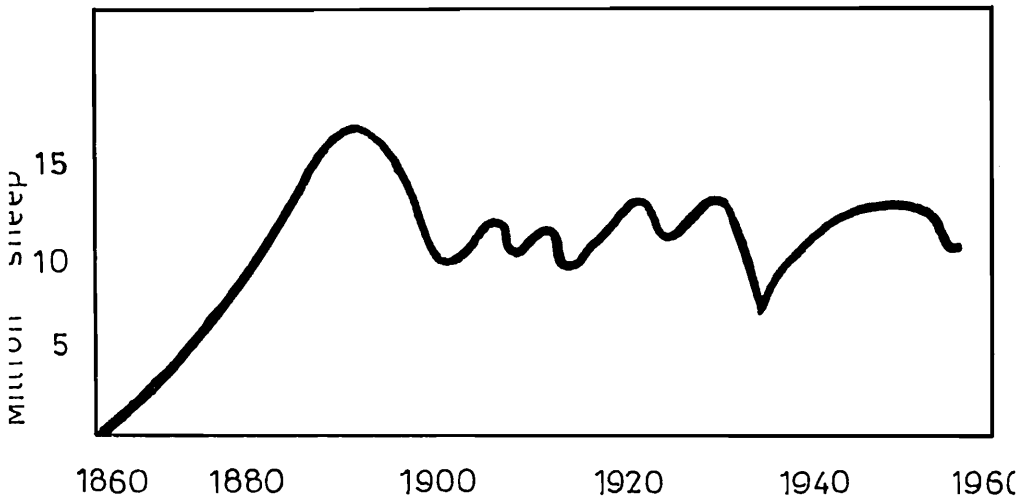
1. The arid and semi-arid territories of the USSR, Kazakhstan, Uzbekistan, Tadzhikistan, Turkmenia, etc.;
2. The arid areas of the USA, Arizona, New Mexico, Nevada, California.

As a third place the deserts and semi-deserts of Australia could be mentioned. In Australia, however, the reclamation of alkali soils has not been frequently practised.

The arid zone in Australia is very large. More than 3200 km from east to west and 2000 km from north to south. It can only be compared in size to the deserts of North Africa and the Middle East. The area of saline soils is rather extended and only partly used for pastoral purposes. Within the rare rangelands all pastoral enterprise is based on the native vegetation. Unlike the USA, there are no large areas of federally owned lands. Each state largely controls all the arid lands within its boundries.

It seems that for the present and future the pastoral exploitation of arid rangelands in Australia remains profitable. The trend is shown in Figure 14.8.

Figure 14.7. The trend in sheep number in the arid zone of New South Wales



A great part of the Australian saline areas belong to national parks.

The main methods for the reclamation of saline soils are very similar in all the developed countries. There are 3 preconditions of effective ameliorations:

1. To keep the water below the critical depth by drainage;
2. To reduce the soluble salt content to 0.4-0.5% in top soils and 2-3 gsl in water. This process can be controlled by irrigation, leaching and drainage;
3. To avoid the re-accumulation of toxic salts in the root horizon, if necessary, by repeated leaching.

In the USA leaching and drainage are planned as far as possible to keep the upper 1 1/2 metres of the soil free of excess salts. Detailed methods are explained for the effective reclamation of saline and alkali soils. The so-called Handbook No. 60, edited by the US Salinity Laboratory, Riverside, California, comprises the recent knowledge and methods in this field.

Similar methods have been elaborated in the Soviet Union where the effective leaching of solonchaks under conditions prevailing in Central Asia and in the Caucasus takes place in late autumn or in winter when the soil moisture is low and the water table deep.

The leaching process should begin on lower lying areas and work up gradually onto higher ground.

For the reclamation of saline soils simple leaching with water of sufficient quality and quantity will only be effective if the saline soil or the applied water contains a certain amount of gypsum. In this case during leaching the absorption of sodium ions by soil particules from diluted solutions is hindered. Only in such cases can the harmful salt content be removed without residual alkalinity in the soils. If no gypsum is available during leaching, the soil particules will absorb sodium ions from the solution and the saline soil will develop into alkali soil.

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To avoid this phenomenon the application of gypsum along with irrigation and drainage has been widely practiced in the reclamation of saline soils.

The application of gypsum or other chemicals, sulphur, calcium chloride, calcium nitrate, etc, is inevitable in the reclamation of alkali soils, particularly where they lack the structural B horizon.

Vast territories of saline soils have been improved in developed countries during the last decades. Unfortunately no exact data are available on the sizes of these soils. On the other side, due to improper methods of irrigation, similarly large territories have been salinized during this time in the mentioned countries. The conclusion can be drawn that the extent of saline land has not diminished in the arid regions of the developed countries. Still, it is a fact that many efforts and attempts were devoted to the elaboration of proper methods for land reclamation and they brought both scientific and economic results.

In the USSR saline soils have been widely irrigated (Figure 14.8) and in Table 14.4 the length of drainage canals are demonstrated which, in combination with irrigated farming, contributes to the amelioration of arid lands.

Figure 14.8. Salt profiles of soils. Profiles 1–3 correspond to the groups described in Table 14.6

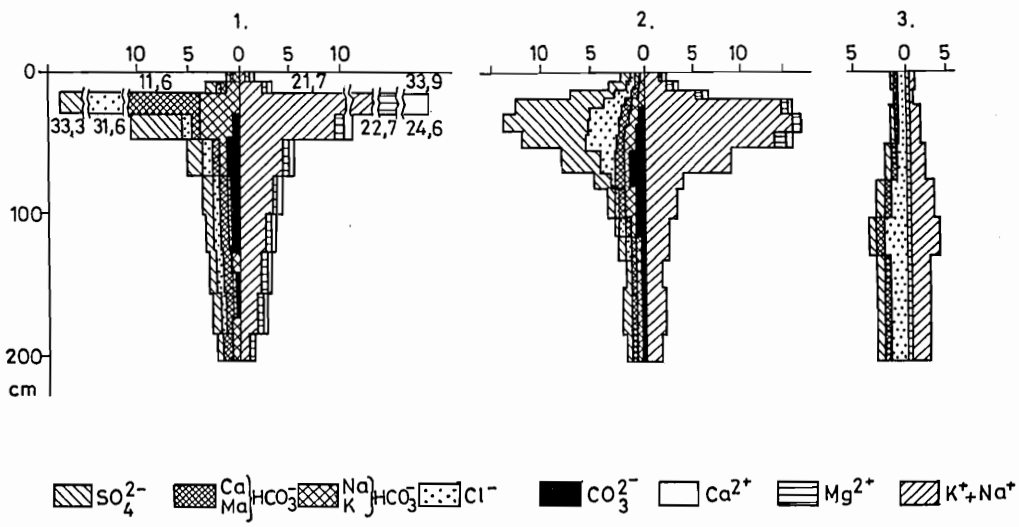


Table 14.4. The length of drainage canals in the arid regions of the USSR in kilometres

Republic	Total length of canals
Uzbek	28,755
Turkmen	2,721
Kirghiz	1,978
Tadzhik	4,194
Azerbaidzhan	4,863
Kazakh	607
Georgian	1,458
Armenian	15
Total	44,491 kilometres

Reclamation of alkali soils

Alkali soils may develop under very different natural conditions, from the permafrost areas to the humid tropics. Alkali soils occur much more often in the developed countries than saline soils. In developed European countries, for instance, the territory of alkali soils is more than 5 times that of the saline soils.

Alkali soils often occur in areas where the precipitation and other conditions are very favourable for rain-fed agriculture and only soil alkalinity hinders good production.

From the above it can be inferred that the reclamation of alkali soils must be more diverse and specific than that of the saline soils.

Alkali soils are extended also in those developed countries which have been mentioned before in connection with saline soils. In the European part of the Soviet Union alkali soils cover vast territories. There are more than 18 million hectares of different alkali soils in these parts according to Table 14.5.

In the USA the occurrence of alkali soils is also very frequent in the states of Illinois, Idaho, Ohio, Indiana, Montana, etc.

Table 14.5. The extent of alkali soils in the European part of the USSR

Belt	Alkali soils in thousand hectares
Chernozem	2.450
Dark chestnut soils	5,400
Light chestnut soils	10,350
Total	18,200

In Australia the improvement of alkali soils is more common than those of saline soils. In the fertile valley of the River Murray and in the various territories of New South Wales, Victoria, Queensland and South Australia the combat against soil alkalinity is one of the most mportant problems both for rain-fed and irrigated agriculture.

In the western hemisphere Canada, which practically has no saline soils, has extensive areas of alkali soils particularly in Alberta, Saskatchewan and other provinces and territories.

It is a general principle that before the reclamation of an alkali soil it is to be determined whether it has a structural B horizon.

In many classification systems alkali soils are named solonchak solonetz, solonetz or solod soils. The dominating group among these types is the solonetz. That is why the terms "alkali soil" and "solonetz soil" will be used in the following as synonyms.

The solonetz soils in a dry region should be reclaimed either under irrigated or non-irrigated conditions. The degree of aridity and the expected crop yield determine whether the reclamation can be succesful without irrigation.

In moderately or non-arid areas the groundwater conditions play an important role not only in the formation of alkali soils but also in their utilization.

In the technical literature widely differing data may be found concerning the utilization and reclamation of solonetz soils in the various developed countries. These differences are caused partly by the widely varying local conditions, including climate, parent material, level of agricultural technology, etc. The different salt profiles and salt dynamics – with particular regard to the depth and the quality of the groundwater – exercise a decisive influence not only on the genetics of solonetz and solod soils but also on the possible methods of their amelioration and utilization. In this respect these soils may be subdivided into three main groups:

1. In the case of solonetz and solod soils where the soil profile and the top layers are linked through capillary forces with salty ground water. The horizons A_1, A_2, B_1 and B_2 contain about 0.2% or more water soluble salts in the surface layer, and 0.5% at a depth of 40-50 cm. The leaching out of salts and drainage are therefore unavoidable. In this case the reclamation of solonetz and solod soils may be similar to that of solonchak, saline or soiss.

   As regards leaching, it may be carried out either by applying irrigation water of good quality and by providing good drainage or – under more humid conditions, when the annual precipitation is enough to leach out the salts – by lowering the water table below the critical level. Chemical amendments should also often be applied parallel with the above mentioned measures or afterwards, especially in the case of heavy textured soils, in order to replace the adsorbed Na^+ in the colloidal fraction by calcium. In certain cases solonchak-solonetz soils may also be reclaimed this way.

   As regards the genetics of solonetz and solod soils, mainly the meadow solonetz and meadow solod soils belong to this group. Some genetical and other properties of these soils are presented in Table 14.6, whereas in Figure 14.8 schematic salt profiles are shown.

Table 14.6. A schematic grouping of solonetz and solod soils with regard to their amelioration

Genetic type	Relation with ground water	Water soluble salt content in the surface layers	Amelioration+
1			
solonchak-solonetz meadow solonetz meadow solod (shallow and middle)	permanently linked	more than 0.2% (about 4 mmhos)	drainage and chemical amendments
2			
meadow solonetz and solod soils turning into steppe formation	temporarily linked	about 0.2% (about 4 mmhos)	chemical amendments, deep ploughing and drainage if necessary
3			
deep solonetz and solod soils, solonetz-like meadow soils	not linked	less than 0.2% (about 4 mmhos)	low amount of chemical amendments proper agrotechnics and suitable crop (deep ploughing, alfalfa, etc.)

+The necessity of irrigation depends on local conditions.

2. If the profile of a solonetz or solod soil is only temporarily linked with groundwater, and the salt content of the A, A_1 and B horizons is lower than that of the soils belonging to the first group, drainage is not always necessary. Informative data and profiles are presented in Table 14.6 and Figure 14.5. In these cases the application of chemical amendments such as gypsum and or others as well as deep-ploughing and loosening of the subsoil may be useful. If in the B_2 and C horizons the quantity of water soluble sodium salts is not high and a considerable amount of gypsum is present, in the course of deep-ploughing it can be utilized as reclamation material. Depending on the local conditions, amelioration may be carried out either with or without irrigation. Under irrigated conditions, however, the provision of good drainage is more important. Soils belonging mainly to this group are often called meadow solonetz and solod soils turning into steppe formation.
3. If the profile is not linked with the ground water, the salt content in the upper layers of the profile should be the most important consideration when the suitable amelioration method is selected. In these cases when the present, natural soil formation processes assure, to a higher or lesser degreee, the leaching out of water soluble salts, drainage must be satisfactory. Frequently these soils are only moderately solonized and/or solodized. Their exchangeable Na_+ content is less than 10-15% of the cation exchange capacity, and it may be found in a comparatively deeper layer, at more than 15–20 cm below the surface.

In the case of these soils, it is possible to employ non-expensive and simple reclamation methods with good results because the basic aim of reclamation is to facilitate natural leaching out processes. The climatic conditions, the possibility of irrigation, etc. are also decisive factors when the proper methods are chosen to remove the salts and to improve the physical soil properties. Chemical amendments, deep-ploughing and subsoil loosening may be used as indicated above, but the use of proper agrotechnics and the selection of the most suitable plants are very important. Soils belonging to this group are mainly called steppe solonetz and solod soils, and solonetz-like meadow and other soils.

A good example of solonetz amelioration can be found in the Hungarian Plain where various salt-affected soils occur including all that belong to the above described three groups and where experiments were conducted with alfalfa cultivation on a deep solonetz soil. Alfalfa was grown from 1956 to 1963 and it was regularly irrigated from the second year. The salt content of the profile was determined at the beginning and at the end of the experiment. As can be seen in Table 14.7, both the dry and the ignition residues of the aqueous extracts of the soil samples considerably diminished in the upper layers of the soil profile due to cultivation of alfalfa. In the deeper layers, however, the accumulation of certain ions could be observed. The decrease in the amount of cations Na and Mg was remarkable just as that of the anions of bicarbonates bound to Na cations. The water soluble humus content of the upper layers, which is one of the features of solonetz process, was also considerably diminished as a result of alfalfa cultivation.

Significant changes occurred in the exchangeable cation contents of the soils (Table 14.8). In the upper horizons the amount of exchangeable sodium was reduced to a small fraction of the initial quantity and a similar trend appeared in respect of the

Figure 14.9. Alkali soils in Hungary

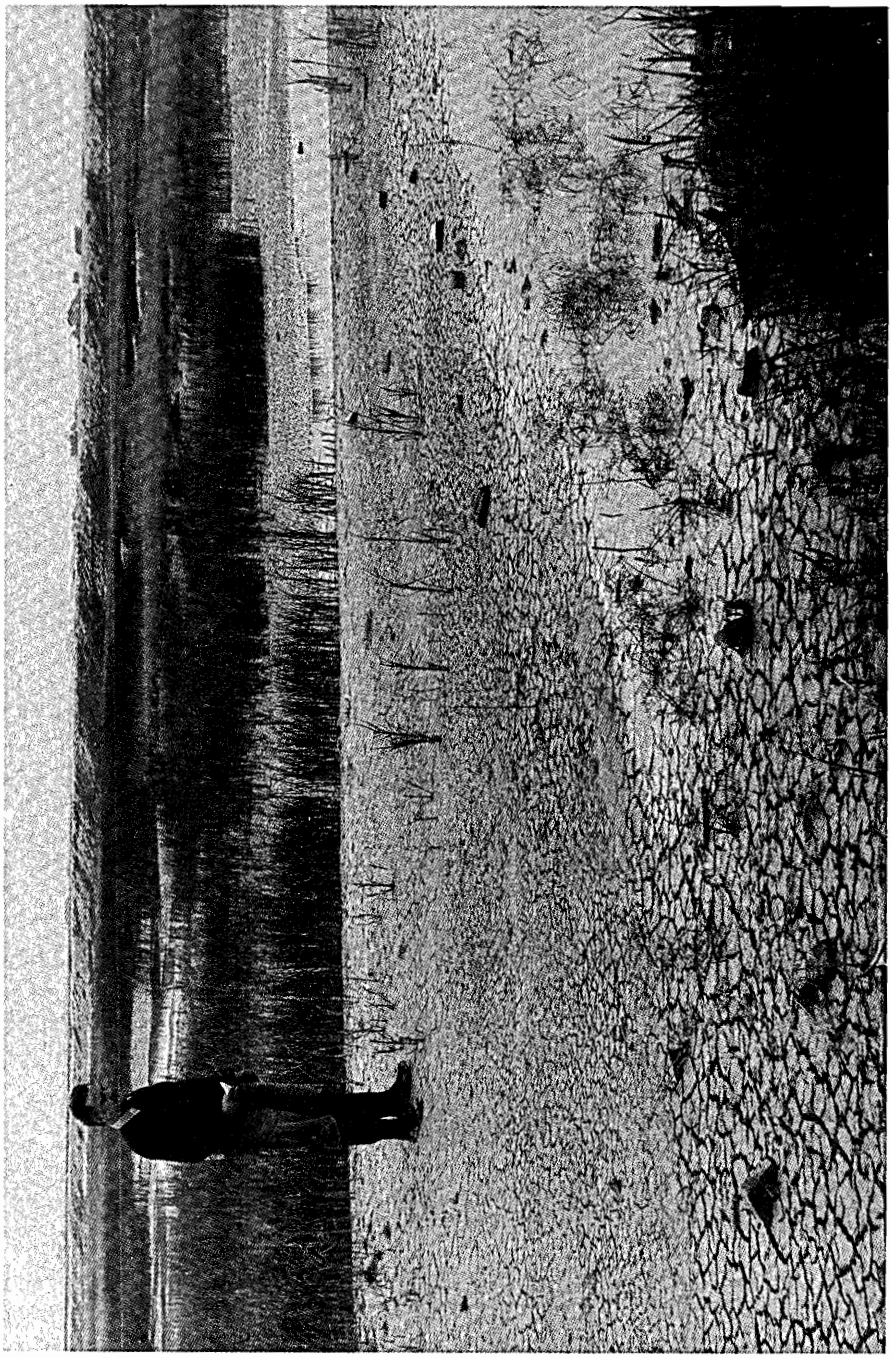


Table 14.7. Analysis of the aqueous extracts of a solonetz soil before and after growing alfalfa on it under irrigated conditions

Depth cm	Dry residue	Ignition residue	Humus	Alkalinity				Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$
				Na_2CO_3	HCO_3^- /Na, K/	HCO_3^- /Ca, Mg/	HCO^-					
0– 20	0.133	0.064	0.016	Ø	1.196	0.105	1.302	0.120	0.354	0.729	0.088	0.817
20– 40	0.148	0.079	0.018	Ø	1.391	0.088	1.479	0.120	0.250	0.284	0.129	0.413
40–	0.229	0.139	0.016	Ø	1.637	0.153	1.796	0.190	0.371	0.513	0.026	0.539
60– 80	0.176	0.068	0.021	Ø	1.567	0.211	1.778	0.180	0.250	0.256	0.142	0.398
80–100	0.236	0.090	-	Ø	1.549	0.130	1.680	0.160	0.208	0.437	0.017	0.448
100–120	0.187	0.104	-	Ø	1.391	0.034	1.426	0.120	0.437	0.329	0.088	0.417
120–140	0.165	0.063	-	Ø	1.567	0.017	1.585	0.140	0.300	0.336	0.169	0.505
				1964 (after amelioration)								
0– 20	0.056	0.026	0.002	Ø	0.441	0.338	0.779	0.127	0.052	0.585	0.016	0.379
20– 40	0.048	0.018	0.002	Ø	0.441	0.252	0.693	0.132	0.162	0.330	0.197	0.544
40– 60	0.078	0.049	0.002	Ø	0.398	0.400	0.798	0.093	0.829	0.180	0.090	0.470
60– 80	0.184	0.171	Ø	Ø	0.926	0.020	0.946	0.144	3.775	0.405	0.362	4.378
80–100	0.168	0.136	Ø	Ø	0.926	0.398	1.324	0.096	2.979	0.385	0.148	4.047
100–120	0.119	0.114	Ø	Ø	1.009	0.295	1.305	0.124	1.652	0.195	0.131	2.953
120–140	0.098	0.071	Ø	Ø	0.967	0.211	1.179	0.124	0.702	0.150	0.007	2.815

Table 14.8. Exchangeable cations of a solonetz soil before and after growing alfalfa on it under irrigated conditions

Date of sampling	Depth cm	$Na^+ + K^+$	Ca^{2+}	Mg^{2+}	CEC	$Na^+ + K^+$	Ca^{2+}	Mg^{2+}
		me/100g				in % of CEC		
	0–20	7.6	12.3	8.1	28.0	27.1	43.5	28.9
1956	20–40	12.5	15.7	23.4	51.6	24.2	30.4	45.3
	40–60	14.7	5.4	18.3	38.4	38.2	14.0	47.6
	0–20	0.39 0.59	26.20	5.76	32.94	3.06	82.03	18.02
1964	20–40	0.83 0.49	23.95	5.78	31.05	4.23	77.21	18.56
	40–60	4.35 0.50	32.20	13.16	41.21	11.76	56.31	31.93

Table 14.9. Influence of complex amelioration works on ESP at Rusetu, draining variant with ceramic tubes at 1.80 m depth and 50 m row space (Obrejanu-Sandu)

Leaching norm, m^3 of water/ha	Solonchak-like solonetz			Leaching norm m^3 of water/ha	Solonetz with columns shallow depth	
	Depth m	Doses of amendment without phospho-gypsum	Doses of amendment 15 m.t. phospho-gypsum per ha	15 m. t.	Doses of amendment phospho-gypsum per ha	Doses of amendment lignite dust per ha
7,500	1	30.89	20.36	10,000	13.62	16.83
	0.00–0.15 2	13.84	16.28		11.88	13.74
	3	10.18	5.92		9.40	13.50
	1	28.47	43.56		29.61	25.23
	0.15–0.30 2	23.47	25.35		26.82	14.18
	3	11.19	17.91		11.28	10.85
	1	25.50	40.84		26.25	28.33
	0.30–0.45 2	29.04	27.86		23.92	23.05
	3	24.20	22.96		23.60	19.45
	1	30.60	46.22		32.36	30.00
	0.45–0.60 2	27.42	34.64		23.11	21.80
	3	16.52	29.51		21.88	16.19

1 = Before leaching/ after levelling/ 2 = After first leaching 3 = After second leaching

exchangeable magnesium ions. On the other hand, the amount of exchangeable calcium increased in the upper layers during the experiment. This may partly be explained by the beneficial effect of alfalfa on the dynamics of cations due to the root system of this crop transporting the calcium ions from the deeper layers to the upper ones. This presumption seems to be supported by the fact that in the deeper horizons no such change occurred.

From the methods of reclamation and utilization of solonetz and solod soils described above in three groups, selection must always be made with great care, and the one chosen will have to be adjusted to the local conditions. The chemical type of the salt contents is very important and must be taken into account when the proper method of reclamation is opted for. In case of soda soils, for instance, the limit values of the admissible salt content in the soil profile are much lower than when the salinity is caused by neutral sodium salts.

As compared to neutral salt types, in the case of soda soils not only a lower level of salinity is required for the successful amelioration, but in order to eliminate or at least lessen the detrimental effect of sodium carbonate, the application of acid chemical amendments – as a factor of reclamation – is practically always necessary.

In most developed countries, first of all in the USA, the application of gypsum is the main method for the chemical amelioration of alkali soils. Many classical examples of this country as well as of the USSR demonstrate the efficiency of this method. However in many cases other chemicals of acidic reaction or capable of acidic hyrolysis are used as amendments. There are several by-products of mining and industry which are applicable for the improvement of alkali soils. One of these by-products of fertilizer factories is phosphogypsum whose effectivity is based on its high sulphate contents.

In the alkali soils of the Rumanian Lowland, good results were gained by the application of phospho-gypsum and leaching as shown in Table 14.9.

Figure 14.10. Changes of pH and harmful sodium contents of a Bulgarian alkali soil when ameliorated, with 13.2 t/ha calcium chloride. (After Raikov)

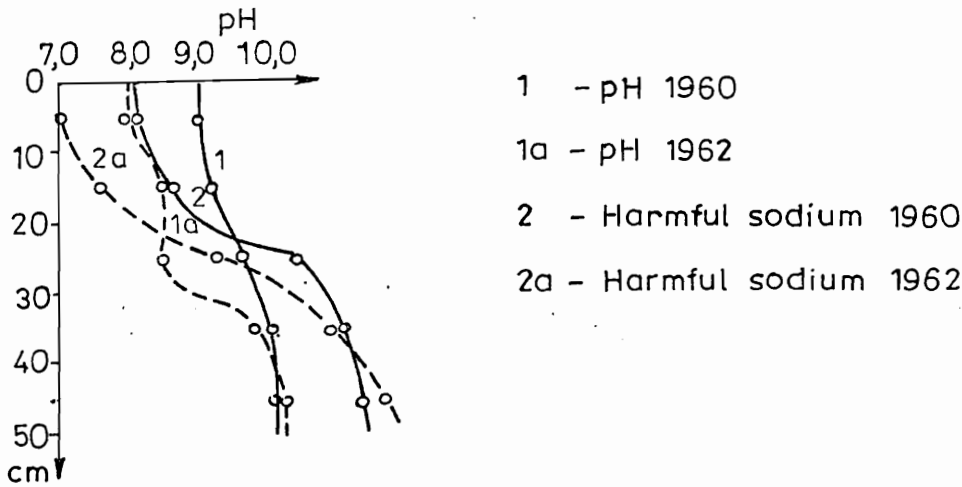


Figure 14.11. Alkali soil surface with waterlogging

Besides gypsum other calcium salts, like $CaCl_2$ or $Ca(NO_3)_2$ also act as ameliorants of alkali soils. As for the calcium nitrate it is at the same time a N fertilizer. Its application can both improve the soil and nourish the crop.

Bulgarian soil scientist Raikov, (see Szabolcs, 1971) gained good results with the application of calcium chloride in Bulgarian alkali soils, as it is shown in Figure 14.10.

In many countries of Central and South-East Europe as well as in certain regions of the USA and Canada, alkali soils with structural B horizon have a rather deep A horizon. The pH of these horizons is often more or les acidic because of the lack of calcium carbonate and the depth of the A horizon. It is a traditional method, particularly in Hungary and neighbouring countries, to improve these soils by the application of materials containing calcium carbonate, lime powder or lime sludge.

Table 14.10. Influence of liming and nitrogen application on hay yields on alkali soils with irrigation in metric tons per ha over an average of 5 years

N kg/ha	Unlimed	Limed	Mean	%
Ø	5.24	5.89	5.56	100.0
50	6.39	6.88	6.63	119.2
100	7.59	8.26	7.93	142.6
150	9.07	9.24	9.20	165.5
200	9.61	10.22	9.92	178.4
L.S.D. at P = 0.05	7.7		5.4	9.7
Mean	7.58	8.12	7.85	14.19
%	100.0	107.1	103.6	

Source: I. Latkovics

The calcium ions will partly improve the water movement, physical and structural properties of the soil in the horizon A and they will also have a beneficial effect on its chemical properties. In Table 14.10 the effect of liming and nitrogen fertilizers on hay yields is demonstrated in the alkali soils of the Hungarian Plain.

In the Mediterranean region, in Spain, various alkali soils developed in the delta of the River Guadalquivir. The marshes were formed by the deposit of small solid elements and precipitated in a saline sodic liquid environment (sea water). This formation gave the main characteristics to the soil. The clay suspended in the river waters fixed sodium on its exchange complex and lost its calcium. Because the soil had been formed from expansive sodic clays, it had extreme impermeability.

The soil was practically covered in winter by rain or overflowing water, which remained until evaporated. On the somewhat higher soils into which water flowed by gravity, the vegetation was halophytic with very superficial roots. The most common natural vegetation comprised *Salicornia fructicosa, Salicornia herbacea, Scirpus maritimus, Juncus maritimus* and *Cynodon dactylon* of little economic value. The plants were parched and died as soon as summer arrived.

The reclamation of these areas has been carried out in the following way:

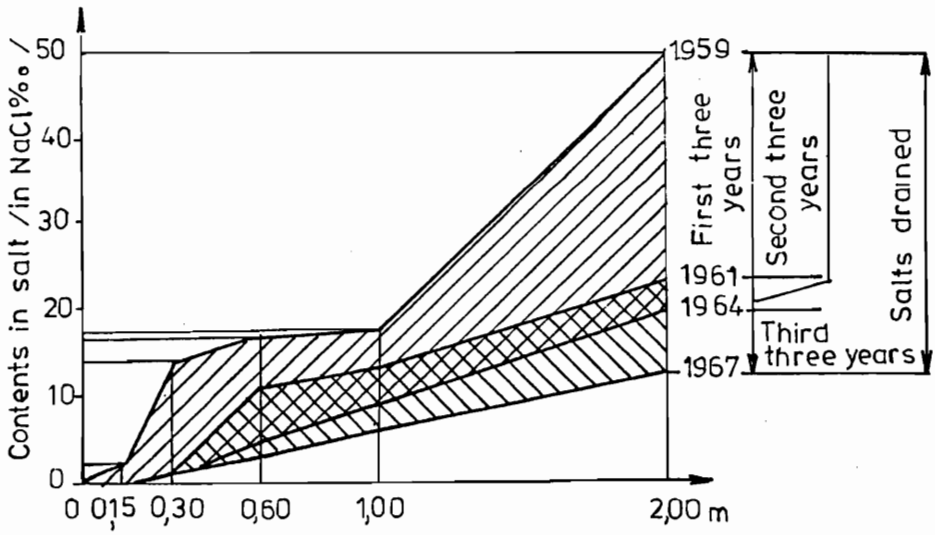
(a) The terrain was enclosed to avoid the entry of sea and river water;

(b) An efficient drainage network was designed to promote leaching;
(c) Subsoil work was done to give the soil an artificial permeability.

Table 14.11. Some productive characteristics of a representative Canadian solonetz and its field associated non solonetz soil

	Duagh silt loam solonetz	Malmo silt loam eluviated black
Yield of bromegrass kg/ha	900	3,630
Main root mass penetration (cm)	23	50

Figure 14.12. Loss of salinity in the soil-variation in depth



These three steps were taken to remove sodium and to mobilize the native calcium.

Analysis of the drainage water showed that sodium was being removed and a study of the piezometer levels showed no significant water rise.

By this method long areas of fertile land have been gained from former sodic marshes. This operation is one of the most attractive examples for the reclamation of salt-affected soils in the Mediterranean region.

In Canada the most outstanding results in the reclamation of solonetz soils were obtained at the Solonetz Reclamation Station, Vegreville, Alberta. In Table 14.11 some characteristics of Canadian solonetz and non-solonetz soils are shown.

The method of reclamation consists of two parts:

(a) Biological method: The solonetz soils of Canada are very deficient in available

nitrogen. This deficiency arises from at least two obvious factors: 1. The A horizon contains little total nitrogen per unit volume and 2. the depth of the A horizon is much less than that of its associated non solonetz soil. By correcting this nutritional deficiency in the field, significant soil amelioration was achieved. Annual applications of ammonium nitrate to bromegrass growing on a black solonetz soil gave the following results: Over a five-year period the average yield per year was 1,506 kg/ha on the check plots, 4,794 kg/ha on the plots receiving the 150 kg N ha -1 and 6,779 kg/ha on the plots receiving the 300 kg N ha-1.

(b) Deep plowing method: Plowing a solonetz soil to a depth of 56 cm, as compared with ordinary plowing (10 cm), greatly reduced the soluble salts, particularly sodium sulphate throughout the 150 cm sample depth. It also reduced the percentage of exchangeable sodium.

The method of deep plowing is very similar to that which was described earlier.

It is very interesting that alkali soils may also occur in rather high altitudes, for instance in the Ararate Plain in Soviet Armenia, about 500 metres above the sea level. Here the alkali soils lack the B horizon, so their amelioration is a difficult process involving the application drainage and chemical amendments. G.P. Petrosian and his colleagues used sulphuric acid and iron sulphate for the successful reclamation of these soils.

The positive effect of the by-products of the mining industry containing green vitriol has been experimentally proved. Apart from neutralizing the alkaline reaction, the application of green vitriol gives rise to a sharp increase in soil permeability and the removal of readily soluble salts. The experiments have shown that the application of half of the equivalent- with respect to sulphuric acid- dose of green vitriol ensures a positive reclamative effect.

In Australia, particularly in the state of Victoria, gypsum and related materials, combined with proper agrotechnical machinery, are the agents for the reclamation of alkali soils.

The method of reclaiming alkali soils in Australia is very similar to the techniques used in Canada and Europe. In the modern farming of Australia the application of chemical amendments and proper agrotechnics makes it possible to gain good yields on alkali soils.

We could only present a few examples above of the different results of reclamation of alkali soils. However, they are characteristic of the improvement of salt-affected soils as it is done in the developed countries.

RETROSPECTS AND PROSPECTS FOR THE RECLAMATION OF SALT-AFFECTED SOILS IN THE DEVELOPED COUNTRIES

In most developed countries there are good data on the extension of salt-affected soils as well as on reclaimed lands. However, as it was mentioned before, we have no

evidence to the effect that in any of the developed countries the salt-affected areas have substantially diminished. The total territory of salt-affected soils so improved does not alter significantly the area of still existing saline and alkali lands. From this it can be concluded that, if the reclamation of soils in developed countries continues at the present rate, it can, at least, counter-balance the process of soil salinization and alkalinization in those countries.

The main limiting factor of the recent reclamation projects of saline and alkali soils in the developed countries is that such measures are rather expensive. It is impossible to give a general cost benefit analysis of reclamation work because there are huge differences of cost and return of such measures under different natural conditions and systems of government having different economical, fiscal and even more different subsidy regulations. The availability of amendments for reclamation purposes also makes the problem of investments and returns very difficult. Recently, as a general rule, developed countries have carried out reclamations of saline and alkali soils when the returns were expected to offset the investments, at least partly, in or a few years of agricultural production. Evidently there are exceptions but great progress in soil reclamation will only be possible if the necessary investment diminishes. It is unforeseeable when and where the necessity of food and raw materials would make the reclamation of salt-affected soils economical in those countries where at present it is considered non-economical. Nobody can predict what the value and availability of food and other materials produced on soil will be in 2000. But the problem will not only remain actual but also of first rate importance for soil scientists as well as politicians and for all people in general.

If vast salt-affected territories must be completely reclaimed, very large national and international efforts will be necessary to elaborate the appropriate plans and even more to realize the amelioration. Such projects must be huge and, as a rule, more associated with the whole environment, water, air, communal establishments, etc. than it has been up to now in most soil reclamation projects.

Nobody knows when the pressing demand for more food and raw materials will make imperative the transformation of the salt-affected wasteland existing in the developed countries into fertile soils. Evidently, it depends on many natural and political factors which are difficult to foretell. But as much can be stated that one of the most important tasks of our science is to study the problem, seek its solution and be prepared with appropriate knowledge, methods and models whenever the time comes for such large-scale amelioration projects in the developed countries.

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CHAPTER 15
The Significance of Desertification

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INTRODUCTION

DESERTIFICATION CONSTITUTES A serious potential threat to the future of world food production – but in a rather more complex way than is represented in most of the arguments and figures published so far. The circumstances of the discovery of desertification led to a particular structuring of the campaign to combat it. From the beginning the campaign held the seeds of conflict in the form of political imbalance. The data that were gathered to further the campaign have served to fuel the conflict. Not only is the conflict not yet resolved: it has received little open discussion. Meanwhile, the campaign languishes.

This chapter seeks to disentangle some of the complexity in the desertification debate, in order to bring the problem into better perspective, so that its future significance can be realistically assessed. The presentation falls into four sections. The first reviews the background to the campaign. The second discusses the organisation of activities and of information, giving special attention to the inherent conflicts of interest that have (it is suggested) been responsible for the difficulties encountered in formulating and implementing practical measures to combat desertification. The third looks at the concept of desertification, as it has developed and continues to develop, as a rationalisation of the ideas generated in the campaign. The final section outlines the prospect for dealing with desertification insofar as it may affect food production at the global level, and formulates an approach to it that may be not only more acceptable politically but more comprehensive scientifically.

BACKGROUND

The modern consciousness of ecological degradation can be traced back at least to the nineteenth century; the conviction that degradation cannot be allowed to continue began to appear only in the 1950's when the international development effort got under way and the limits of the world's capacity to produce enough food to satisfy anticipated levels of demand seemed to come within sight. That development effort was based on the assumption, very simply, that increased production and improved health and well-being (and reduced population growth) could be induced by the injection of investment and the transfer of technology into existing low-growth systems of production. In the 1960's, as it became clear that results were falling considerably short of expectations, this assumption began to be questioned. At the same time ecological degradation was diagnosed by specialists as endangering the overall success of the effort. Implicit in this diagnosis was the related assumption that such degradation was not only increasing and intensifying but was caused by the traditional systems that development was designed to transform. The situation was particularly grave in areas subject to either continuous or regular annual water deficit – the world's drylands.

Initially the Sahelian drought which lasted from 1968 to 1973 and had particularly severe effects in many areas that had recently been the scene of intensive development efforts, can now be seen to have dealt the deciding blow to the paradigm of development that was based on those assumptions – although at the level of implementation the change has been slow, largely because of the difficulties of operationalising and mobilising the concepts that have begun to take their place. The effects of drought also led to the formal establishment, at the official level, of the term "desertification," when at the end of 1974 the United Nations General Assembly passed a resolution calling for an international conference on desertification (UNCOD), to be held in 1977.

Since the case for a campaign against desertification is *prima facie* ecological and is argued in ecological terms, while the case for development is economic and social and is argued in economic, social and political terms, it tends not to be recognised that both spring from different orientations towards the same historical process – the struggle of increasing numbers of people for an optimum distribution of available resources.

The difference in orientation reflects a difference in social background and social identity. Failure to see the intimate relationship between desertification and development is not surprising since the two concepts derive from different orientations towards various aspects of the global food supply problem. To put it simply, desertification implies that people must change their ways to fit nature; development implies that the use of resources must be rearranged with the aid of newly available technologies to fit policy requirements. Neither gives sufficient attention to the often intractable nature of social or cultural factors. The effects of the Sahelian drought were so startling that for a time the ecological emphasis implied in the concept of desertification eclipsed the development orientation. A chronological survey of the

literature since the early 1970's shows that enormous progress has been made towards resynthesising the two orientations, but we have still not brought the problem of desertification fully into perspective. The United Nations Organisation has played the major organising role in the desertification-development debate. (It has possibly been able to do this only because of the pervasive, but mistaken, sense – especially early on – that desertification is an ecological and not a political problem. As the political dimensions of the problem have become clearer the coherence and cohesion of the United Nations' organising role have dissipated).

The resolution of the United Nations General Assembly specified that "a world map should be developed showing areas vulnerable to desertification, all available information on desertification and its consequences for development should be gathered and assessed, and a plan of action to combat desertification should be prepared with emphasis on the development of indigenous science and technology" (UNCOD 1977a). Between early 1975 and the summer of 1977 the UNCOD Secretariat, aided by various United Nations agencies and a number of interested governments, accumulated and synthesised an impressive amount of information on the nature of desertification, the rate of its advance and the seriousness of its effects (although they were not able to do much on indigenous science and technology, since the apparatus for gathering and organising this information was not available to them, and in fact barely exists), and compiled a draft Plan of Action which if passed by the Conference would provide the basis of corrective action at the national, regional, and international levels. This draft was discussed and modified at five regional meetings and again at the Conference itself, where it arrived at its final form. Unanimous approval of it (in a form significantly modified to accord with political considerations) constituted the culmination of the Conference. So far efforts to implement this Plan of Action have been disappointing.

At the present time it would seem that everyone – all governments – acknowledge that desertification is a serious global problem, but similar unanimity is lacking on the analysis of its component processes and on how it is related to other problems that are also considered serious. As a result there is significant disagreement about how the problem should be dealt with. The Plan of Action states *what* should be done, but not *how* it should be done. More exactly it states what should be done politically and economically to combat desertification, but it does not (and could not, even if the compilers and the delegates were conscious of them) attack the political and economic conditions that are an integral component of desertification processes. It is symptomatic of this situation that neither the Desertification Unit, set up in Nairobi to co-ordinate the Plan, nor the intergovernmental Consultative Group, which includes representatives of both prospective donor and recipient countries, and which met twice in May 1978 and March 1980 to facilitate the organisation and especially the funding of the measures agreed on in the Plan, have produced tangible results. It appears that governments generally do not perceive desertification (as it is presently defined), to be among the most pressing of their problems, whether it is viewed in local or in global perspective.

In the context of this volume these governmental perceptions demand a careful reconsideration of the campaign to combat desertification. The hypothesis that

underlies the reconsideration that follows is that desertification must be reconceptualised – if anything is to be gained from its discovery. The original conceptualisation, insofar as it was ever expressed in a generally accepted definition, was partial and inadequate as a result of stunned reaction to the efficient cause, which was the natural disaster in the Sahel. With the lapse of time a more balanced definition should be possible, that would take into account the intimate interrelation of desertification and development.

THE ORGANISATION

The desertification debate has been dominated by UNCOD and the bureaucratic processes leading up to it and deriving from it. The nature of the problem can be seen in some of the conflicts that developed at the Conference itself.[1]. The delegates were presented with a comprehensive synthesis of existing knowledge, examples from twelve countries of experience in specific projects, and six feasibility studies demonstrating practical ways to achieve supranational co-operation (that is, co-operation at the level of ecological and regional rather than national and political units) to combat desertification.[2] On the basis of this material they were told that they should accept existing knowledge as adequate for the immediate purpose of establishing an international Plan to combat desertification. They should therefore devote their attention during the Conference to the problem of organising the successful application of this knowledge. They were told that their task lay in the organisation of programmes and resources in order to make possible (in the words of the Plan of Action) "the immediate adaptation and application of existing knowledge." For, "Desertification can be halted and ravaged land reclaimed in terms of what is known now. All that remains is the political will and determination to do it" (UNCOD 1977a). Like all U.N. conferences, therefore, UNCOD was – implicitly at least – a political conference, in that it was concerned primarily with organisation.

Organisation on this scale transcends the province of ecology where desertification was diagnosed. Answers to the problems of ecological management inevitably beg questions of management of the political economy. As often happens in such international forums, the discussions were conducted on two levels. While ostensibly the delegates were discussing means and guidelines for the organisation of programmes in which they would co-operate to mobilise resources and combat desertification,

1. The argument of this section appears also in Spooner and Mann 1982.
2. These transnational Projects, of which there were six – two ecological monitoring projects in Southwest Asia and South America, two greenbelt projects in the North African and Sahelian coutnries, a livestock stratification project in the Sahel and a ground water conservation project in Northeast Africa and the Arabian peninsula – although they survived the Conference, began soon after to disintegrate. In an attempt to save some of them the Desertification Unit (which succeeded the UNCOD Secretariat, Nairobi) redefined them as sets of interrelated national projects. The twelve "Case Studies" were from Australia, Chile, China, India, Iran, Iraq, Israel, Niger, Pakistan, Tunisia, United States, USSR. Four "component reviews" were prepared on desertification and climate, ecological change, society, and technology. There were also a number of country reports and other minor documents.

many were using the discussion to bargain about relations between the parties to the Conference. Most delegates saw the solution to desertification in the mobilisation of resources, but many also blamed the incentives for exploitation of people and resources that they considered to be inherent in the present system, and saw the solution in the reorganisation of the world economic order. While all the delegates accepted the ecological explanations of desertification and the technical solutions, many were more concerned with causation at another level: that of the economic and political conditions that generate land use decisions. The organisers of the Conference pursued a strategy designed to keep deliberations at the former level, but the "political will and determination" that they sought to stimulate were more abundant at the latter level – though more difficult to harness.

These two levels of discussion are evident in other arenas of the anti-desertification debate. They are inherent in the political process, and it is unrealistic to hope to keep them entirely separate. The campaign to organise for the purpose of conserving resources can never entirely free itself from the campaign to reorganise the distribution of resources. The consequent dialectic between overt discussion of how to organise in the existing system and the underlying theme of how to reorganise the system is particularly noticeable in two other arenas. Most obviously, it arises in the relations between populations which are at risk or suffering from desertification and the planners and implementers of management programmes designed to combat desertification. But perhaps most significantly, it characterises the relations between natural scientists concerned with the viability of physical and biological systems and social scientists concerned with the viability of social and cultural systems.

For example, management programmes designed by range scientists to address the long term ecological balance in the relationship between animals and carrying capacity in the arid and semi-arid rangelands of the world are based on values and perceptions different from those of pastoralists. Coming from a different cultural environment and a different social class and trained in different land use systems, the ecologists are led to define the universe of the problem differently and to place a different emphasis in the aims that they pursue in relation to it. The ecologist is primarily concerned with the long term productivity of the resource; the pastoralist is primarily concerned with survival – first in the short term and then in the long term, and survival is for him not only his own personal survival but survival of his socio-cultural unit, which is based on the productivity of the herds. It is obvious that these concerns overlap – but they are centred on different priorities, which are in turn based on different values. In the interaction between the ecologist and the pastoralist over the implementation of a management programme that would redress the balance in the ecological system of which the pastoral population is a component, the explicit bargaining concerns specific elements of the management programme; implicitly the values of the ecologist are pitted against the values of the pastoralist – a conflict that will be resolved eventually in the larger political process.

In the study of ecosystems where the productivity of natural resources is reduced as the consequence of activities in the human use system that incorporated them, the ecologist's reaction has commonly been to focus on the degraded resource, and attribute the degradation to the immediate cause in the form of the social group exploit-

ing it, as in many cases of traditional pastoralists and degraded rangelands. Desertification, then, is caused by social factors, but solutions are generally designed by focusing on the natural symptoms of the problem (for example, reduction in the quantity and quality of vegetation) and by attempting to rearrange the social factors in relation to them. Judging by the record, this approach commonly fails to lead to a satisfactory solution, and besides often brings about new adverse social factors which may accelerate desertification. Cause is translated easily into fault, and central authorities with large urban constituencies are indulged in their prejudices against marginal rural populations. Cultural discrimination of urban against rural increases; the population concerned suffers further reduction in its range of economic options and tends to become an increased burden on its immediate natural resources. The ecologist focuses on natural processes and sees the fault in the behaviour of the human population which failed to reorganise its activities in the way prescribed. The social scientist is invited to devise ways to encourage the people to confine their activities within boundaries prescribed by the ecologist. As with the UNCOD delegates some social scientists are happy to accept these terms of reference and seek to apply their expertise as a service in the ecologists' programme; others seek to redefine the terms of reference: they seek to redefine the situation in terms of the interests of the human population and to develop an ecologically feasible strategy that will serve those interests. In dealing with desertification the social scientist tends to look for the ultimate social cause, which is likely to be outside the affected area.

Where an ecologist is studying an ecosystem without a human component, or where his research interests allow him to ignore the role in the ecosystem of other members of his own species, he implicitly determines relative values for the various species in his study. For example, in an open steppe ecosystem the survival interests of grasses and forbs, shrubs, herbivores and predators are obviously in conflict. The ecologist stands outside the system but bases his research design implicitly on certain inter-related assumptions such as 1) the system should not run down, 2) the number of species should not decrease, and so on. However objective his research design, the ecologist is led by his assumptions to discriminate in favour of the survival of the system. The survival of the system may, of course, be in the long term best interests of all the component species. It is not, however, in the best interests of all living individuals in the system, some of whom will, for example, fall prey to predators. A reduction in the number of predators would, therefore, be in the best interests of some at least of the living herbivores and a reduction in the number of herbivores would be in the best interests of many living plants. If a gazelle or a shrub could produce a study of the same ecosystem, therefore, we might expect their results to differ from those of the ecologist inasmuch as they would, as a matter of course, be based on different assumptions. The ecologist can argue in terms of the survival of species and of the system, because survival on that level suits his own socially determined values best. A member of the system, such as the gazelle, whose personal interests are at stake will argue for his own survival first. Both arguments may be equally objective and scientific, but differ on grounds of morals and personal interests, which are socially relative. The conflict between them is resolved politically as a result of the difference in power of the populations in question. This reduction of the relationship

between the ecologist and his subject matter to questions of morals and politics is exaggerated, and in the case of plants may seem absurd, but by bringing out the fact that the ecologist's argument is based on the attribution of a value to the survival of a species or a system which might conflict with the values of individuals, it serves to focus attention on the moral and political aspects of the problems that develop between scientists and local populations in the treatment of declining ecosystems, especially in the cause of desertification. It is worth noting that this problem arises in all the applied sciences – social, biological, and physical. It has effectively paralysed the theoretical development of applied social science; in the physical and biological sciences it has generally been possible to ignore it.

When the ecologist includes a human population in the system he is studying, his recommendations for treatment and management are likely to conflict with the perceptions and values of that local population. These conflicts can be presented as differences between scientific understanding and uneducated superstition and self interest, but it may be more realistic to minimise the difference between science and lore to see them as differences between socially-derived perceptions based on an interest in the long term survival of a total ecosystem and its usefulness to human populations on the one hand and perceptions based on less long term interests in individual economic and group cultural survival on the other. Pragmatically, there has to be a compromise between such differing perceptions. Such compromise is the essence of any national political process. The ecologist's case is commonly reinforced by the central authority, which often shares his assumptions. However, the government depends on the political process and, ultimately therefore, on the various interest groups which achieve participation in it. The population involved in a process of desertification may or may not have a voice in the political process. In any case, to the degree to which the populations using the resources that are at risk of desertification are represented in the larger political process, they are divided into different interest groups. Any proposal to manage the threatened resources according to the scientist's values unavoidably benefits some interest groups at the expense of others. Since the final arbiter is the political process and relative power (in which the claim to be on the side of absolute values is an important but not a determining factor), it may not in the long term be a realistic ecological management policy to allow the terms of reference for the solution of desertification problems to be defined exclusively according to those supposedly absolute values.

The campaign to combat desertification, as it has been organised – logistically and intellectually – so far, has implied an adversary relationship between those who (consciously) fought it and those who (perhaps unconsciously) caused it. The adversary relationship has often also had the nature of a class conflict. But the question of who stands to gain or lose in particular situations has seldom been carefully investigated. Without such investigation the social dimensions of the concept cannot be understood. Throughout the preparations for the Conference, and since, there has been no general agreement on a definition of desertification – even without the social dimensions (cf. UNCOD 1977b). The concept has evolved and continues to evolve as the progressive rationalisation of the logistical structuring the the campaign. The following section discusses this continuing process of rationalisation.

THE CONCEPT

Desertification does indubitably occur. In popular usage its meaning seems obvious. But determination of the details that should be included or excluded from even a working definition for use outside particular disciplinary forums in conservation or planning has proved difficult.

Desertification is detrimental to settlement, health, recreation – but most importantly to food production. But what are the chances that it will significantly affect the quantity or quality of world food production in the foreseeable future? Are its effects most likely to be direct, in reduction in acreage or productivity? or indirect, in problems caused by the resulting redistribution of population and increased pressure on distribution networks, in the organisation of labour, of investment, or of society generally? Will it be a serious problem at the international level? Finally, what might be done to counteract or, failing that, to reduce its severity. Agreement on answers to these questions depends on more careful investigation of the conceptualisation implicit in the campaign. Despite the enormous outpouring of literature on the subject of desertification that occurred between 1975 and 1978 as direct and indirect results of the Conference, there is still room for another appraisal of the problem – partly because now that eight years have elapsed since the Conference some of the dust raised in the logistical, emotional and political flurry of organising the Conference has settled, and partly because as time has passed more information has arrived and some earlier perspectives on the phenomenon will now bear modification or revision.

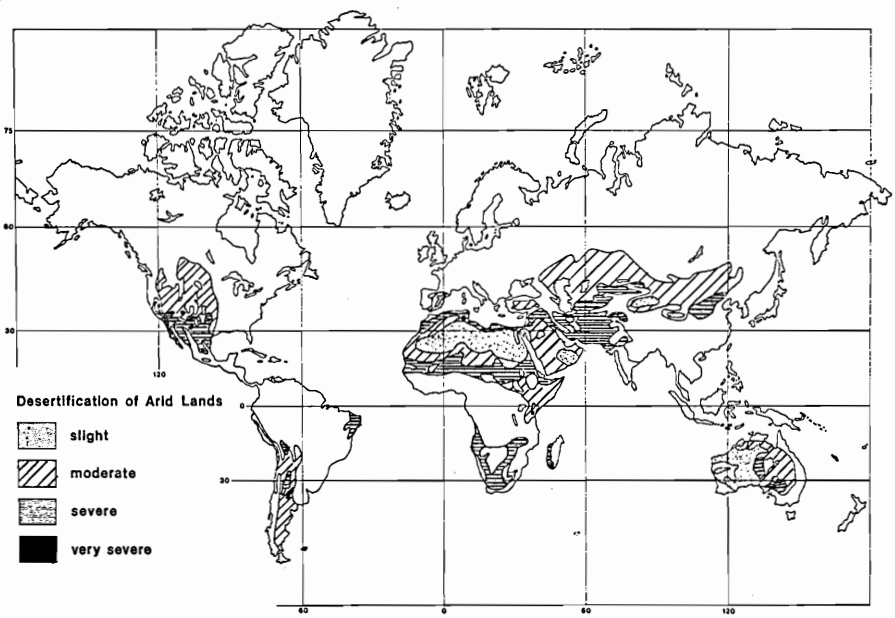
Despite considerable efforts on the part of the Secretariat to cost out all the implications of desertification, there has been a tendency all along simply to define desertification as a type of ecological decline which is *per se* evil. This tendency alone may explain the relative political failure of the global campaign to combat it. In general it has not been made entirely clear just who is suffering or stands to lose by specific cases of desertification. The disadvantages of desertification are commonly left as self evident. It is well, therefore, at the outset to make it clear that – at least at the political level – they are self evident only given the assumption that the resources which are thereby degraded are irreplaceable for the population that currently depends on them. Outside certain intellectual circles the argument that future generations will suffer carries little weight. Most governments, because of the exigencies of the individual politician's career and the recurrence of elections, have perspectives of less than five years. Here we are not limited by such a perspective, but in order to understand the concept of desertification it is necessary to understand the variation in perspectives on it and the basis of that variation. This aspect of the problem was only implicit at the Conference and has received little open discussion. The following discussion cannot be comprehensive but attempts to include at least some indication of all the significant questions.

In developing the concept of desertification in relation to future food production it is necessary to ask, first: what are the factors relevant to the prediction and planning of food production? They are population (*sc.* size, structure, spatial distribution

and organisation of labour), culture (tastes, values and expectations), technology, climate (temperature, wind and precipitation), and the condition of productivity of natural resources (especially soil and vegetation), to which must be added national and international factors of political economy that affect choice of crop, investment patterns, terms of trade and distribution networks. Prediction or planning of food production involves predicting or planning what is going to happen to each of these variables. Desertification, as it is usually defined, constitutes only one of these variables – resources – and then only in certain environments, though it is of course intimately interrelated with all the others. It is possible to see, therefore, that however dangerous the threat of desertification may be other threats may with some justification attract more political attention.

Secondly, what is the case for giving desertification high priority? It is now conventional wisdom that desertification is "the impoverishment of arid, semiarid and subhumid ecosystems by the combined impact of man's activities and drought. It is the process of change in these ecosystems that can be measured by reduced productivity of desirable plants, alteration in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration, and increased hazards for human occupancy" (Dregne, 1977). Defined in this way desertification is generally understood to be affecting large areas of every continent, especially Africa, and to be increasing. Potentially productive but threatened lands have been estimated at 45 million square kilometres or 30% of the land surface of the world, distributed through two thirds of the world's 150 nations. The rate of desertification is said to be increasing and "some experts have suggested that it has reached at least 50,000 km^2 per year" (UNCOD, 1977a 6–7).

Figure 15.1.



The accompanying map (Figure 15.1) shows four classes of desertification: slight, moderate, severe, and very severe. The last category is defined as "economically irreversible" (Dregne, 1977). However, "there just are not many large areas where economically irreversible desertification has occurred" (Dregne, 1977). This judgement was "shared by all persons contacted – thus far – who have helped improve the first draft" (*ibid.* note) of his article. Professor Mikhail Petrov suggested to Dregne that "very severe desertification might be limited to small areas up to 20 km wide around oases" (Dregne, 1977). If this is true, it suggests not only (as Dregne concluded) that "therefore the true extent of the very severely affected areas will not be shown on small scale continental or world maps" but that true or irreversible desertification – as distinct from reversible reduction in productivity – may be a function of settlement rather than (as is generally assumed) the over-intensive practice of particular food production technologies (cf. Spooner *et al.*, 1980).

Whether or not desertification is irreversible, it threatens reduction in productivity over vast areas which are already relatively low in productivity and poor in economy. However, because of their vast extent the total productivity of these areas is of great consequence for world totals – the more so because they are as yet relatively undeveloped and their potential for increased productivity may therefore be relatively high. As yet also their production is relatively unintegrated into larger economic systems. The actual figures, therefore, as marshalled for UNCOD, that one third of the land surface of the world containing (in 1976) 15% of world population, or 630 million, of whom already 8% or 50 million are threatened by desertification's productivity losses (see Hare *et al.*, 1977) may be a misleading understatement, because desertification is threatening the as yet unrealised and unknown potential of as much as one third of the world's land.

Desertification in its most widespread forms is generally represented as the immediate result of one or another of three practices: over-grazing, "over"-cultivation, or over-irrigation – in increasing order of investment required and of potential productivity per hectare, and decreasing order of area at risk.

Natural rangelands sustain pastoralism up to a certain threshold beyond which grazing and browsing are likely to eliminate not only individual plants but entire species and so cause modification in community composition as well as reduction in percentage cover throughout the range. Although less vulnerable species may take the place of those eliminated, they are always less palatable and so less useful to pastoralism (or any other form of food production) and invariably provide less protection against soil erosion. This threshold varies seasonally and annually with the variation in precipitation that is typical of arid and semi-arid climates. Population growth or loss of territory in many pastoral societies has led to increases in animal population per hectare to the point where that threshold is often and even continuously exceeded. Because of social and cultural factors pastoralists seldom adapt simply and directly to the ecological situation by reducing their herd size in tune with the reduced carrying capacity of the range (cf. Sandford, 1982. Their technological adaptability to recurrent conditions of reduced carrying capacity has also in some cases been prejudiced or impaired by the effects of nationally and internationally sponsored projects to increase their productivity and integrate it into the larger economy, especially

by making new watering points available which facilitate greater exploitation in good years and lead to herd growth (cf. Bernus, 1977). As ranges become more heavily overgrazed they first lose their more palatable species, then gradually overall cover is reduced leading to reduced absorption of precipitation, increased run off and erosion. The conventional cure is reduction of the animal population to the point where the vegetation may recover, but this measure does not always produce a simple reversal of the process. Undesirable species may invade and take over the range before the earlier vegetation (which may have lost its seed base) can reestablish itself (cf. Conant, 1982).

In the case of rainfed cultivation, the main hazard arises from the extension of the system on to marginal soils that will not support it. Opportunistic ploughing of such soils, which may produce a few good harvests in the short term, in the longer term leads to erosion. The wild vegetation produced by such soils often constitutes the better rangeland of traditional pastoralists. As a result of erosion the land is lost to both agriculture and pastoralism, and the pastoralists are thereby pushed back in denser numbers on to less productive rangeland which becomes further impoverished as a result. In addition to – or instead of – being extended, cultivation is sometimes intensified by the reduction of fallow periods – which similarly leads to the impoverishment and loss of soil and to long term reduction in productivity. These forms of "over-"cultivation have been encouraged not only by population growth but by increased economic demand and opportunity resulting from integration into a larger, cash economy, and also by the increasing availability of mechanical aids to labour such as tractors, which allow a much faster rate of growth in acreage than would be possible given simply the rate of population growth. A further important factor in over-cultivation is the reduction in the farmer's dependence on his land that often accompanies his incorporation into the cash economy. This shift and its implications in the historical study of the relationship between natural processes and human activities have been appropriately termed "the ecological transition" (Bennett, 1976). The farmer begins to worry what will happen to him when his land is farmed out: he sees the economic opportunities of the urban or industrial economy which may even appear more attractive than farming. In this way the socio-economic reorganization that goes with development may bring in its train reduced ecological sensitivity in local populations. It is worth noting, however, that the social security of these populations may at the same time be increased.

Over-irrigation, as a form of desertification, occurs in the land use system which is not only the most intensive and productive (though admittedly with the least – actual and potential – extent) but it is in a sense the most directly caused by industrialisation. Unlike most other desertification processes over-irrigation is scarcely affected by local levels of population: it is a function of the large scale engineering of irrigation, in which the local operators do not control their own operation, did not develop it themselves and therefore have a less detailed "folk" understanding of the ecology of it. The investors, developers or organisers, whether in late prehistoric and early historical Mesopotamia or in the Punjab under the British in the nineteenth century approached it as an economic enterprise, and now that the ecology is understood by the organisers it remains to work out ways to arrange the efficient operation of the

system. In short, the limiting factor in agricultural production in many arid areas is water. Many arid areas can be transformed into agricultural miracles by the controlled application of water – which is possible, especially in large river basins, given large scale organisation, engineering and above all industrial construction. But in order to be ecologically successful over a long period the flow of irrigation water must be engineered in such a way that it reaches the root zones in optimum quantities for the needs of the specific crops. Excess water that seeps out of the channels before reaching the crops, or sinks below the root zone of the crops, unless it can somehow be drained out of the basin, sooner or later causes trouble. However deep the original water table, excess irrigation water gradually builds it up until it approaches close enough to the surface to cause first salinisation (since it invariably has a high mineral content) through capillary action, and finally waterlogging. The result is serious decline in yields and, in severe cases, total loss of productivity for indefinite periods.

Since this type of land use system is basically modern and industrial, generated by national or international investment, and integrated into the larger economy, loss of its production due to desertification is of more immediate economic significance than in the case of over-grazing or over-cultivation which are often unintegrated so that the potential value of their production in the larger economic context is difficult to determine. In the case of over-irrigation, therefore, figures are both more available and more meaningful. The following depict what is perhaps the most serious example.

In Pakistan before the development of the irrigation system in the Punjab, water table depths over most of the area now irrigated were about 24 to 28 metres. Of the 123 billion cubic metres of Indus water diverted annually into the irrigation system, only about 71.5 billion cubic metres are available at the heads of watercourses: the rest is lost through seepage. It has been estimated that from 2 per cent to as much as 27 per cent per kilometer is lost in the watercourses. Altogether, less than 30 per cent of the water diverted from the rivers is stored in root zones for crop use. Historical data show that the water table has risen an average of 15 to 35 cm per year since modern irrigation was introduced. Further, in an area where the underground water has a salinity of 1,000 parts per million, which is acceptable for virtually all crops, evaporation at a rate of 60 cm per year, which is a typical value where the water table is only a few feet deep, will raise the salt content of the top three feet of soil to about 1 per cent in 20 years. This level is too high for even the hardiest crops. Not only, therefore, are environmental problems causing loss of cultivable land – the irrigation system is working at only 30 per cent efficiency and this inefficiency is responsible for the loss. These processes are exacerbated by inefficiences in actual irrigation and cultivation, that is, in application of water to crops. In the 1960's it was estimated that up to 40,000 additional hectares were being affected each year and, in the worst districts, 40 per cent to 50 per cent of the cultivated land was already severely damaged.[3]

A certain amount can be done to correct this situation by more engineering. Fields may be levelled, canals may be partially or wholly lined to reduce or prevent seepage; drains may be dug. Tube wells may be installed to pump the ground water back up to the surface for recycling where the mineral content is low enough. But these mea-

3. This section on Panjab (Pakistan) is based on Michel, 1967 and Spooner 1979 and Hasan, 1976.

sures all increase both the capital cost and the running cost of the operation and reduce its profitability without increasing its efficiency. The basic aim – to provide the root zone homogeneously with just the right amount of water – remains elusive and can probably be solved only at the level of the individual operator or some social grouping of operators. There have been moves to approach the problem at this level (Merrey, 1982), but little practical success so far; partly perhaps because so much rethinking of the relationship between government, official, engineer, and local operator or farmer is required.

Desertification, then, as conventionally defined, is a function of the complex interaction of a series of factors, which includes: topography, soil, vegetation, groundwater, wind, temperature, precipitation, and the nature and intensity of human activity. It is not new. It is not peculiar to any particular land use system, area of the world or culture. In fact it can accompany any land use system and has probably accompanied all land use systems to some extent at least in some periods. It is not qualitatively different from ecological change as a result of human activity in more humid areas. It has only recently been perceived as a problem – partly because the rate of global population growth has for the first time brought us to the point where it is not only conceivable that we shall run out of resources, but we have felt threatened by imminent failure to feed ourselves. It is important to note that the present consciousness of this threat derives at least partly from intellectual developments that have generated a new perception of the environment. But however infallible this perception may appear among planners and ecologists, it is not universal. Even where the problem is perceived to be immediate the perceptions are not all uniform, and there are legitimate differences of opinion about the analysis of particular situations. It will be useful here to discuss the causes of desertification, bearing in mind that any causal analysis is likely to reflect a particular perception of the problem, and although one analysis may seem more persuasive than another, in the last resort what will determine the acceptance of one or another analysis in any campaign to combat desertification will be the political process of interaction between the various agencies, governments and social groups concerned. The most useful aim of the intellectual level of this volume is to seek to inform that political process by making available to the various parties to it the maximum amount of relevant information in its most digestible form.

What then are the causes of desertification? Arguments about ecological deterioration have been usefully grouped as:

> "(a) *Structural* arguments. These lay the main blame on social and economic structures and relations (patterns of ownership, rights of use and control over resources).
> (b) *Natural events* arguments. These see largely uncontrollable events, such as droughts or outbreaks of disease, as the prime causes of deterioration. We can also include in this category political developments whose origins lie outside the context of pastoralists and rangelands, and which are, therefore, similar.
> (c) *Human fallibility* arguments. These lay the blame on the stupidity, ignorance, or shortsightedness and perversity of pastoralists, of governments, and of do-gooders.
> (d) *Population* arguments. These see the main cause of the deterioration in the rapid growth of human and livestock populations." (Sandford 1976)

In the terms of the conventional wisdom there has been a tendency always to assume

implicitly that the immediate human cause of any particular symptom of desertification, such as over-grazing, was the significant cause, to look no further to pursue the reconstruction of a chain of causation, but to prescribe simple remedies in the form of management regimes and expect them to be easily and efficiently implemented. This tendency derives from the fact that the consciousness of desertification arose among specialists in the study of natural phenomena, who naturally sought to solve it in those terms. They were able to communicate their concern fairly readily to the community of the agricultural sciences, but they had less success with the communities of economics and the social sciences, whose first priorities were the efficient use of labour and social well-being respectively rather than the conservation of renewable natural resources. Although the dangers of desertification could have been presented in economic or social terms, the ecologists did not make a very convincing case in such terms. For this reason, and because of the underlying problem of the sectoral fragmentation of science there has been little interdisciplinary synthesis of desertification or transdisciplinary co-operation to develop recipes for solutions. The communication, or lack of it, between the disciplines or professions, with regard to desertification, has been exacerbated by the conviction of the ecologists, who discovered it, of the urgency of the situation – that something had to be done immediately in order to save a significant proportion of the world's resources not only for posterity but for the future wellbeing of the present generation, and especially for the good of the affected people themselves. This element of panic is reminiscent of other similar campaigns also having to do with the global ratio of people to resources that have hit us since the mid-sixties. The first was population; then came food; more recently it has been energy. No time could be lost working out the ideal way of dealing with the situation. Early faint protestations from social scientists that simple imposition of management solutions based on experience in other areas which may well be ecologically comparable, but whose populations are socially and culturally non-comparable, were met with accusations of callous detachment. Invariably, however, though they often seemed feasible at the time, we now see that Western-devised management solutions for non-Western situations of desertification, or for that matter of "under-development", have not been successful, and we can now see that this lack of success should not surprise us. These management solutions are a form of technological change. It is now generally accepted that technological change does not occur in isolation from, and cannot be induced in isolation from, economic change and general social change. The development campaign generally has not fulfilled expectations because it has been technology-led, formulated in terms of technology and investment (and management) with the implicit assumption that the social relations that constitute the society in question will rearrange or re-form themselves in adaptation to the new exogenous techno-environmental conditions. It is now possible for the social scientist to join in the development effort – and therefore also the effort to combat desertification – because it has now become clear that in order to induce change successfully in any social system it is necessary first to investigate the dynamics of the existing system. It is unscientific to expect to change particular social practices without first ascertaining what generates the social formation underlying those practices.

The question then arises whether the plan to induce the change can be morally justified – especially when it is often based implicitly on assumptions about the interests of future populations. This is too large a question to be dealt with fully in this chapter, but its existence and importance must be acknowledged. For the time being we can assume that in the case of desertification many will argue that the attempt to induce change is morally justified by the prediction of ecological consequences based on the assessment of current ecological trends. However, there is still a moral problem insofar as the over-grazing or other practice that is the immediate cause may be a response not to local factors such as inefficient management of resources but to external factors such as market opportunities and the terms of trade for pastoral products. In this case do moral principles dictate a solution to the problem by imposition of a pastoral management regime (which is likely after all to be distasteful, if not a cause of serious hardship, to the local pastoral population)? or, for example, by administrative changes in tax structure that would alter the relationship between the pastoralists and the larger economy in which they are encapsulated, and possibly reverse the desertification trend by imposing some degree of hardship on other sectors of the population that use pastoral products and were benefitting from it?

In many cases of desertification the production system, for example pastoralism, may constitute a less significant pressure on the vegetation than the demand for fuel and for construction materials. Apart from forage the vegetation often has to satisfy the need for fuel for heating, cooking and in some cases also for processing milk into yoghurt and other products, and for roofing and the construction of animal pens. In an area of arid rangeland in northeastern Iran the average domestic consumption of firewood has been estimated at 5.3 metric tons per year per family plus as much as an additional 7-10 tons for milk processing (Horne, 1980). Historically the same area has also produced charcoal for urban markets. In other Middle Eastern rangelands, where no ligneous vegetation survives to satisfy even local fuel demands, animal dung is also collected for fuel purposes. Perhaps the most surprising point is that there are still whole cities with cold winters, such as Kabul, in which wood serves as a major fuel for heating. The distribution of fuel and construction materials is even more obviously a matter for central economic planning and political decision-making, and the "fault" therefore lies at the national level, not at the level of the user. It has to be generally accepted that desertification demands a "no-fault" approach, in which the interests of existing populations should not easily be set aside in favour of future generations, especially when the burden could be spread.

These simple examples enlarge the perspective on desertification by suggesting the moral, political, economic, as well as social and ecological, dimensions of any process that involves the interaction of human activities and natural processes in the modern world. If the problem of desertification is to be approached realistically, all these dimensions must be taken into account. Conceived in this way, the problem of desertification can be resolved only in the political process, but the political decisions necessary to resolve it are unlikely to be made for purely ecological reasons. We are likely, therefore, to have to live with increasing desertification for some time to come. Meanwhile, the goal of science should be to synthesise research on these various dimensions of the problem as conceived above, and seek to feed information from

that synthesis into the political process.

In fact, however, there is little or no evidence either that current trends (where they are bad) are long term trends, or that direct intervention is likely to reverse them, and not enough notice is taken of contrary indications. For example, in at least two arid areas – northern Nigeria in the vicinity of Kano, and Rajasthan in northwestern India – population densities have exceeded 150 per square kilometre, and although there is definitely evidence of desertification, living standards are not deteriorating and disaster is not imminent (Hare *et al.*, 1977).

Some diagnoses of desertification are questionable. For example, erosion may not necessarily be disadvantageous. "In northern Libya many small dams were built specifically to trap the eroded sediment and to create deep, well-watered soils for agriculture. Roman agriculture could have expanded in a short period of favorable rainfall, much as agriculture expanded into the northern Sahel in the early 1960's. The Romans, like the Hausa, may have had to retreat in the face of a drought and what was, in effect, only a marginal increase in erosion" (Hare *et al.*, 1977; Vita-Finzi; 1969). The use of a natural factor, such as soil, as a yardstick of desertification, may disguise the assumption that a particular set of human social interests had priority – those that valued the present state of soil distribution over those that were happy to see it changed. The following example merits quotation in full:

> In the Valley of Nochixtlan in southern Mexico, many side slopes "are ravaged by active gullies which remove the surface wholesale and leave the slopes bare of vegetation, fields or houses. Since the Spanish Conquest, an average depth of 5 m has been stripped from the entire surface area, producing one of the highest rates of erosion recorded in the world.[4] Set between the forested uplands and the agricultural valley floor, the area seems a wasteland which only drastic soil conservation measures could reverse.
>
> Government experts share this view and have instituted conservation measures including the construction of low earth ridges to slow down soil movement. Few scientifically trained experts would disagree with their general perception of the gullying as a problem but the view from inside the valley is different. Gullies are seen not as a hazard but as a resource. by directing the flow of the eroded material, Mixtec farmers can annually feed their fields with fertile soil and can, with greater effort, extend their agricultural land by building new fields over a few years.
>
> Over the past 1000 years, Mixtec cultivators have managed to use gully erosion to double the width of the main valley floors from about 1.5 km to 3 km; and to infill the narrow tributary valley floors with flights of terraces several kilometres long. Judicious use of gullying has enabled them to convert poor hill-top fields into rich alluvial farmland below, using the gullies to transport the soil. Thus before large-scale gullying began, the agricultural productivity of the valley area was less than it is today.
>
> The difference between the "outside expert" view and the inside Mixtec one rests on the farmers' greater experience and knowledge of the local situation. Their experience of the highly fertile and erodible local deposits, and their familiarity with the technical and social bases of controlling soil movement, are too particular to the Valley of Nochixtlan to be readily translated to other areas. Thus the concept "gullies are good" is not part of the outside expert's portfolio. Nor could he be expected to know that intermarriage between the hill-top and valley bottom communities enables families to "move with their soil" downvalley.
>
> The Valley of Nochixtlan is an unusual case; usually different groups agree that soil erosion is a problem but disagree about how to solve it. This example is intended, however, to illustrate the importance of understanding local perceptions of the environment in the context of local resource use and social structure. But this is only the first, important step. In

> the example of Nochixtlan – as almost everywhere – both perceptions of the environment are valid, within their own contexts. For the farmers in Nochixtlan, gullies are an important agricultural resource. For the government authorities concerned with the area as a whole, gullies are also a problem – not for those farms whose owners remain, but for the farms abandoned by their urban-migrating owners and no longer receiving replenishment and protection from the gullies. Thus, the national "problem" is that of urban migration and rural depopulation, which is the higher-order one, and which is outside the scope of agricultural authorities and local communities." (Whyte, 1977).

The average erosion rate over the whole surface was in the order of 10 km per year over the last 500 years for a drainage basin of area 0.4 km^2 (M Kirkby, 1972).

Analogous examples have been documented in the history of the Negev (Lamprey, 1976) and of parts of Iran (Dennell, 1982).

Any process of ecological change is likely to be perceived differently by different social groups. Desertification studies so far focus on ecological change resulting from human activity. If progress is to be made in the campaign to combat desertification, their focus must be shifted to the relationship between population and resources. But it will still be necessary to develop a yardstick to measure desertification in those terms. "Flexibility" may serve this purpose. A major factor in the social tragedy that followed the Sahelian drought was the recent loss of flexibility in resource use. In arid and semi arid lands where precipitation is often more irregular and unreliable than insufficient, flexibility is the most important aspect of any land use system. Nomadism has survived for so many millennia in many such areas because it is a strategy that gives first priority to flexibility. The value of this strategy is still not fully appreciated (see Bernus 1977). Flexibility is often lost as a result of modernisation and the introduction of new technologies, but it could be safeguarded as a matter of public policy – though such an objective would require a major reorientation in development planning and in government intervention in land tenure generally.

Over the last decade a few attempts have been made to develop research programmes that would illustrate the interaction of social and natural factors in desertification and provide better understanding of its dynamics in different cultural contexts. The switch away from a focus on natural processes irrespective of their social referents is slow, and data from these programmes are still in the process of publication but examples may be found in Lamprey (1978), Mann (1982) Spooner *et al.* (1980), and Novikoff *et al.* (1973–1976.)

THE PROSPECT

Desertification is real, but more complex and less well understood that even UNCOD documentation suggests. However, for the most part, it is probably not irreversible and therefore not as critical as we thought. As a slogan, an organising concept, it is part of the international history of the late twentieth century, taking its place alongside population, food and energy. But in the final analysis it seems not to

have the same force as the others. Many of the figures used to maximise its force appear to have been exaggerated, unrepresentative, in some cases misunderstood or mistaken (see Simon, 1980). The danger now is that its credibility will decline further.

It is important that the campaign to combat desertification should not lose force, but in order to maintain it, desertification must be put over in such a way that the implications for counter measures appear politically fair and advantageous to a much larger proportion of the people who may be affected. To achieve this end a great deal more rethinking is necessary than has been achieved so far. We need a yardstick and a set of indicators that will be applicable in different political and cultural contexts.

The first essential step in this direction is to discontinue the exclusive use of ecosystems as units of analysis. For example, if Rajasthan is providing meat and dairy products to the population of Delhi (UNCOD, 1977a) it would be unrealistic both politically and ecologically to seek to combat desertification in Rajasthan simply by rearranging pastoral activities in Rajasthan. Central governments are responsible for the formulation and implementation of policy, and therefore also for the measures that influence the distribution of economic activity, developing some areas and marginalising others. It is at this level of organisation and planning that desertification can serve as an important concept to minimise the ecological degradation of drylands.

An historical perspective suggests that a certain degree of desertification (as conventionally defined) is the inevitable consequence of human activity. It should probably, therefore, be approached more positively as one aspect of an unavoidable compromise with population growth, bearing in mind that another aspect of that compromise can be (and in some cases has definitely been) improved social productivity. The reality of social factors cannot be overemphasised; they have their own dynamics and we have little scientific understanding of their interaction with natural processes such as desertification. The concept of adaptation which is borrowed from evolutionary biology to facilitate discussion of this interaction as yet has no theoretical content in this usage. It is possible that systemic relationships generally cause social factors to intervene before desertification becomes severe – except in cases of critical external intervention. In any case ecological degradation can be accounted an evil only in relation to society – not in its own right (cf. Passmore, 1974). In the Sahel there is evidence that social disruption had set in before the drought (Bernus, 1977). For this reason, if for no other, it is important to develop traditional systems rather than seek to replace them.

To attack desertification is to select one symptom arbitrarily from a range of symptoms generated by a pervasive disease. The disease lies in the relationship between society and natural resources on a global scale. Desertification has come into vogue only since that relationship has been perceived on a global scale. We are not prepared to deal with it on that scale because of the political and other divisions in society. We have a fair view of the natural resources on that scale and we must keep this ecological knowledge in mind as we search for social and political answers. In so doing we shall develop a new approach to development generally – a new approach that will be both scientifically more comprehensive and politically more acceptable.

The significance of desertification for the foreseeable future as far as food produc-

tion is concerned (as distinct from, for example, the quality of life in new urban and industrial communities in areas like the Southwest of the United States) depends on the political process and is a relatively insignificant aspect of it. Despite a number of excellent scientific papers on the biological and physical processes involved (for example, Le Houerou (1977 and 1978), there is no hard evidence that overall food production is likely to decrease as a result of it. But the overall political process could be helped and smoothed if the information deriving from the campaign against desertification so far, and from now on, is fed into it more efficiently. There is no need for a special fund, as recommended (less than unanimously) at UNCOD. The campaign will have served its purpose, if it has led to a situation wherein from now on ecological consultation will be built into the development process. Though undeniable, desertification is not only insignificant relative to the overall socio-political problems of organising production and distribution (while raising living standards and freedom) but is integral to that effort and unbeatable except as part of that effort.

To summarise, desertification may reduce the productivity of natural resources seriously in the foreseeable future, but it is unlikely that a frontal attack on the problem, which attempts to rearrange human activities in direct management solutions, will have much impact. Desertification is intimately related to development and represents one aspect of the inadequacy of the development effort so far. The development effort is undergoing a process of re-thinking, in which the emphasis is shifting from purely economic criteria to criteria of social welfare and broader public participation. The campaign to combat desertification can be effective only as a component of this general development effort.

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CHAPTER 16
Insect Control

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INTRODUCTION

PRODUCING ADEQUATE FOOD for the existing population to alleviate malnutrition and hunger, and progressively increasing food production to meet the requirements of the expanding population, are amongst the greatest challenges the world faces today. It has been estimated that to meet these demands, the total food production will have to be almost doubled by the end of this century. This will require increasing both crop yields per hectare and cropping intensity as in many areas virtually all arable land is already under cultivation. Since high crop densities and continuous cropping are generally considered conducive to insect population build up, the problem of insect control will require sustained efforts and innovative approaches.

EXTENT OF CROP LOSSES DUE TO INSECT PESTS

Several hundred species of insects, out of nearly 10,000 different species known to damage agricultural crops, inflict severe losses in food production. Different pests feed on all parts of the plant, transmit diseases, and damage the produce in storage. While it is difficult to accurately assess the extent of losses caused by insect pests, because their incidence varies during different seasons and even in different fields in the same area, Cramer (1967) considered the preharvest crop loss due to insect pests on a worldwide basis to be 14% of the total production. The losses are lower in developed countries where better plant protection measures are followed than in the developing countries. This is illustrated by 5.1% crop loss by insects in Europe (exclusive of Russia), 9.4% in North and Central America and 20.7% in Asia (exclusive of Peoples Republic of China).

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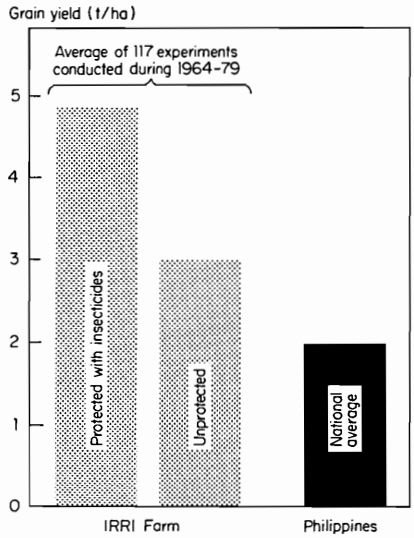
Figure 16.1. Rice yields with and without insect protection



The extent of loss the rice crop suffers from insect pest damage in Asia is illustrated by the summary of the results of all field experiments on insecticides conducted at the International Rice Research Institute (IRRI) during 1964–1979 (Figure 16.1). The figure implies that the current rice yields can be improved by 50% by proper crop management practices even without insect control, but can be increased by 2.5 times if proper pest management practices are also followed. Furthermore, results from about 100 different experiments conducted in farmers' fields in various provinces of the Philippines have shown that plots treated with appropriate insect control measures yielded an average of about 1.0 t/ha more rice than untreated control plots. This amounted to about 20–25% more rice than the untreated control plots. Similar results are also available from many other Asian countries.

These facts emphasize the necessity of effective pest control and the availability of pest control measures as an insurance against crop failure caused by epidemic pest populations such as locusts, planthoppers, etc.

FACTORS AFFECTING PEST ABUNDANCE

Insect pests are generally more abundant in the warm and humid environment of the tropics and subtropics, and in fields with dense crop stand in which they are protected from direct sunshine and certain predators. Therefore, crops grown under improved agronomic practices such as high rates of nitrogenous fertilizers, proper water and weed management practices, etc. are generally prone to more insect infestations than

the sparsely growing crop with poor agronomic practices. Also, insects are more abundant in areas cultivated year around with the same crop. For example, pest problems have intensified in areas where traditionally only one crop of rainfed rice was grown but now with the availability of irrigation water two or more rice crops are grown per year.

Certain crops are inherently more susceptible to insect pests than others (Table 16.1). The high susceptibility of cotton, mung beans, and maize has been a limiting factor in their cultivation in many developing countries, while wheat, barley, certain millets, etc. are subject to far fewer insect species and numbers. The pest problems also vary considerably in different geographical regions. For example, the rice crop is subject to severe insect pressure in tropical Asia but insects are not a major problem in U.S.A. and Europe. Also, the short statured and heavy tillering plant type of modern improved varieties of wheat and rice supplemented with high rates of nitrogen application, develops a totally different microclimate than those planted with conventional tall varieties. These factors have brought about changes in the relative importance of certain existing pests of these crops, and have brought in some totally new pests as well. These developments, known as second generation pest problems, include such changes as the increased pest status of the brown planthopper *Nilaparvata lugens*, rice gall midge *Orseolia oryzae*, rice leaf folder *Cnaphalocrocis medinalis*, and whitebacked planthopper *Sogatella furcifera* on rice. Two insect species, sugarcane leafhopper *Pyrilla perpusilla* and pink rice borer *Sesamia inferens*, which were earlier not known to infest wheat have become its pests of major importance.

Recent studies have shown that the use of certain herbicides and insecticides makes the plants more suitable for the survival and growth of some insect pests (Manwan, 1975; Oka and Pimentel, 1976; Chelliah and Heinrichs, 1978).

Table 16.1. Losses due to insect pests in major agricultural crops on a world basis[1]

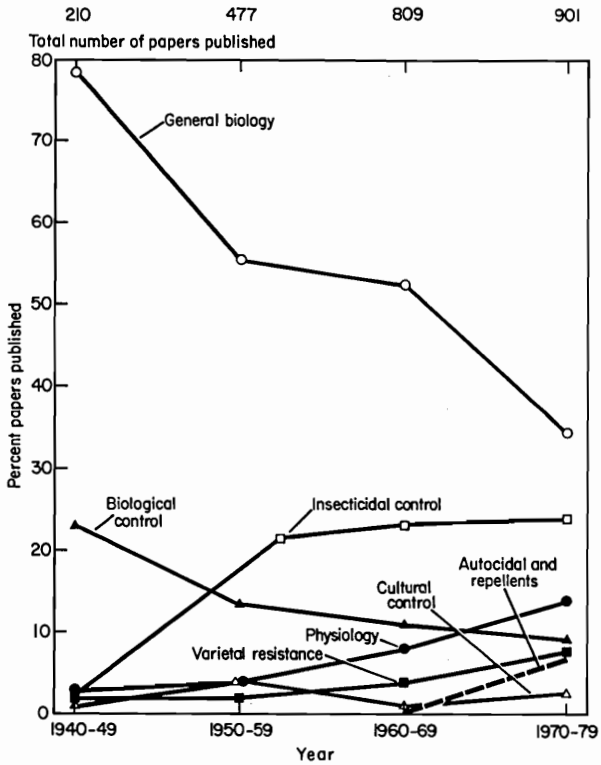
Crop	Loss (%)	Crop	Loss (%)
Rice	26.7	Sugarbeet	8.3
Sugarcane	20.1	Oats	8.0
Cotton	16.1	Potatoes	6.5
Maize	12.4	Fruits	5.8
Oilseeds	11.5	Wheat	5.0
Millets and sorghums	9.6	Barley	3.8
Vegetables	8.7	Rye	2.2

[1]Adapted from Cramer (1967).

ADVANCES IN INSECT CONTROL

Thus, with the intensification and modernization of agriculture, the problem of insect pests was being increasingly realized. Also, many cases of severe loss in crop yields hitherto attributed to other factors were found to be caused by insect pests, for example the high percentages of unfilled rice grains caused by rice bugs and the failure of mango crop due to the mango leafhopper *Amritodus atkinsoni*. Consequently, various methods of insect control are being keenly investigated and many outstanding advances have been made during the last 4–5 decades. Highlights of these methods are reviewed as follows. The relative emphasis in research on these methods in a developing country during the last 40 years is illustrated in Figure 16.2.

Figure 16.2. Change in emphasis on different aspects of entomology research in India, 1940–1979
(Based on all papers published in the Indian Journal of Entomology during this period)



Cultural control

Several cultural practices have a profound influence on the insects' survival, their persistence in a particular environment and damage to a crop. Sometimes even a slight population reduction brought about by these practices delays insect build up to reach damaging levels. These measures are aimed to disrupt or slow down population build up of the pests and include sanitation (destruction or utilization of crop residue, alternate hosts including weeds, habitats for aestivation or hibernation), tillage and flooding of fields to destroy insect pests in stubbles, crop rotation, mixed cropping, timing of planting and harvesting dates to escape pest infestations, use of trap crops, and proper fertilizer and water management practices. Many of these practices are simple and easy to follow but have greater impact when practiced on a community basis.

Removal and destruction of stubbles has been found highly effective in minimizing overwintering populations of many species of insect pests such as rice stemborers, sugarcane stem- and rootborers and maize borer *Chilo partellus*, etc. The cutting and burning of cotton sticks soon after harvest can considerably reduce the populations of the pink boll worm *Pectinophora gossypiella* and cotton boll weevil *Anthonomus grandis* (NAS, 1969). Fall ploughing results in high mortality of overwintering pupae and eggs of many insect pests. In China, ploughing and flooding of large areas of rice fields prior to transplanting have been used as a standard practice to reduce stemborer population on the subsequent crop (Chiu, 1980). Several experiments at IRRI have shown that corn and peanut intercropping or planting of corn in widely spaced rows reduced Aran corn borer *Oștrinia furnacalis* population. Proper crop rotation programs have helped to control corn rootworms *Diabrotica* spp. (Glass, 1975) and brown planthopper (Oka, 1979).

The timing of planting and harvesting dates has been practiced for many crops to escape pest damage. In many countries it is regulated by ordinances or by regulating the availability of irrigation water. Adjustment of sowing or harvesting time is only practical for areas with distinct cold and winter seasons. Delayed planting of crops to evade insect pests emerging from overwintering populations has been practiced in temperate areas for many years. In the tropics and subtropics, however, the life cycle of many insect species revolves around the availability of host plants. Therefore, effectivity of these practices need to be continually evaluated except in minimizing pest outbreaks, for example in 1973, a moratorium of a 2-month period of having no rice crop during May and June in the province of Laguna, Philippines, helped bring down an epidemic population of the brown planthopper.

Cultural practices may be an important method of minimizing pest incidence but each practice needs to be evaluated as a part of the total crop production system. While some practices such as good land preparation are compatible with other production technology, others such as change of planting dates may not be acceptable because of adverse effects on yields or creating favourable conditions for other insect pests.

Biological control

The fact that insect pests are subject to a wide variety of parasites, predators, and pathogens has been utilized for nearly 100 years in devising measures for their control. This approach has proved highly effective against many insect pests.

Biological control measures are expected to be successful particularly where the ecosystem remains fairly stable from year to year, for example, in large scale plantation crops such as coconut, cocoa, coffee, etc. or in the continuous cropping of a particular crop such as sugar cane, corn, or rice and in areas where fluctuations in annual temperatures are not extreme.

The two principal ways of utilizing biological control agents are by conserving and augmenting indigenous populations, and by introducing exotic parasites, predators and pathogens. The fact that the existing natural enemies continuously exert a certain degree of control over various pest species in a particular area is often overlooked. Thus, when a particular pest is recurring, it is an indication that its biological control agents are not effective in that area. In such cases, methods to conserve and augment their populations such as cultivation of certain plants which are attractive to the parasites and predators, continuous cropping of small areas, minimization of practices which may be harmful to natural enemies such as excessive use of pesticides, etc, are helpful.

The mass release of laboratory reared parasites and predators has been practiced for control of several insect pests with the objective of preventing the pest populations from reaching economic injury levels. Such releases generally have not been very successful in earlier years, but a few outstanding results have been obtained during the last decade. These include control of cabbage pests in the U.S.A. (Parker 1971), maize borer in Pakistan (Simmonds and Bennett, 1977) and rice leaf folder in the Peoples Republic of China (Chiu, 1980). Several trichogrammatids (egg parasites) are mass reared and released over hundreds of thousands of hectares annually in the USSR (Klassen, 1976).

Results with the field application of insect pathogens have been outstanding. There are about 300 different types of viruses, 100 species of fungi, 100 species of bacteria and 75 species of protozoans known to attack various pests (Angus, 1977). Many of these can be mass cultured using relatively simple methods, and applied like ordinary sprays. A sprayable formulation of *Bacillus thuringiensis*, a bacterial pathogen of the cabbage looper *Trichoplusia ni* and many other insect pests, has been available in the market for over a decade now and has been extensively used. However, the need for repeated releases or sprays of these biological control agents is a major drawback of this method.

The introduction of new parasites and predators has generally been far more successful. Once established in a new environment, these organisms, in the absence of their natural enemies, multiply fast and often bring about dramatic control of their hosts. They usually remain effective for many years or forever. A total of 120 different species of insect pests have been suppressed (42 completely controlled, 48 substantially controlled and 30 partially controlled) up to 1970 by importation of their natural enemies in about 60 countries (DeBach, 1974). A few additional successes were later

Table 16.2. Selected examples[1] of successful control of insect pests brought about by the introduction of exotic parasites and predators

Crop	No. of insect species controlled	Natural Enemies		
		No. of species imported	Imported to	Imported from
Apple	2	3	New Zealand, U.S.A.	Japan, U.S.A.
Banana	1	2	U.S.A.	Guam, Thailand
Citrus	12	19	Barbados, Cuba, El Salvador, Greece, Israel, Jamaica, Japan Mexico, U.S.A.	Australia, Hong Kong, India, Japan, Malaysia, Pakistan, Taiwan, South America, U.S.A.
Coconut	4	9	Fiji, Mauritius, West Africa	Indonesia, Malaysia, Singapore, Sri Lanka, Trinidad
Coffee	1	1	Kenya	Uganda
Maize	1	1	New Zealand	Pakistan
Soybeans	1	1	U.S.A.	India
Sugarcane	4	5	Barbados, Mariana Islands (Saipan), Tanzania, U.S.A.	Australia, India, Philippines
Tea	1	1	Sri Lanka	Indonesia
Walnut	1	1	U.S.A.	Iran

[1]Based on DeBach (1974), Coppel and Mertins (1977), and Simmonds and Bennett (1977).

reviewed by Coppel and Mertins (1977), and Simmonds and Bennett (1977). These cases are summarized in Table 16.2.

Thus, biological control has great potential in suppressing pest population and causes no environmental pollution problems. It requires little or no fossil energy, since biological control agents are self powered, gaining their energy directly from pest populations. Unfortunately biological control has not been investigated thoroughly and on a sustained basis, particularly in the tropics and subtropics where it should have the greatest potential. This has been partly due to the lack of specialists and partly because it often take many years before the results of such studies can be utilized for practical pest control. The conservation and augmentation of natural enemies requires detailed information on their biology and behavior. The introduction of parasites and predators into new areas should be made only after careful considerations that these would not cause any upset in the existing natural enemy complex and will themselves not become problems for beneficial insects.

Varietal resistance

The use of insect resistant cultivars is an ideal method of insect control. Painter (1951) defined varietal resistance to insect pests as the "relative amount of heritable qualities possessed by the plant which influence the ultimate degree of damage done by the insect. In practical agriculture, it represents the ability of a certain variety to produce a larger crop of good quality than do ordinary varieties at the same levels of insect populations." He classified varietal resistance into the following three categories:

(i) *Nonpreference* – when a plant is unattractive to the insect pest for feeding, oviposition or shelter.

(ii) *Antibiosis* – when the host plant adversely affects the growth and survival of the insects and their progeny infesting it.

(iii) *Tolerance* – when the host plant has the ability to withstand a heavy insect population sufficient to damage severely the susceptible hosts.

A plant's resistance to insect pests may be caused by one or more of these factors. However, antibiosis is considered to be the major aspect of host plant resistance, although under certain circumstances the nonpreference response can be equally important, especially when brief infestations cause severe damage. Examples of the latter are the infestations by insect vectors of plant diseases, or insects which sever growing parts or peduncles of the plants such as stemborer infestations resulting in white heads. In field plantings, nonpreferred varieties frequently escape insect infestations and even when insects are caged on nonpreferred hosts, they lay fewer eggs and thereby develop smaller populations than those caged on susceptible varieties. Thus, both antibiosis and nonpreference affect insect populations.

Tolerance, on the other hand, is mainly attributable to plant vigor, and has no adverse effect on the insect pest. However, the ability of tolerant varieties to support insect infestations for longer periods without loss in yield or quality than the susceptible varieties enables them to frequently escape insect damage either by getting harvested before the pest population becomes too large or by exposing the insects for longer durations to their natural enemies and other physical factors which eventually bring down the pest populations.

Utilization of resistant varieties in insect control

Cultivars resistant to insect pests provide insect control at no additional cost, act as preventive measure against build up of insect populations, are generally compatible with other methods of pest control, and are free from environmental pollution problems. Furthermore, generally there seems to be no problem of genetic incompatibility of insect resistance with other desirable traits of the plants such as high yields, grain quality, and tolerance/resistance to other biological and physical constraints. Depending upon the level of resistance, resistant varieties can be used either as the principal method of control or as a supplement to other methods of pest control. For example, varieties of rice resistant to the brown planthopper or rice gall midge generally do not need supplementary control measures to protect them against these insects but those resistant to the striped borer *Chilo suppressalis* need additional protection from infestations beyond the booting stage of the crop or even earlier if the borer population is too large.

Resistant varieties offer cumulative reduction in pest populations. Available data on 21 different insect species show that the populations of insects caged on susceptible plants became 5–10 times larger within one generation than those caged on resistant plants (Pathak, 1970). The populations of the striped borer become 30-fold larger on a susceptible rice variety Sapan Kawai than on a moderately resistant rice Chianan 2 within 120 days or approximately in four generations, while the brown planthopper and green leafhopper *Nephotettix virescens* caged on varieties having high levels of resistance frequently died off within the first generation (Pathak, 1975).

The use of resistant varieties is compatible with other methods of pest control and, in certain cases, is even more conducive for them. For example, the restless behavior of insects on resistant varieties makes them more vulnerable to parasites and predators than those on susceptible hosts. Cotton bollworm *Heliothis zea* larvae hatching from eggs placed on plant apices remained longer on the terminal growth of resistant cotton and consequently two times as many of them were killed by predators as those hatching from similarly placed eggs on a susceptible variety (Lincoln *et al.*, 1971).

Varietal resistance to insect vectors of plant diseases often limits the spread of the diseases transmitted by them. In Colombia, fields of the rice variety, IR8, which is resistant to the rice delphacid *Sogatodes orizicola*, but is susceptible to hoja blanca virus transmitted by it, remained virtually virus free while other susceptible rice varieties growing in adjacent plots were heavily infested (Jennings and Pineda, 1970).

The development of insect biotypes capable of damaging the resistant plants is a problem limiting the use of resistant varieties (Figure 16.3). Although biotypes have been recorded in only about 10 of the 50 different insect pest species for which varietal resistance is being used as a practical method of control, monitoring of the development of biotypes and measures to overcome them should be carefully pursued. Generally, the development of insect biotypes is a considerably slower phenomenon than the development of physiological races in plant pathogens and so far insect biotypes have been recorded only on varieties with monogenic or high levels of resistance (Table 16.3). Therefore, varieties with moderate and polygenic resistance are expected to remain resistant for longer periods.

Examples of resistant varieties in insect control

One of the earliest and most spectacular examples of insect control by varietal resistance was the control of the grape phylloxera *Phylloxera vitifoliae* in Europe, by using phylloxera resistant grape varieties from U.S.A. The root cuttings of these resistant varieties were imported in Europe in late 1860's and were used for grafting on the grape vines from Europe. The resistant plants were resistant to the aphid and had the desirable quality of European grapes.

Systematic studies on the use of varietal resistance for combating phytopagous insects were initiated in 1930s, but received wider attention of scientists only during the last 30 years. These studies have led to the development of insect resistant varieties in 15 different crops to about 50 different insect pest species. These varieties are currently being grown over millions of hectares, and are providing effective control of many pests of major economic importance. Several of these varieties are also resistant to a few other insect pests, and even to certain diseases, physiological disorders

Figure 16.3. Resistance of rice to different biotypes of brown planthopper. Biotype 1 damaged varieties with no gene for resistance while biotypes 2 and 3 also damaged those containing Bph 1 and bph 2 genes respectively. IRI3240 has bph 4 gene which imparts resistance to three biotypes. (IRRI, 1980.)

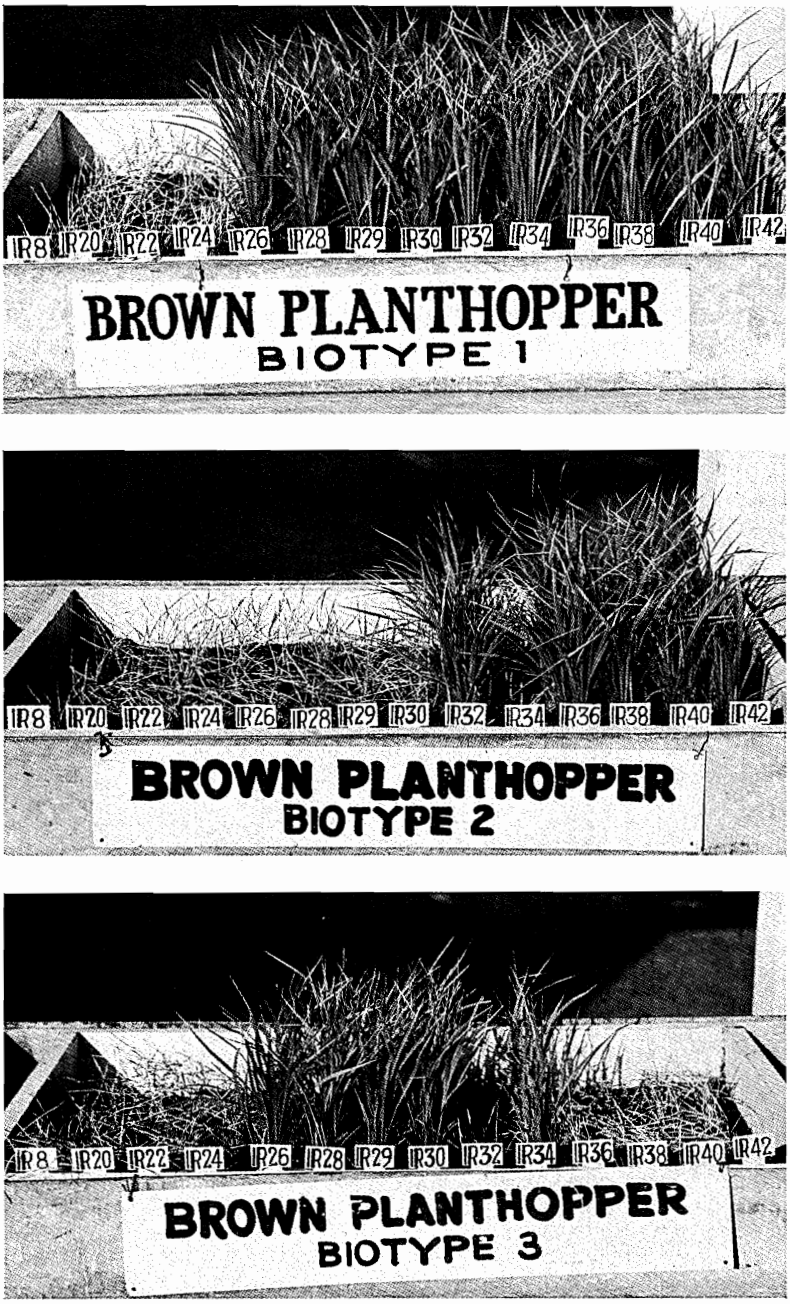


Table 16.3. Insect biotypes involved in plant resistance[1]

Insect pest	Crops	Number of known biotypes
Acyrthosiphan pisum, pea aphid	Alfalfa, peas	9
Amphorophora idaei, raspberry aphid	Raspberry	4
Aphis fabae, bean aphid	Beans	2
Eriosoma lanigerum, wooly apple aphid	Apple	3
Mayetiola destructor, hessian fly	Wheat	9
Nephotettix virescens, green leafhopper	Rice	2
Nilaparvata lugens, brown planthopper	Rice	5
Rhopalosiphum maidis, corn leaf aphid	Corn, sorghum	5
Schizaphis graminum, green bug	Barley, sorghum wheat	5
Therioaphis trifolii f. maculata, spotted alfalfa aphid	Alfalfa	8

[1]Updated from Pathak (1970).

and problem soil conditions. Their role in crop production has been immense. Only a few selected examples are discussed below.

The Hessian fly *Mayetiola destructor* used to be a serious pest of wheat in the U.S.A., but its incidence was reduced from nearly 100% to below 1% levels in certain areas by the cultivation of resistant varieties. By 1974, nearly 16 million acres were planted to Hessian-fly-resistant wheat cultivars, and by 1977 more than 28 Hessian-fly-resistant varieties had been released to the farmers in U.S.A. (Gallun, 1977). The cultivation of resistant varieties has reduced the Hessian fly and wheat stem sawfly *Cephus cinctus* from very serious problems causing annual crop losses of 10 million dollars in U.S. alone (Gallun *et al.*, 1975) to the status of minor pests.

Similarly, the cultivation of European corn borer resistant corn has effected a reduction in use of insecticides by about 22,000 tons per year against this insect but has increased corn yields considerably, and the use of resistant varieties to the spotted alfalfa aphid *Therioaphis maculata* has led to an annual saving of about 300 tons in insecticides in U.S.A. alone (Schalk and Ratcliffe, 1977). Many good agronomic types of cotton with different mechanisms of resistance to major insect pests such as boll weevil, bollworms, plant bug *Lygus* spp., and fleahopper *Pseudatomoscelis seriatus* are now available which, in some cases, suppress the pest activity up to 60–90% (Maxwell, 1977).

The success in developing insect resistant varieties in rice has been outstanding although concerted work on these was started only after 1962. Cultivars resistant to the striped borer, the brown planthopper, the green leafhopper, and the gall midge have been developed and are being extensively grown. Most of these varieties are also resistant to a few other common insects and diseases, and have high yield potentials and good grain quality (Table 16.4). This has been possible primarily because of the availability of nearly 40,000 different collections of rice from all over the world and a multidisciplinary approach to varietal development. The brown planthopper populations were at very high levels in several areas when the first batch of resistant

Table 16.4. Insect and disease resistance ratings of a few recently developed rice varieties[1]

Variety	Growth duration (Days)	INSECTS						DISEASES			
		Brown planthopper			Green leaf-hopper	Stem borer	Gall[2] midge	Blast	Bacterial blight	Grassy stunt	Tungro
		Bio-type 1	Bio-type 2	Bio-type 3							
IR8	130	S	S	S	R	S	S	S	S	S	S
IR20	130	S	S	S	R	MR	S	MR	R	S	MR
IR26	130	R	S	R	R	MR	S	MR	R	MR	MR
IR30	108	R	S	R	R	MR	S	MS	R	R	MR
IR32	140	R	R	MR	R	MR	R	MR	R	R	MR
IR36	110	R	R	S	R	MR	R	R	R	R	R

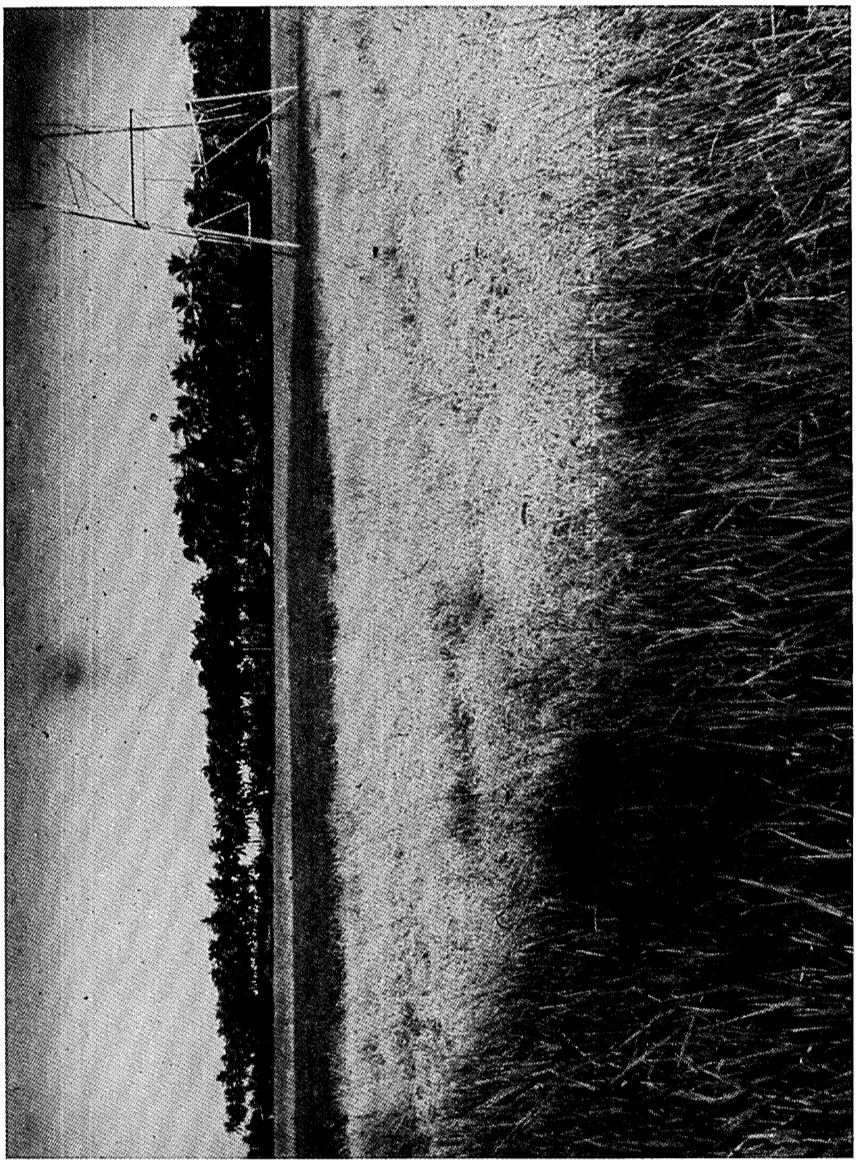
Source: IRRI, 1980

R - resistant; MR - moderately resistant; MS - moderately susceptible; S - susceptible

[1]Many of these varieties are also tolerant to adverse soil problems like alkalinity, salinity, zinc deficienty, salt deficiency, etc.

[2]Rated in India

Figure 16.4. Brown planthopper damage to rice crop in farmers' fields. The fields planted with a resistant variety (dark) suffered little damage. Laguna, Philippines. 1973.



varieties were released during 1973-75. Apparently, the high level of resistance of these varieties has played a major role in bringing down the population of the insect in many areas. At present, varieties resistant to the brown planthopper are being grown on nearly 25 million hectares and they seldom require insecticidal protection against the brown planthopper (Figure 16.4). However, in certain areas new biotypes of the brown planthopper, capable of damaging the resistant varieties, have developed but additional varieties resistant to these biotypes have been bred and are now being widely cultivated.

INSECTICIDAL CONTROL

The use of insecticides is the most common method known to bring about immediate reduction in pest populations. Thus, it constitutes the most effective method of pest control. Prior to the availability of insecticides, human beings watched helplessly as pest epidemics destroyed their crops and cattle. Thus, with the availability of insecticides a new era of human welfare and prosperity dawned. The advent of organic insecticides was considered such an important event that Dr. Paul Muller was awarded a Nobel Prize for his synthesis of DDT in 1939. As is well known for many years, DDT was the most commonly used insecticide. Subsequently, a wide variety of insecticides became very important inputs in agriculture, forestry and health (Table 16.5).

Role of insecticides in increasing crop production

Insecticides have played a major role in raising the world's food production. Availability of insecticides made cultivation of crops profitable in areas where this was previously not possible because of pest problems, as for example with cotton in East Africa. Pesticide use almost universally brought about increased crop production by minimizing pest damage and thereby encouraging farmers to adopt better agronomic practices and obtain high yields.

An average of 38 percent of the world cotton crop is saved from destruction by insect pests through the effective use of pesticides (Adam, 1976). Based on extensive data on the control of cotton insects during 1928-58 in South Carolina, U.S.A., Fye *et al.* (1962) summarized that during the first 18 years, yields of plots sprayed mainly with inorganic insecticides were about 25 percent higher than those of unsprayed plots. During the next twelve years yields were increased a further 50% when more effective organic insecticides became available.

In Japan, the national rice production increased progressively following the wide adoption of parathion in 1953 and the subsequent use of other insecticides (Jung and Scheinpflug, 1970). The use of insecticides has resulted in 20-30% yield increases over untreated rice plots in many Asian countries. Significant increase in yields with the use of insecticides has been reported in maize (Walker and Hodson, 1976) in United States and many other crops around the world. Furthermore, insecticides are an effective weapon to combat pest epidemics such as locusts, armyworms and cutworms. It has been estimated that if no pesticides were to be used the crop production in U.S.A. would be reduced by 25% (Ennis *et al.*, 1975).

Table 16.5. Development of major groups of insecticidal compounds[1]

Class of insecticide	Selected examples	Year developed	Mammalian toxicity – Acute oral LD_{50} (mg/kg)
BOTANICAL	Phyrethrins	1820	584–900
	Rotenone	1895	132–1500
	Nicotine sulphate	1909	50–60
INORGANIC	Paris green (copper aceto-arsenite)	1867	22
	Lead arsenate	1894	100
	Calcium arsenate	1906	35–100
ORGANIC			
Chlorinated hydrocarbons	DDT	1942	113–118
	BHC	1942	88–91
	Chlordane	1945	457–590
	Aldrin	1948	67
	Dieldrin	1948	46
	Heptachlor	1948	100–162
	Endosulfan	1956	80–110
Organophosphates			
Phosphorothioates	Parathion	1947	13
	Diazinon	1952	300–850
	Fenitrothion	1959	250–500
Phosphorodithioates	Malathion	1950	2800
	Phorate	1954	1.6–3.7
	Dimethoate	1956	320–380
	Disulfoton	1956	2.6–8.6
Phosphates	Schradan	1941	9.1
	Dichlorvos	1951	56–108
	Phosphamidon	1956	17–30
	Dicrotophos	1963	12.8–30
	Monocrotophos	1965	14–23
Phosphonothioates	EPN	1949	33–42
Phosphonodithioates	Fonofos	1967	7.9–17.5
Phosphonates	Trichlorfon	1952	560–630
Carbamates	Carbaryl	1956	850
	Aldicarb	1965	0.9
	Carbofuran	1967	8–14

[1]Source of information: Worthing (1979)

About 1.7 million tons of pesticides are applied annually in the world (Pimentel, 1974). Of these, about 45 percent are used in United States, 36 percent in Europe, 8 percent in Japan, 7 percent in developing countries, and the rest in other countries (Furtick, 1976). Of the total insecticides used on crops about 35 percent are on cotton, followed by rice and corn (Table 16.6). The level of usage on a per hectare basis may be as high as 10 kg in Japan, 2 kg in U.S.A., but is only 0.35 kg in developing countries like India (Tilak, 1977). Thus, even though the insect pests inflict heavier losses to the crops in developing countries larger amounts of pesticides are used in the

developed countries where farmers can afford them as compared to their counterparts in the developing world. These suggest the possibility of a substantial increase in the use of insecticides as improved production practices become more adopted in the developing countries.

Table 16.6. Insecticidal input on various crops on a global basis[1]

Crop	Percent total value of insecticides used in plant protection in 1974
Cotton	36.5
Rice	13.3
Corn	9.5
Apples	5.3
Potatoes	3.8
Citrus	3.6
Tobacco	2.1
Wheat	1.5
Sugarbeets	1.5
Sorghum	1.4
Soybeans	1.4
Peanuts	1.3
Alfalfa	0.8
Pasture and rangeland	0.2
Other fruits	7.1
Other vegetables	7.1
Other field crops	2.9
Other grains	0.3
Other hay and forage	0.2

[1]Adapted from Farm Chemicals, September 1975. Total money spent on insecticides in 1974 was $1,822 million. In 1971 this amounted to $842 million but the projected figure for 1980 was $2,413 million. The proportions of insecticides used in 1971 and projected for 1980 were identical to those of 1974.

Limitations of insecticidal control

The effectiveness and high economic return of insecticide use had a spectacular impact on world agriculture and insecticides became the predominant method of insect control. The tonnages of insecticide used increased rapidly, and there was a growing feeling that the battle against insect pests was finally being won. However, the intensive use of insecticides has caused many undesirable side effects on pest control efficiency as well as on the general environmental cleanliness. These have led to strict regulations on the use of pesticides, some of which have been totally banned, and to the general conclusion that pesticides should be used only when absolutely necessary. Some of the major points of the dilemma of their use are discussed below.

(a) Development of insecticide resistant strains of insects. Virtually all insect species against which a particular insecticide has been used over a period of time have evolved strains which are considerably less susceptible to the insecticide than the original population. It is believed that generally such resistant insects are already present in the original population but their proportion increases as the insecticides selec-

tively eliminate susceptible individuals. However, resistant strains also develop by mutation and interbreeding of less susceptible individuals in a pest population during the course of the use of an insecticide. Resistance may develop in one year, e.g., organophosphorus resistance in cotton leafwork *Spodoptera litteralis* or may not develop at all, e.g. DDT resistance in European corn borer (Brown, 1974) and boll weevil resistance to malathion (Brown, 1978).

Since the first occurrence of resistance in San Jose scale *Aspidiotus perniciosus* to lime sulphur in 1908, a total of 364 species of insects and mites are reported to have developed resistance to insecticides (Table 16.7). Of these, 225 species are agricultural pests while the remainder are of medical and veterinary importance. As expected resistance is more common in regions and on crops where insecticides have been intensively used. As a consequence, these areas require larger number of treatments compounding the problems of environmental pollution and promoting development of insecticide resistance. The largest proportion of insecticide resistant strains are among cotton pests and continue to increase further. A world survey revealed that 20 species of cotton pests had developed resistance to insecticides by 1965 (FAO, 1967) but the number increased to 33 by 1975 (Reynolds, 1977). These resistant strains are rendering insecticides inefficient particularly in regions where resistance has developed in several insect species and to more than one insecticide as is the case in several parts of the United States, Egypt, Australia, Peru, and Nicaragua.

There does not appear to be an easy solution to resistance as a general phenomenon. A rational attempt would be to develop insecticides which are effective to specific insects and are less hazardous to parasites and predators, and to avoid all but only absolutely necessary treatments by resorting to the use of as many alternative pest control approaches as possible.

Table 16.7. Insect and mite resistance to different insecticides[1]

Order of the insect/mite	INSECTICIDES					
	DDT	Cyclodienes	Organo-phosphates	Carbamates	Others	Total
Total number of species	203	225	147	36	35	364
Percent species belonging to different groups						
Diptera	44.8	44.4	27.2	16.7	11.4	36.5
Coleoptera	12.8	21.3	12.2	19.4	22.9	15.4
Hemiptera	6.9	10.2	21.1	11.1	11.4	15.1
Lepidoptera	15.3	14.2	15.0	33.3	11.4	14.3
Acarina	10.3	4.4	21.8	16.7	37.1	11.8
Other orders	9.9	5.3	2.7	2.8	5.7	6.9

[1]Adapted from Georghiou and Taylor (1977).

(b) Effects on nontarget organisms in the treated agroecosystem. An insect pest in a crop is only a part of a complex ecosystem comprising other pests, parasites, predators and pollinators. The insecticides are usually also toxic to the natural enemies of the pest which affects a fast resurgence of the pest population and also encourages the build up of other pest species against which the insecticide applied was not effective. Such changes have been recorded on many crops but the problems on cotton, which receives high levels of insecticides, have been particularly complex. For example, the use of DDT and toxaphene to control leafworm in Egypt resulted in problems with aphids *Aphis gossypii*, mites *Tetranychus* supp., and spring bollworm *Earias insulana* (Reynolds *et al.*, 1975). Also, the excessive use of these two insecticides and methyl parathion and endrin resulted in cabbage looper, beet armyworm *S. exigua* and plant bugs *Creontiades* spp., becoming major pests in Nicaragua (Vaughan and Leon, 1977). Application of carbaryl to control pink bollworm caused severe outbreaks of cotton leafperforator *Bucculatrix thurberiella*, spider mites and beet armyworms in the U.S.A. (Smith, 1970). It has been suggested that the leafhopper and planthopper pests of rice became more serious in Japan following extensive use of insecticides which caused mortality of predators (Jung and Scheinpflug, 1970). Similarly, resurgence of the brown planthopper on rice crop has been reported following application of methyl parathion and diazinon (Chelliah and Heinrichs, 1978).

Therefore, there is a growing apprehension that if appropriate precautions are not taken similar situations may develop on other crops as well. In addition insecticides destroy honey bees and other pollinators not only by direct contact poisoning, but also from consumption of poisoned nectar and water, and the transport of poisoned nectar or pollen into the hive.

(c) Environmental pollution and toxic hazards to human and other lives. The widespread use of insecticides has led to contamination of the human environment. Insecticides have been detected from soils, water and air, and by getting in the food-chains they have contaminated all forms of life including fish, birds and mammals including mother's milk. Although these quantities have been generally low there is the danger of a build up of their amounts with time and of course there is no way of accurately knowing the long range effects of these minute quantities on the health and survival of human beings and other animals. Furthermore, there are a large number of accidental cases of insecticide poisoning either by direct contact or through food, some of which result in death or prolonged sickness.

These have aroused great concern about the safety from adverse effects of insecticides. Consequently, many countries have imposed extensive tests on chronic and acute toxicities, environmental pollution problems and residual duration of candidate insecticides before they are formally approved for commercial use. Also, there is greater emphasis to use as little insecticide and as infrequently as possible.

(d) High cost of insecticides. The increasing cost of insecticides is a factor severely limiting their use particularly by smaller farmers in developing countries. Although many crops in these countries suffer severely from pest damage, appropriate pest control measures are often not followed because the insecticides are too expensive for the small farmers to initially afford them, even though they may provide high economic returns.

The future of insecticidal control
In spite of these limitations, insecticides will probably remain a primary method of insect control unless some startling discovery is made which replaces them. Therefore, ways and means need to be devised to use insecticides with discrimination, to develop better formulations, better timing and methods of application. For example, the root zone application of insecticides in rice fields requires only about one-half of insecticide needed for paddy water application, but is effective for 3-5 times longer duration (Pathak *et al.*, 1974). This is a remarkable saving over the conventional methods of pesticide use and appears to have considerably low adverse environmental implications. It has been estimated that judicious use of pesticides can lead to about 35 percent reduction in their usage on global basis (Chou *et al.*, 1977). Also, greater emphasis should be laid on developing safer insecticides. The advances made during the last decade are quite encouraging and new insecticides being developed are expected to cause little or no damage to beneficial arthropods or wildlife.

Biorational control

Several approaches of insect control utilizing chemicals that affect insect behaviour, growth or reproduction have been extensively evaluated in recent years. These approaches have shown promising results against certain insect species and are reviewed as follows:

Repellents and antifeedants In many areas, farmers have used since ancient times certain herbs and roots to repel insect pests from their crops and storage. A classical example is the use of leaves, bark and seed of the neem tree *Azadirachta indica* as an insect repellent. Recent studies using extract of neem seed have confirmed this repellent effect on a variety of insects (Ketkar, 1976). This repellent effect has been demonstrated to be so strong that the locust *Schistocerca gregaria* starved to death rather than feed on plants treated with the extract from the neem seed (Pradhan *et al.* 1962,; Butterworth and Morgan, 1968). The chloroform extract of a closely related tree *Melia azedarach* possesses pronounced antifeedant activity against the larvae of the corn earworm *H. zea* and the fall armyworm *S. frugiperda* (McMillian *et al.*, 1969). The feeding of the cotton leafworm is inhibited by an alkaloid, insoboldine, obtained from the climbing shrub *Cocculus trilobus* (Munakata, 1970). A number of alkoglycosides from various species of *Solanum* inhibit feeding of the Colorado potato beetle *Leptinotarsa decemlineata* (NAS, 1969).

A compound, *trans*-aconitic acid, isolated from barnyard grass *Echinocloa crus-galli* has strong antifeedant properties against the brown planthopper (Kim *et al.*, 1976). The compound 4'-(dimethyltriazeno)-acetanilide has shown antifeedant properties against certain surface-feeding insects such as the cabbage looper, cabbage worm *Pieris rapae*, hornworm *Manduca sexta*, boll weevil and cucumber beetles *Diabrotica* spp. (Ascher, 1970). Since the target pests are not killed by these chemicals, it would help in maintaining the natural enemy balance. There is a need to develop systemic antifeedants which could be effective against sucking insects and on growing plant tissues. The use of antifeedants appears to be a promising approach

and a considerable amount of additional work is needed before they can be used on commercial scale.

Attractants including sex pheromones

The discovery and identification of several powerful chemicals responsible for attraction of insects to their food (food lures), egg laying sites (oviposition lures) and mates (sex pheromones) have made possible the use of insect attractants as a tool in pest control. Among these, sex pheromones appear to have the most potential and have been widely investigated in recent years. These attractants, because of their high specificity, appear to be an ideal means for monitoring insect pest populations but can also be used in control of insect pests by either mass trapping or by disrupting mate selection.

(a) Monitoring pest populations. The high specificity of insect attractants has been exploited by using them for monitoring the population of the responsive insect species, for example – trimedlure for Mediterranean fruit fly *Ceratis capitata*, methyl eugenol for oriental fruit fly *Dacus dorsalis* and phenethyl propionate for Japanese beetle *Popillia japonica*. Pheromone traps have been used in survey trapping for gypsy moth *Porthetria dispar* with dispalure, codling moth *Laspeyresia pomonella* with codlemone, cabbage looper with *cis*-7 dodecenyl acetate, and cotton pink bollworm with gossyplure (Metcalf and Metcalf, 1975). Pheromone traps provide a sensitive method for determining the initiation of flight activity of the insects. The information can be used to determine the appropriate timing of control measures.

(b) Mass trapping. The population of certain insect pests can be effectively suppressed by attracting them into baited traps. The classical example of this approach is the eradication of oriental fruit fly from a Pacific island by using a combination of methyl eugenol and a quick-acting contact insecticide, naled (Steiner *et al.*, 1970). Such combination also resulted in the elimination of this pest from southern California (Chambers *et al.*, 1974). The sex pheromone *cis*-11-tetra-decenyl acetate of red-banded leaf roller *Argyrotaenia velutinana* has been used in apple orchards in sticky traps for male moth control (Trammel *et al.* 1974). The pheromone of the male boll weevil, grandlure, has been used for attracting weevils into cotton fields treated with the systemic insecticide aldicarb which subsequently killed the weevils as they fed on the treated cotton (Lloyd *et al.*, 1972).

(c) Mating disruption. Since many insect species find their mates in nature through odor, introduction of synthetic sex pheromones in their habitats has been found to greatly reduce the capacity of the insect to locate its mate. Experiments with continuous release of gossyplure, the natural sex pheromone of the pink bullworm, and a less active synthetic analog, hexalure, into the air of cotton fields showed disruption of mating which resulted in a reduction in boll infestation comparable to commercial insecticide applications (Shorey *et al.*, 1974). Similarly, the mating success of gypsy moth was decreased from 81% to 35% when dispalure was dispensed at a rate of 5 g/ha (Cameron, 1973). In tests using a microencapsulated formulation of dispalure at the rate of 15 g/ha the matings were disrupted so efficiently that population increases were kept below 10 percent level (Cameron *et al.*, 1974). The microencapsulated materials have also provided excellent results for European corn borer and red-banded leafroller (Klun *et al.*, 1975).

Insect attractants discovered to date have very low mammalian toxicities, are not known to possess any adverse qualities and are used in extremely low concentrations in the atmosphere. Moreover, attractants are highly specific and thus work for pest species only. These are, therefore, ecologically most acceptable and appear to have great potential for use in pest control programs.

Sterilants

The concept of inducing mating by sterilized male insects with normal females in nature which then lay unfertilized eggs and thereby bring about a reduction in the insect population has been tested against many insect pests in recent years. It is particularly effective against species whose females mate only once. The sterilization of the insects can be accomplished by irradiation, chemical treatment or by inducing chromosomal translocations in laboratory reared insects. Also, the wild populations can be sterilized by exposing them to appropriate mixtures of chemical attractants and sterilants. The sterilized insects seek out females even in very sparse populations and under difficult terrain and, therefore, this approach has been utilized in insect eradication programs.

The eradication of the screw worm fly *Cochliomyia hominivorax* from Curacao and the southereastern U.S.A. is a classical example of the success of the sterile male release technique (Knipling, 1960). About 54 million sterile flies were produced per week from fly pupae exposed to a predetermined dose of gamma radiation from a cobalt-60 source, and were dispersed by air. The cost of the entire project was $10.6 million or approximately half of the annual losses caused by this insect in previous years (Davidson, 1974). Since then, although occasional infestations occur in the area in association with imported livestock, these are quickly eliminated (Coppel and Mertins, 1977).

Attempts have been made to use the sterile male technique for the eradication of some agricultural pests but with limited successes. Examples are fruit flies, cotton boll weevil, codling moth, cabbage looper, and the corn earworm.

Several chemosterilants have been tried with promising results on codling moth, cotton pink bollworm, cotton boll weevil, and cabbage looper. However, the chemosterilants available to date are highly toxic and are likely to cause environmental contamination problems. Therefore, the feasibility of using chemosterilants in insect control appears to depend on finding effective but safe chemicals and standardization of appropriate methods of dispensing them.

Various deleterious genes have been identified in insects which could be introduced into wild populations with a view to induce sterility, alter sex ratio or produce other harmful effects. When incompatible male insects mate with native females, there is no development of offspring as the sperm is blocked before it could fuse with nucleus of the egg. The introduction of incompatible strains of certain species for the control of public health insects has been explored and it has been suggested that this genetic approach could be used more economically than sterile males in release programs for some insects. Curtis (1968) demonstrated the utility of this approach for the control of tsetse flies *Glossina* spp. and indicated that twice as many sterile males as incompatible males would have to be released into a population to achieve the same level of control. Whitten (1970) believes that a single release of four strains provides

a load equivalent to a 20:1 release of sterile insects and when continued for five generations this load is sufficient to provide direct control of insect pests. However, this approach has as yet not been successfully exploited for the control of agricultural pests.

Hormones

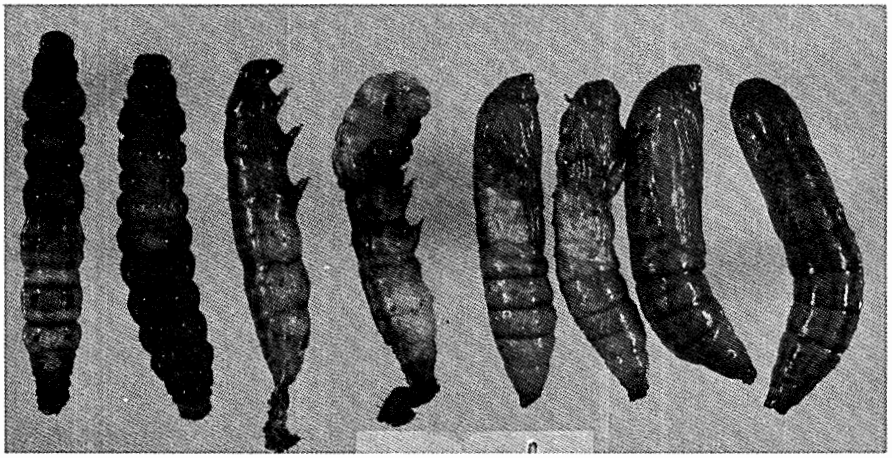
The concept of using certain hormones and their analogues to disrupt the normal growth, moulting and pupation of insects to bring down their population was welcomed under the title 'third generation pesticides' (Williams, 1967). Since then its feasibility has been tested on many insects with promising results. For example,a peptidic analog of insect juvenile hormone, ethyl pivaloyl-L-alanyl-p-aminobenzoate has shown pronounced systemic effects in sunflower plants at 100 μg/plant and inhibited the metamorphosis of larvae of red cotton bug *Dysdercus cingulatus* exposed to the treated plants for 24 hours (Babu and Slama, 1972). Nassar *et al.*, (1973) demonstrated that ZR-777 (prop-2-ynyl 3,7,11-trimethyl-(2E,4E)-2,4-deodecadienoate) induced sterility in the adults of the green bug *Schizaphis graminum*, at concentrations of 0.01 to 0.1% in the greenhouse. Similar effects were observed on the citrus mealy bug *Planococcus citri* (Staal *et al.*, 1973). Strong and Dickman (1973) reported that Altozar (ethyl e, 7, 11-trimethyl1-2, 4-dodecadienoate) and Altosid (isopropyl 11-methoxy-3, 7, 11-trimethyl1-2, 4-dodecadienoate) incorporated into food substrates at 5 to 20 ppm concentration prevented emergence of adults of certain stored product insects and brought about population reduction comparable to that obtained by treatment with malathion. Certain rice varieties resistant to striped borer have been found to contain chemicals which have a juvenile hormonal effect on the striped stem borer (Figure 16.5) (IRRI, 1978). Bowers *et al.*, (1976) isolated two chemicals from the bedding plant *Ageratum houstonianum*, which possess antijuvenile hormone activity and induce precocious metamorphosis and sterilization in several insect species.

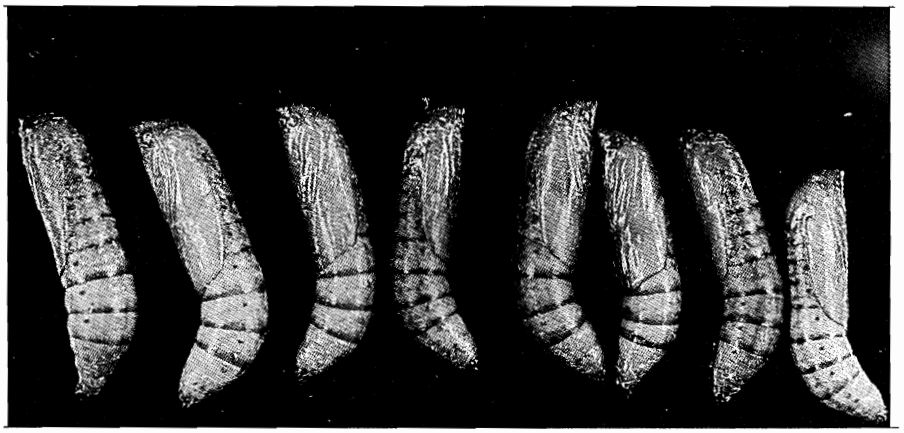
At present, the field use of hormones is very much limited because of the problems of critical timing in application, short persistence in the environment, lack of immediate control and reinvading populations. Moreover, the earlier thinking that insect species may not develop resistance to hormones, does not seem to be correct. There are reports that insecticide resistant strains of tobacco budworm *H. virescens* show an enhanced tolerance to juvenile hormone analogues (Brown, 1974) and a multiple resistant strain of *Tribolium castaneum* was found highly tolerant to all of the five synthetic hormones tested (Dyte, 1972). However, these chemicals are known to be comparatively safe to mammals, birds and fish and thus are likely to have minimal environmental hazards. The hormones appear to offer promising lead to the development of more safe and specific chemicals for pest control. However, this approach is still in the infancy and additional research on mode of action, environmental safety and appropriate formulations is needed before hormones can be used on a commercial scale.

Integration of different methods of insect control

It has been increasingly realized during the past decade that effective insect pest control can not be achieved by the use of any one method of pest control alone. This conclusion was arrived at because of many pest control inefficiencies and environmental hazard problems that arose due to the intensive use of pesticides in many developed

Figure 16.5. Topical application of extract from a stem borer resistant variety on striped borer larvae caused abnormal development (upper photo) as compared to normal pupation of those treated with the solvent alone. (IRRI. 1977).





countries and on high profit-cash crops around the world. Therefore, careful considerations have been given in recent years to develop a systems approach in evolving pest control measures which will be practical, economical and non-pollutant to the environment. This approach, popularly known as integrated pest control (Smith and Reynolds, 1966) or integrated pest management (Geier, 1970), utilizes cultural practices which suppress pest populations, planting of insect resistant varieties, close monitoring of the pest populations in the field, and applying pesticides only when needed and in a manner compatible with other methods of pest control. Different methods of insect control have been discussed in the preceeding section of this chapter. For utilizing them in an integrated pest management program, information on the following two additional aspects is essential.

(a) Economic thresholds. An economic threshold is the level of pest population which causes significant crop loss and at which the pest control measure followed will give economic return. Critical studies on population dynamics of the insect pest and the nature of its damage are needed to determine its economic thresholds. These values are generally very low for pests affecting the quality of crops or vectors of diseases. Availability of reliable methods of sampling pest population densities is an essential aspect of the use of economic thresholds in integrated pest management programs (Southwood, 1978).

(b) Forecasting of pest populations. Ability to forecast pest populations is immensely valuable in pest management programs as it enables intelligent application of control measures to prevent population increases above economic thresholds. Forecasting requires surveillance for populations of pests and their natural enemies, climate, stage of crop growth, etc. Climatic uncertainties frequently make forecasting of insect populations unreliable, but the surveillance data are used for consecutive pest control treatments.

At present considerable research is underway for developing reliable techniques for forecasting pest populations and many countries have an extensive network of pest and disease surveillance teams. The information is compiled at district or provincial headquarters and is broadcast on radio and television programs advising the farmers of appropriate actions to be taken. In China and Korea, plant protection workers maintain close surveillance for pest problems in each field. They install a red flag in the field to indicate that pesticide application is needed. A white flag is placed adjacent to the red flag as soon as the field is treated to show that the treatment has already been made.

(c) Examples of integrated pest management.

Currently, integrated pest management programs are being intensively investigated on many crops such as cotton, apples, tobacco, alfalfa, citrus, sorghum, corn, soybean, and rice. In general the results have been very promising. In many developed countries, or on certain cash crops even in developing countries, where pesticides have been indiscriminately used, the emphasis on integrated pest management has been to reduce the amount of insecticides being used, use of more selective insecticides to conserve natural enemies wherever applicable, use of resistant varieties, and other appropriate cultural methods to help restore the parasites and predators found in the ecosystem. On the other hand, in many developing countries where gen-

erally appropriate pest control practices have not been followed and farmers use inadequate quantities of pesticides and often inappropriate methods and time of applications, integrated pest management relates to more efficient use of pesticides applied when absolutely necessary to supplement other methods of control. Greater emphasis is placed on cultural and biological methods of insect control. Insect resistant cultivars, where available, constitute the core of the integrated pest management program.

A few selected cases of integrated pest management which have provided promising results are reviewed as follows:

On cotton, the integrated pest management approach helped in reducing the frequency and the total amount of insecticides used and has provided a great relief from the adverse effects associated with excessive use of pesticides. The pest management system for cotton involves the use of pheromones to determine the time of appearance and seasonal abundance of insects, employment of economic thresholds, use of selective dosages of insecticides to conserve natural enemies and the use of crop management practices (Reynolds *et al.*, 1975). The integrated approach has resulted in reduction of insecticide use by 50% in the San Joaquin Valley in California, 80–90% on a 100-square-mile area in Arkansas and the use of insecticides has almost been eliminated in the trans Pecos area in Texas, while maintaining high yields (van den Bosch, 1978).

The integrated pest management for apple and citrus pests is based on monitoring of insect pests by several techniques including the use of pheromones and the control measures are applied only when the populations reach economic thresholds. Selective chemical control measures are employed against all pests without disturbing the natural enemies thus permitting them to take maximum toll of their prey and help to lengthen the gap between sprayings. This system has led to considerable reduction in insecticide use (DeBach, 1974).

The integrated pest management for corn in USA involves the services of scouts in 7 pilot states. The scouts make quick surveys of the fields and take detailed counts only if infestations are present, thus covering 3000 – 4000 acres per week. Based on scouting information, selective treatments are accomplished by predicting population levels, relating these levels to economic thresholds and making the decisions on the need and time of treatment. Other strategies include the use of European corn borer resistant varieties and cultural practices, but active manipulation of natural enemies is not accomplished. This approach has brought about substantial reduction in the insecticide use on corn in Iowa, and also in Illinois (Chiang, 1978).

Although the need for integration of different pest control tactics in developing countries was emphasized as early as 1967 (Pradhan, 1967), the progress in large scale adoption of integrated pest management approach has been slow.

Several pilot project type of schemes on integrated pest management are presently being evaluated against rice pests in several developing countries. The integrated management of rice pests in Asia relies heavily on the use of insect resistant varieties, certain cultural practices, biological control agents, and pest surveillance to determine time of insecticide applications (Pathak and Dyck, 1973; Heinrichs *et al.*, 1979). The use of selective insecticides such as in Solomon Islands (Stapley *et al.*,

1979) and root-zone application of insecticides help build up biological control agents which play an important role in stabilizing pest populations. Insect resistant varieties constitute the core of integrated pest management programs for stem borers, leafhoppers, planthoppers and gall midge pests of rice.

The integrated managements of insect pests of rice appears to be highly effective in China. This has been made possible by the organizational structure and the adequate labor available to implement the various integrated control tactics like cultural, biological, physical and chemical control methods. The proper time of application of insecticides is determined by a network of pest forecasting systems set up at four levels: the county, the commune, the production brigade, and the production team. The data collected by production teams, brigades and communes are transmitted to the county forecasting station, which in turn advises the commune and production brigades about the proper timing of insecticidal applications. In certain areas mass releases of *Trichogramma* spp. which parasitize eggs of several common insect pests, are also practiced. Pest control operations are carried out by specialized plant protection teams at the brigade level and in case of heavy outbreaks, masses in the commune are called upon to help in implementing the control measures. The insect resistant varieties which, for a long time, were considered to be the missing link, have recently been employed in integrated control programs (Chiu, 1980). Similarly, pest forecasting combined with selective chemicals or formulations has resulted in a substantial reduction in the amount of pesticides used in Japan and Korea.

In India, Operational Research Projects on integrated control of rice insects have been started at seven sites each covering about 2,000 hectares of farmers' fields in six major rice growing states (Kulshreshtha, 1979). In Thailand, an integrated project on rice insect pests has been started on pilot basis in farmers' fields (Kovitvadhi *et al.*, 1978). Both these programmes emphasize the use of insect resistant varieties, pest surveillance to determine economic thresholds, as well as the use of selective insecticides only when absolutely necessary.

The basic idea behind these projects is that the pest control technology may be quite effective at research stations, but may not perform satisfactorily on the farmers' fields. The projects are located in areas which are known to be endemic for the most destructive insect pests. The information provided by roving surveillance teams along with light trap catches data is the backbone of these programs. Depending upon the incidence of insect pests in an area, farmers are advised to follow the appropriate control measures. The scientists work in close asssociation with the farmers and demonstrate to them the improved methods of pest control, cost-benefit ratio of different control measures and the benefits that could be achieved by integrated pest control approach. These programs are still in their infancy and have yet to show their feasibility on a large area basis, but preliminary information reveals that the total amount of insecticides needed can be considerably reduced without loss in rice yields.

In the developing countries, the present use of even less than 0.5 kg per ha of insecticides is likely to increase at least by 3 times, even when well thought of integrated pest management programs are implemented. Extreme precaution would be needed by the scientists and policy makers to ensure that this prospective increased use of

insecticides is based on a careful selection of chemical, time of application and formulation, and the insecticides should be used only when absolutely necessary.

INSECT CONTROL STRATEGIES FOR THE FUTURE

Based on current advances in research, the integrated pest management system seems to be the answer for handling pest problems in the future. Consequently, future researches on various methods of pest control will emphasize their mutual compatibility. The cleanliness of the environment, safety from health hazards and energy saving methods will be of paramount importance. Development of insect resistant varieties, which is becoming increasingly more important both in developing and developed countries, will be strengthened and special attention will be paid on methods to minimize development of insect biotypes capable of surviving on resistant plants. The cultural practices, cropping systems to avoid monoculture, and biological control research need greater attention. Also, greater emphasis is neded on the development of pesticides which are selective and safe to nontarget organisms, and their apropriate formulations and methods of application.

More basic work is needed on sex pheromones and other behavioral chemicals to develop practical methods of using them. Basic research may reveal completely new approaches to insect pest control and will certainly bring significant improvements in techniques which are already known. All these approaches need to be integrated and implemented effectively.

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CHAPTER 17
Disease Problems and their Management

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INTRODUCTION

PESTS AND DISEASES reduce the yield of crops in developing countries where the production is already low because of several other constraints. In general, plant diseases are said to cause a 10% reduction in yield. Disease epidemics in the past have caused food scarcity, famine and even brought changes in the cropping systems. With the escalating cost of the inputs, it is necessary to streamline plant disease management operations to minimise crop loss and maximise production.

PLANT DISEASES

Diseases are caused by fungi, bacteria, viruses, viroids, mycoplasma like organisms, nematodes, algae, phanerogamic parasites in addition to nonbiotic reasons such as mineral deficiency. In the tropics and subtropics where weather fluctuations between the seasons are minimal, the cropping is both extensive and intensive. These conditions are conducive to better survival and rapid disease development. While in the temperate countries below freezing winter temperatures reduce the inoculum load, and, therefore, the very survival of the pathogen. Rice breeders of 10 Asian nations were of the unanimous view that production in the farmer's field is seriously affected by pests and diseases (Hargrove, 1977). In a sample survey of the rice growing areas of India, very heavy crop losses to a maximum of 96 percent on the high yielding varieties were observed (Raheja *et al.*, 1978). The same survey also showed that diseases of cotton were the main biological constraints in increasing yield. It is believed that in the tropics the number of crop diseases and losses caused due to them are substantially higher in comparison to the temperate countries. The number of recorded dis-

Table 17.1. Number of crop diseases reported in tropics and temperate regions

Crop	Number of diseases	
	Temperate	Tropics
Rice	54	500–600
Maize	85	125
Citrus crops	50	248
Tomato	32	278
Beans	52	253–280

eases and pests on rice, maize, citrus crops, beans and tomatoes is almost twice or more in the tropics compared to the temperate regions (Table 17.1). This emphasises the need for enhanced efforts to minimise crop loss in the tropics by proper management of plant diseases.

Crop loss

How an epidemic grows?

Prior to scientific farming epidemics plagued agricultural crops and man fought them based on his past experience. Increasing knowledge on the epidemic growth pattern has now rendered their control possible. An epidemic is any increase and decrease of a plant disease in a host population occurring in time and space (Kranz, 1974a). An epidemic is a spatial and temporal process, occurring when the disease triangle is completed (Figure 17.1).

At the onset of an epidemic, only a few infected plants occur, and subsequently under ideal conditions inoculum from these plants spreads creating an epidemic. An epidemic progress curve is sigmoid, and the shape of it is influenced by the type of physiologic race, cultivar, time of application of chemicals etc. If the disease's progress is to be kept below the economic threshold, appropriate plant protection technology is to be developed.

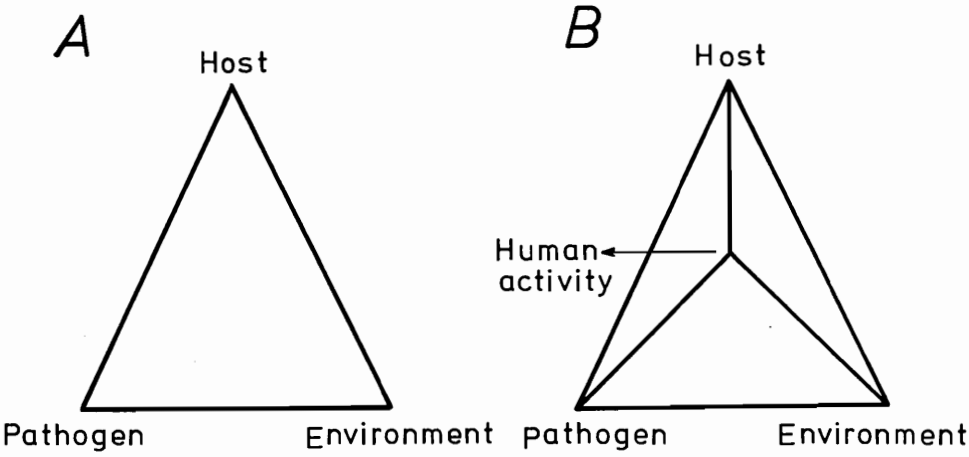
The disease growth has an initial slow phase called the lag phase, a middle phase when growth is very fast and a third phase when growth gets stagnated, known as plateau. To exercise control on an epidemic growth, the rate of disease growth or a delay has to be imposed in the lag phase itself, otherwise it will not be that effective subsequently. This calls for early detection and action to minimise crop loss.

Epidemics and crop loss

The 1845 Irish famine, the 1942 Bengal famine and the increased cost of animal products in the USA during 1970-71 were caused by phytoepidemics. The coffee rust (*Hemileia vastatrix*) epidemics of the last century compelled Sri Lanka to abandon coffee growing which became uneconomical, and to switch over to tea cultivation. There are many more such examples available in literature.

The term 'crop' refers to a unit of plants that provide food, fiber or stimulant and their produce is 'yield'. Crop loss is then a reduction in either quantity or quality of

Figure 17.1. (A) The disease triangle explains the conditions needed for the disease symptom to appear (Monocyclic)
(B) epidemic a polycyclic process needs completion of many disease cycles due to human activity



yield or both. Yield obtainable under most ideal conditions of input and management is the 'Attainable yield', while under farmers' conditions the 'Actual yield' is reaped. Actual yield varies between years and is influenced by drought, energy shortages, pests, weeds and diseases. Damage by pests, diseases, weeds and rodents is referred to as 'Biological constraints'. With better management, yield loss due to biological constraints can be minimised.

Farmers' understanding of plant disease

Pearl millet *(Pennisetum typhoides)* is a dry land crop and ergot (*Claviceps microcephala*) is the most serious biological constraint. A survey around Hissar, Haryana in India, revealed that most of the dryland farmers were aware of the recommended disease control measures. However, only about 30 percent farmers understood it properly, for example 'roughing reduces ergot', while less than 20 percent of them followed even that little they knew. All those who roughed the diseased plants did not burn but just dumped them in one corner of the field (Table 17.2). Practically, therefore, no control measure was followed (Hiranand *et al.*, 1981). This is just to give an example of the level of action adopted by a majority of the farmers of developing countries.

Decision making

The cultivator, who is an agri-businessman, makes certain capital investments in raising a crop. The high input costs, variety and other market considerations dictate his attitude towards pest management risks. His aversion to risk is the important impulse behind decision making, and could partly account for the difference between the

recommended and executed number of treatments. Many factors such as his perception of loss, availability of chemicals, equipment and the cost benefit ratio influence the decision making process (Figure 17.2). Farmers would take corrective actions, if at least the cost of that action is equal to the amount of additional crop income that he would realise. To make him enthusiastic and take prompt action the cost benefit ratio should be more than one. And the economics of decision making may vary from location to location, even though the extent of loss may be the same (Carlson, 1979). Fungicide sprays are considered essential for producing certified seed because only a disease free seed would fetch a price. In plantation and cash crops routine plant protection sprays are done, more to avoid the risk of epidemics than to face the consequences of it.

Table 17.2. Disease occurrence, farmer's perception of loss, knowledge and extent of adoption of control measures

Crop	Disease	Extent of loss perceived	Control measure (Sanitation) Known	adopted
Bajra (*Pennicitum typhoides*)	Ergot	50%)	30%	20%
	Ergot + downy mildew	50–75%)		
	Ergot + smut	75%)		

after Hiranand *et al.* 1981

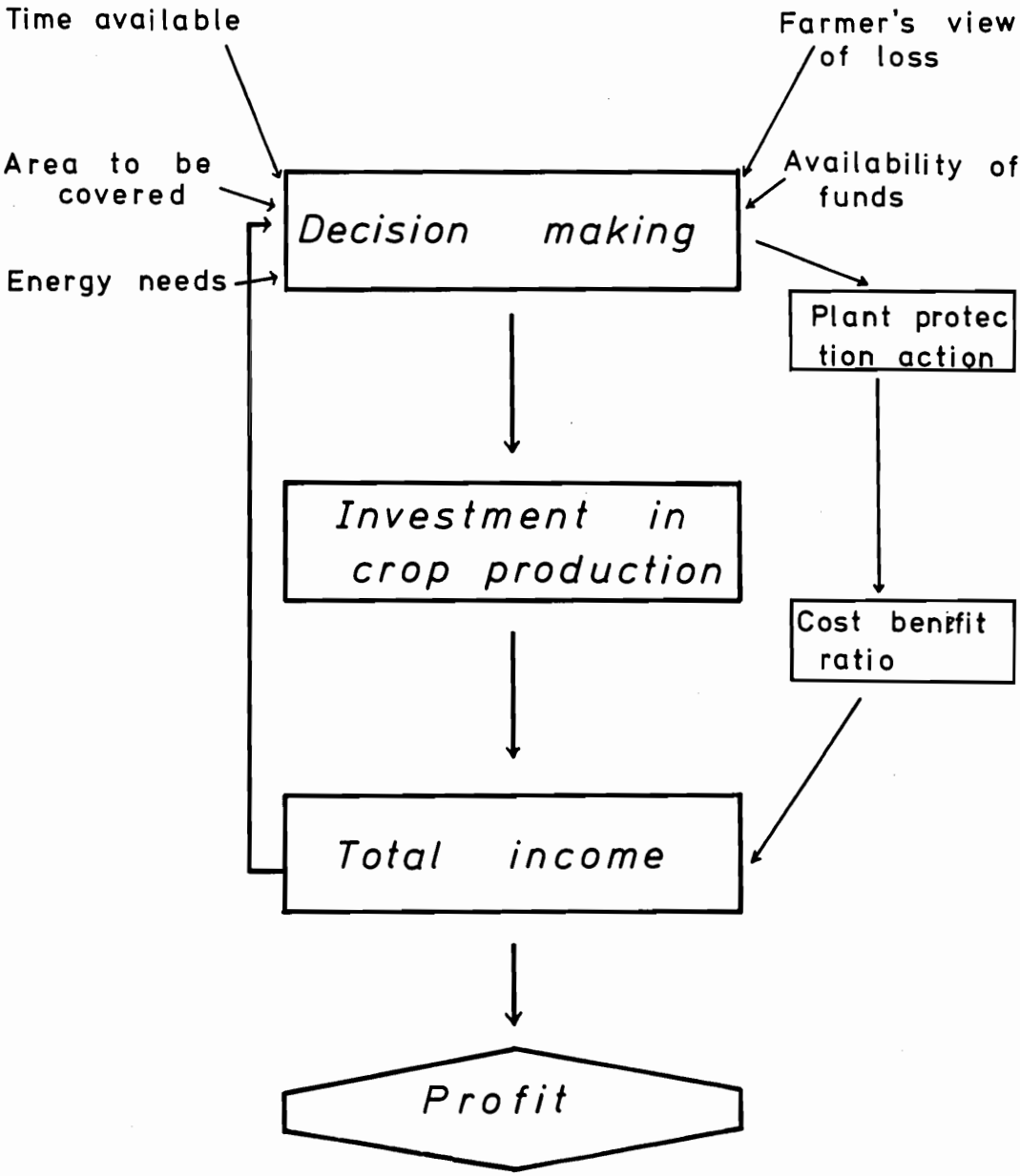
PRESENT LEVEL OF PROTECTION TECHNOLOGY

An understanding of the present technology is necessary before assessing what is needed by the year 2000 to protect our crops. A single approach, be it chemical control or breeding for disease resistance cannot give complete protection to the food, fiber, fuel and stimulus crops. Since the level of technology, crops, weather conditions and resources vary from country to country no generalization can be made. Most of the developing countries have a 'Dual technology', with certain degrees of backwardness and sophistication. But the basic approaches remain the same. A good crop protection requires monitoring of pathogen variability, disease prediction systems, plant quarantine or exclusion approaches and a good chemical control technology.

Pathogen variability

Variability is the basis for survival and can be achieved by sexual or parasexual

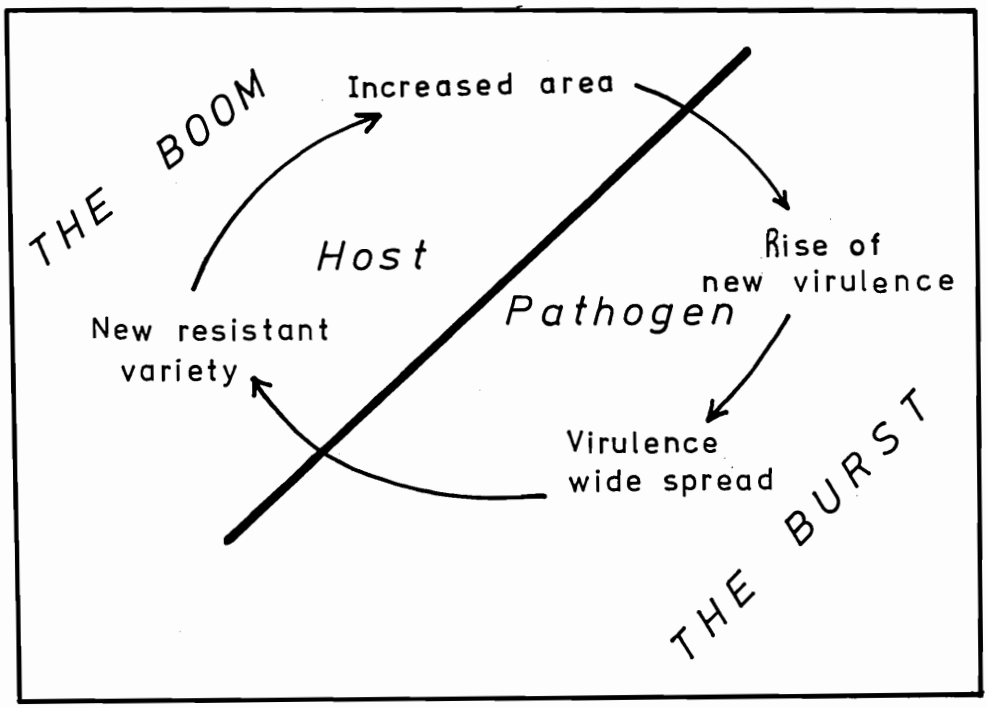
Figure 17.2. Factors that influence the decision-making process of the farmer with regard to disease management



means. The wheat rust pathogen are highly dynamic and often generate new biotypes and virulences. Mutation also creates variability in the organism that may result in varietal break down. When a single spore infects and produces a pustule, it produces between 5 x 10^4 and 1.5 x 10^7 spores during the 10 days of active sporulation. The amount of spores produced from a severely infected 10 hectare field will be an astronomically high number. By virtue of their high reproduction rate, they get transported over long distances; though most of them may land on non-hosts. Even a fraction that land on matching hosts establish successful colonies. Because of their high adaptability to changed environments a close watch on the pathogen dynamics needs to be maintained.

Pathogen can be monitored by various means (Young *et al.*, 1978) and survey is the main stake behind. Realizing its importance the National Commission on Agriculture, Govt. of India, strongly urged that regular surveys of major crops be carried so that disease build up information could be disseminated without any delay (Anon, 1977).

Figure 17.3. The boom and burst cycle characteristic of over-exploitation of vertical resistance



Crop loss can be minimised by disease resistant varieties. The capital investment for the varietal programme is almost negligible when compared to the benefits derived. Resistant varieties when grown over a large area exert selection pressure on the pathogen (Vanderplank, 1963), as a result of which it is compelled to undergo a change. In Korea, during 1971 almost the entire acreage was under the Japonica type

of rice and the rice blast (*Pyricularia oryzae*) race Japonica was dominant. Gradually the Japonica rice became less popular and by 1978, the Indica-Japonica types occupied 80% of the area. This was clearly depicted by the changes in race flora. The Indica-Japonica race increased, with corresponding increases in the area of the matching hosts. In this, and in many other cases, it has been found that pathogen co-evolves, mainly influenced by the host resistance. Such a vicious cycle is due to the occurrence of new races and biotypes of the pathogen. This in essense is the boom and burst cycle (Figure 17.3) and is characteristic of the vertical resistance (Vanderplank, 1963).

With the gene-for-gene theory (Flor, 1942) the race identification concept has undergone a change and virulences are identified by the differential reaction on a set of lines with known resistant genes or isogenic lines (Black *et al.*, 1953; Watson and Luig, 1963; Roelfs and McVey, 1974). Monitoring pathogen variability and dynamics in genetical terms enable better management of the vertical resistance genes. Even a release of varieties based on pathogen variability has been recommended to increase their agricultural utility (Borlaug, 1978).

Chemical control

Trends in production and consumption

Despite the escalating cost of chemicals, and their environmental pollution effects, chemical control will remain a major means of combating crop loss due to plant diseases. There is a big difference in pesticide consumption between nations. Over 900 pesticides are in use in the world today, out of which nearly 120 of them are in use in India. Japan with 7 million hectares uses 80,000 tonnes, while that of India with 160 million hectares is 30,000 tonnes of pesticides of commercial formulations. If India adopts the Japanese technology she may need more pesticide than that which the entire world is at present producing. The cost of the chemicals, availability of funds and toxicity problems limit pesticide consumption. Yet, there is an increase in the level of chemicals utilized for crop protection. Consumption of insecticides in India registered a steep growth between 1954 – 1971. During this period use of insecticides increased from 434 tonnes to 22,013 tonnes and that of fungicides from 578 to 2,967 tonnes.

There is a rapid growth in the consumption of plant protection chemicals in all the developing countries. The upward trend is at a rate of 15.6% per year in Asia; 17.9% in the Middle East, 4.0% in Africa and 8.0% in Latin America (Oram *et al.*, 1979). Despite the growing demand for chemicals it is difficult to say how much of these would be locally manufactured in the countries of these zones. Except for India and Egypt, that manufacture substantial quantities of pesticide, for most of the other developing countries imports are necessary. The area to be covered by plant protection activities would increase substantially by 1990, and the annual cost of the operation would run to a few billion dollars (Table 17.3).

At present plant protection activity is through demonstration trials, farmers' meetings, pamphlets, radio and television broadcasts and training programmes. These

Table 17.3. Estimated cost of plant protection activity of some developing countries by the year 1990

Countries	Area in million hectares		In US $ 1,000	
	Assumed to be treated during 1977	Additional area to be treated by 1990	Cost covering additional area by 1990	Total cost by 1990
Egypt	0.17	2.55	15,045	16,048
Ethiopia	0.35	1.92	10,560	12,485
India	28.43	47.74	381,920	609,360
Indonesia	3.43	8.14	65,120	92,560
Niger	0.24	0.83	4,565	5,885
Nigeria	1.06	6.77	37,235	43,065
Pakistan	5.09	5.08	40,640	81,360
Phillipines	2.42	1.48	11,840	31,200
Sudan	0.16	3.09	18,231	19,175
Uganda	0.15	0.83	4,565	5,390

Based on Oram et al. *(1979)*

activities are neither continuous nor concerted and hence there is a necessity to strengthen them if the area to be protected is to increase. Farmers in developing countries have to travel long distances to depots, which are located mainly along national highways. In India, for example, there is one depot for every 19 or 20 villages. And about 60% of the pesticides marketed is by the private enterprise, the remaining being through co-operatives and government agencies. A survey of the marketing of plant protection appliances reveal that only large farmers with irrigation facilities and raising cash crops use them. Unfortunately the small farmers due to financial constraints do not adopt this technology (Anon, 1980a). With the rapidly increasing demand for all sorts of farm appliances, India alone by 2000 would need about 8 million power sprayers and dusters of two H.P. engine. They would approximately account for 12.5% of the total farm energy that would be possibly consumed by then. On the whole, in South East Asia and South Asia, there will be a growing demand for plant protection equipment. At present production hardly meets 40 to 45% of the demand and hence indigenous manufacture should be stepped up considerably (Anon, 1971).

The simple hitch back, semi-automatic Knapsack sprayers are cheap, easily serviceable and are ideal for small farmers. In the tropics this is the most common plant protection machinery, as large machines enter the fields with great difficulty and are uneconomical to operate. In areas where water is scarce, ultra-low volume sprays will be advantageous, and when a large area is to be covered in a short time, aerial sprays could be preferred. A centrally planned co-operative plant protection action through aircrafts has become a common feature for the protection of sugarcane, cotton and citrus. In future, demand for both fixed-wing aircrafts and helicopters for plant protection operations would increase substantially (Anon, 1977).

Fungicidal resistance and residue

In the last few years, indiscriminate use of fungicides has created many new problems. One of the main limitations imposed on chemical control of plant disease is the appearance of fungicide resistant strains (Dekker, 1977). Fungicidal resistance is a stable herited adjustment of the organism to external toxic or inhibitory substances. Continuous usage of a particular chemical against a pathogen is liable to cause such a situation. In plantation crops or cash crops where many protective sprays are given, fungicidal resistance of the pathogen also should be monitored and spray schedules be adjusted accordingly.

Model ecosystem approaches for bio-degradation of pesticides and their ecological fate on terrestial and aquatic ecosystems have been proposed to control the environmental problem of pesticide usage (Tomigzwa, 1980). In this approach a complete degradation of the compound and its assimilation by various aquatic and terrestial systems, are investigated. Such studies reveal the possible long range consequences of using chemicals for plant protection operations. Evaluation of new formulations and products through model ecosystems would enable corrective measures to avoid environmental pollution to be taken.

Organising co-operative control operations

The co-operative control programme is yet to be well organized in Asia and Africa. But the Taiwanese co-operative pest control in rice, is one of the most successful operations. The farmers' demonstrations, subsequently developed as a co-operative pest control team of 50 or more farmers covers about 100 hectares. A progressive farmer with some training co-ordinates the field activity while both the government and the enterprising farmers undertake the operations. In 1978, 4,872 rice villages were covered by these co-operatives, benefiting about 281,359 farmers (Ku *et al.*, 1980).

The farm adviser of the co-operative must keep a dynamic table to calculate cost-benefit ratios to suggest protective action and at the same time, for purposes of control operations should allow the cultivator to make his own judgements on the threshold value. If given appropriate guidance in the economics of it for a few seasons, gaining self confidence, the cultivator will become a good manager of his farm. Such co-operative approaches have many plus points; one being the motivation generated by participation and the experience gained therefrom. It creates a social awareness and action at community level, and hence there is no scope of inoculum surviving in some stray unsprayed fields. Organising such plant protection co-operatives in other developing countries, at least for the major crops, should be the future line of action.

Disease prediction

Developing disease prediction systems would enable optimal usage of pesticides to manage disease problems. In the case of late potato blight where the vulnerable host and the pathogen are available due to contaminated tubers, the main factor that decides the epidemic growth is the weather.Bioclimatic approaches have been developed for predicting the potato late blight occurrence and spread (Everdingen,

1926). Blight forecasts are issued in Ireland mainly by assessing the weather parameters (Bourke, 1957). This approach minimises the extra work required for plant disease investigations, and hence enables the issue of immediate warnings on the probable occurrence and severity of the disease. Such synoptic approaches for predicting occurrence of stem rust in India, namely, 'The Indian Stem Rust Rules' have been developed (Nagarajan and Singh, 1975). It is now evident, that in future for the full application of epidemiology in disease management, plant pathologists must confer with trained meteorologists. Statistical approaches such as multiple regression analysis, step wise regression analysis etc. have been used in developing predictive models (Kranz, 1974b). Despite shortcomings, it is being widely followed in tea plantation to predict blister blight caused by *Hemileia vastatrix* and is followed up by protective sprays.

A simulator facilitates ideas being tested before conducting elaborate experiments. There are many simulation models that have been designed for various plant diseases but the earliest is EPIDEM (Waggoner and Horsfall, 1969). Another simulator, Blitcast (Fry, 1977), advises the potato grower on the fungicide spray schedule. This system saved 40% of the fungicide that would have been otherwise applied if the advice of blitcast had not been followed. The systems approach involves various aspects of crop production and depends on a broad based data bank, and computer technology for execution (Fry and Thurston, 1980). Based on twenty years of information on the yellow rust of wheat (*Puccinia striiformis*) and its behaviour in the Netherlands and elsewhere, 'EPIPRE', a simulator, has been developed (Zadoks *et al.*, 1980). The EPIPRE is a co-operative approach involving hundreds of farmers, extension agencies and the Institute for Plant Protection, Wageningen, the Netherlands. This simulator used for practical disease management operates on a field by field basis. Observations sent by the farmers to the control room are entered into the data bank of the computer and by using simplified simulation models and following a decision system, expected crop damage and loses are calculated. Within hours the responding farmers are informed telephonically whether they need to treat their fields. When the information is inadequate the farmer is requested to make another observation. Following the EPIPRE Advisory System, the amount of Balayton sprays needed for controlling yellow rust has been optimised in the Netherlands. To the EPIPRE system other diseases and pests of wheat such as brown rust, powdery mildew and green aphid have also been added making it a systems approach (Zadoks *et al.*, 1980).

Plant quarantine

Plant quarantine orders promulgated by Governments restrict the entry of plants, plant products, cultures of organism, improper packing material, other commodities and their means of transport, soil etc. The aim is to protect agricultural crops and related activities from hazardous organisms that may unintentionally get introduced due to human carelessness and negligence. Such a measure is justifiable only if the pathogen cannot gain a natural entry to a new area. International exchange of plant

material is on an increase and plant quarantine must render an efficient service without compromising its responsibilities for society. Creation of a central quarantine station, in an off-shore island, if available, with all modern facilities, would increase the efficiency of operation.

Not all the organisms that sneak-in reach the nuisance value. An analysis conducted in the USA, regarding the introduced plant pests in the last four centuries showed that out of 614 insects and mites introduced, 108 reached nuisance level which means that 18% of the introduction were of consequence, though in their country of origin all of them were important. This shows that introduction of a pest, and its reaching epidemic level, are not necessarily interlinked (Hewitt and Chiarappa, 1978).

Vanderplank (1963, 1968) proposed a theory that when a host is not in contact with the pathogen for long, resistance gets eroded. Occasionally, when some of the crops were propagated around the world away from the centre of origin, some of the pathogens were left behind. After scores of years, the pathogen gained entry into the area where the host was previously introduced for agricultural purposes. When the pathogen finally got the host, it created major epidemics while in its original home it was a minor pathogen. The maize rust (*P. polysora*) in Africa and coffee rust (*H. vastatrix*) in Sri Lanka and Brazil are some examples of man made problems, created as a result of erosion of resistance. As against this, when a host is introduced to a new geographical tract, it may encounter pathogens not occurring in its place of origin. When *Coffea arabica* was introduced to Kenya, the coffee berry disease (CBD) (*Colletotrichum coffeanum*) was a weak parasite on the then grown coffee but became a major pathogen. Apparently this happened because the introduced host lacked resistance for the pathogen, which was never prevalent in its old ecological niche.

Role of international institutes

Developing resistant varieties for major crops is one of the main strategies to minimise yield loss due to diseases. In the developing countries, as the infrastructure for chemical control is still inadequate, breeding for disease resistance is a major option.

Exploiting the pathogen variability between locations, CIMMYT, Mexico, evaluates thousands of crosses and segregates lines of wheat and maize at more than 100 locations. This enables identification of broad levels of disease resistance, with adaptation and yield potential. Despite a wide spectrum of resistance possessed by these lines, the danger of loss from epidemics due to new races is not minimised (Borlaug, 1978). These broad based lines are utilized by the national program and after adaptive trials are identified for varietal release.

IMPACT OF THE HOST

Genetic vulnerability

With better communication, organised extension services and the socioeconomic change of the last two decades, vast stretches of land are now occupied by one or a few varieties of similar resistance. Such a genetic vulnerability has virtually eliminated the time and space obstacle against the epidemic. The National Academy of Science, USA after the Southern corn leaf blight (SCLB) epidemic, had a fresh look at the genetic vulnerability of crops. Vulnerability is defined as "a narrow genetic base of a crop exposed to the broad and unknown genetic basis of the pathogen" (NAS, 1972).

The 1960 crown rust of oat epidemic of USA is attributed to the extensive cultivation of genetically similar varieties. The southern corn leaf blight epidemic, resulted from the common male sterile cytoplasm that was used in developing hybrid corn. The hybrid pearl millet program in India also suffered from the green ear disease (*Sclerospora graminicola*) because of the common male sterile cytoplasm (Safeeulla, 1976). The brown hopper is an important rice pest in China, Japan and Korea for more than a century but was of no consequence in the tropics. This hopper is also the vector for the grassy stunt, a serious virus disease of rice. When similar rice lines were grown extensively in parts of South Asia and South East Asia, incidence of this vector became serious mainly due to genetic vulnerability. This minor pest became major and the associated disease assumed serious proportions. The only remedy for vulnerability then, is to incorporate genetic diversity.

Boom and burst cycle

During the early years of this century when disease resistance was shown to follow Mendelian inheritance (Biffen, 1905), there was a sense of optimism. Varieties resistant to various diseases were bred and soon they were broken down by new races. The ones that became susceptible were replaced by resistants, and the chain went on. Such a breakdown of resistant varieties after attaining wide propagation is referred to as 'the boom and burst cycle', which is characteristic of vertical resistance (Figure 17.3). By applying the 'Peter Principle' (Peter and Hull, 1969) two basic principles of vulnerability can be developed to explain the recurrent burst cycle.

1. Every agronomically superior cultivar increases in its hectarage, until it becomes vulnerable.
2. Once vulnerable, epidemic resistance can be accomplished by superior pipeline material that have not yet become vulnerable.

These two principles explain how vulnerability breeds vulnerability while exploiting vertical resistance.

On pathogen dynamics

In a natural ecosystem the host-pathogen interactions have reached an equilibrium as a result of their continuous long term association. Near relatives of domesticated crops, if they had evolved in contact with the pathogen are excellent sources of both vertical resistance and horizontal resistance (Wahl, 1970), and can be utilized in crop improvement programs. In agroecosystems, the host resistance has upset the balance as a result of which pathogen populations shift either by re-adjustment of race frequency or by the incorporation of a new character that may give a selection advantage. This compulsion of the host making the pathogen change is 'directional selection'. This can be measured taking the appearance of new races or biotypes as an index, as it is directly correlated with the extensive cultivation of near immune varieties. Once the selection pressure is withdrawn, the organism tends to revert back. In fact, there is a genetical resistance to change, referred to as homeostasis, or stabilizing forces. In a viruliferous insect population of *Sogatodes orizicola* and *Nilaparvata lugens*, the percentage of active transmitters of the disease varies. Attempts made to increase the percentage of transmitters by selection was suspended and the percentage of active transmitters reached the original level. This explains that stabilizing forces operate in insect vectors as in fungal pathogens. Such forces may operate in multilines, or for that matter even with horizontally resistant varieties.

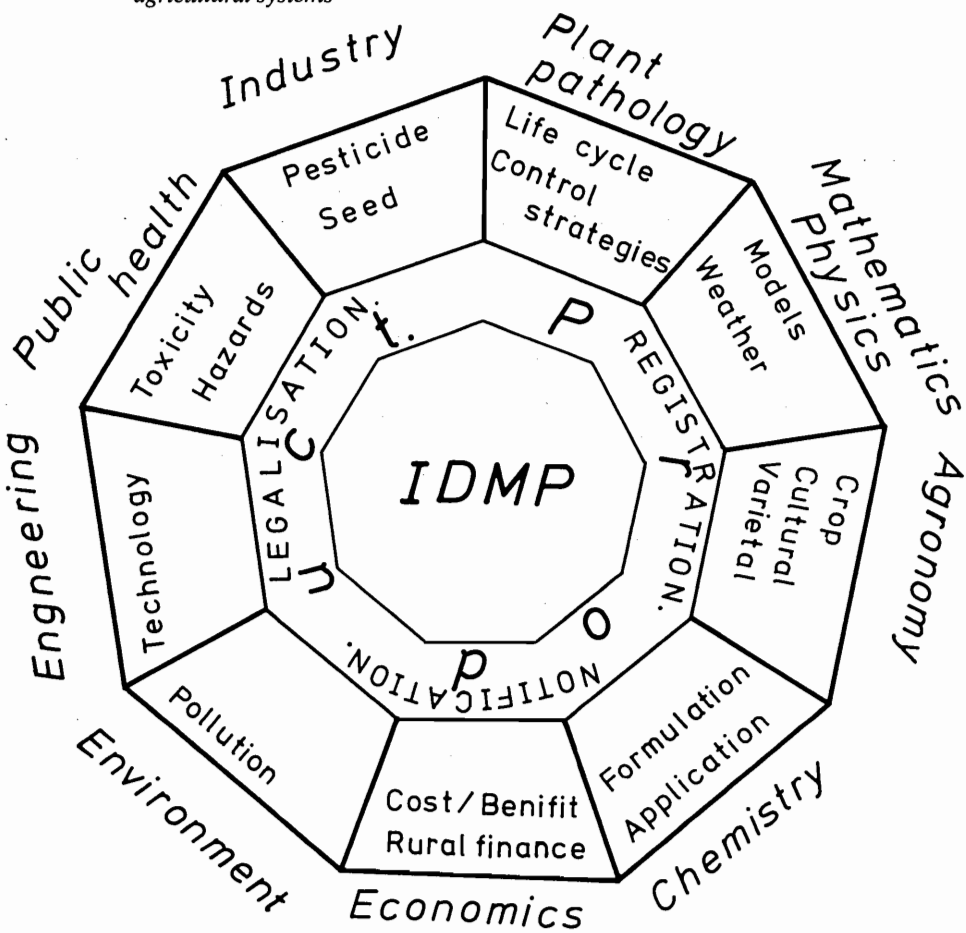
Groth and Person (1977) are of the opinion that there is a limit to the number of virulence genes that can be accumulated through natural selection. Such a limit is achieved when the advantages of infecting more hosts is balanced by loss of fitness in individual disease reaction on the host population that is infectable. For purposes of study of fitness and survival various models have been proposed (Vanderplank, 1963, 1968).

Using oat *P. graminis avenae* studies from Sweden and Canada, MacKey (1974) concluded that the pathogen selection without and with race specific resistance had a high number of virulence genes. Further, MacKey (1974) believes that it is the new resistant varieties which screen the already existing virulence gene combinations of the pathogen, giving a selection advantage to those gene combinations that are capable of breeding resistance. Mutation to new virulences, as an explanation for varietal break down need not be the only reason. Gaining of additional virulence by the pathogen occurs even when the host is not in contact with it. In the oat *P.graminis avenae* system, pathogen flora of Sweden possess virulence to gene d, and that of the USA to gene e. Virulence against these genes are said to be unnecessary as these genes were never exploited agriculturally in these countries (MacKey, 1978). Vanderplank (1963) reasons that loss of fitness to survive of simple varieties increases with the complexity of race. With a convincing number of examples he has explained the exceptions where even a simple race has some complexity and where races occur with no commercial varieties bearing that gene (R 4 of Potato and *P.infestans* race 4). Hence, observations of MacKey (1978) only add to the argument of Vanderplank (1963).

INTEGRATED DISEASE MANAGEMENT PROGRAM (IDMP)

The United States Department of Agriculture defines IDMP as 'A desirable approach to the selection, integration and use of methods on the basis of their anticipated economic, ecological and sociological consequences' (Allen and Bath, 1980). The various groups of scientific, legislative and environmental aspects involved in the IDMP are shown in Figure 17.4. In the integrated control approach all the available control techniques are blended to minimise the economic damage caused by diseases, with a minimum disturbance to the common environment. At farm level it means that resistant varieties, sanitation, changed agromomy and disease monitoring for operational disease management needs to be done, in addition to taking timely sprays. All these vigilant actions lead to integrated disease management.

Figure 17.4. Levels of interaction in the integrated approach for disease management in agricultural systems



In the Valle-Del-Yaqui in Sonora, Mexico, till recently a poor crop of cotton was raised with 10 to 15 protective sprays. During the last few years a better management system has been evolved where with an average number of 2.5. sprays a good crop of cotton is being raised. The date of planting, sanitation, biological control of pests and the time of application of biocides allows for a reduction of the over-head cost of the inputs and an increase of the yield (Borlaug, 1978).

With the increasing cost of energy, the scarcity of fossil fuels and fluctuating price policy, it is very difficult to imagine how management of plant diseases would be twenty years from now. Management of plant diseases is dependent on the level of agricultural technology that prevails. The high yielding varieties would continue to be the main stake in increased crop production. The cost constraints due to energy would impose a level of restraint on fertilizer uptake, farm machinery, tube well irrigation etc., and would compel adequate levels of plant protection action to balance yield losses with the minimum available energy. Pest and disease management would then more and more depend on regional and ecological control strategies (Allen and Bath, 1980).

Role of agronomic practices

By adjusting the dates of sowing and other agronomic and cultural practices reduction in disease level can be attained. Disease escape thus created can also be termed as culturally induced resistance. For example, when the plant population level is very low, almost all the groundnut plants get the rosette disease. This viral disease, transmitted by the aphid vector *Aphis craccivora*, is influenced by the canopy type, date of planting and plant density (Anon, 1967). In Africa, though a population density of 360,000 plants per hectare is ideal, the seed cost would be very high and hence 200,000 plants per hectare would still achieve a complete cover of the field and yield adequately. While under early sowing 100,000 will be enough to give a good yield, these changed plant population densities influence the aphid population and the incidence of the rosette virus (Figure 17.5). There is a possibility of reducing rice tungro disease by adjusting the time of sowing to a period when the edaphic conditions are not conducive for the multiplication of the vector *Nephotettix virescens* (Shukla and Anjaneyulu, 1981). Most of the plant pathogens have a wide host range, and if hosts of common susceptibility are together then the disease spread is much faster than when the two crops are grown further apart. For example, incidence of groundnut stunt, a viral disease, is more severe when white clover fields are adjacent, than when they are isolated (Tolin *et al.*, 1970).

A large number of cultural practices influence disease development. For example, the application of superphosphate decreases *S.graminicola* on pearl millet (Deshmukh *et al.*,1978). The wilt of banana is reduced by flooding heavily diseased fields which brings down the population of *Fusarium* spp. (Meredith, 1961). Irrigation through sprinklers enhance the development of *Phytophthora infestans* and *Alternaria solani* in potato and tomato (Rotem and Palti, 1969) while the frequency of irrigation influences infection of *Sclerotinia sclerotiorum* (Bald *et al.*, 1978). Under

Figure 17.5. Influence of groundnut population/acre on the number of rosette infected plants (Based on Anon, 1967)

natural conditions oospores of *S. graminicola* remain in the soil for months after harvest. There is a gradual build-up of oospores due to monoculture of susceptible sorghum and maize (Safeeulla, 1976). The 1968 maize downy mildew epidemic of Karnataka is attributed to the monoculture of sorghum and maize.

Improper field levelling results in poor drainage of the monsoon water, and at times even gets stagnated. The surface run-off water that gets acumulated also carries with it the oospores of sorghum downy mildew (*Peronosclerospora sorghi*) and result in pockets of increased inoculum load. Such damp pockets create congenial conditions for infection and from here disease spreads rapidly creating epidemics (Rajasab *et al.*, 1979). In many parts of India and South East Asia, multiple cropping is followed. In Taiwan two crops of rice are grown, and the second crop is more vulnerable due to continued availability of the host (Ku *et at.*, 1980). Because of this it has become standard practice to apply chemicals aerially so that large areas can be treated in a short time. In rice fields that received aerial spray, disease incidence was 36.5% less than those treated with ground level spray. Thus a change in the system structure completely alters the system behaviour and that the system should be tackled in its totality in a more pragmatic way.

Biological control

Biological control can be defined as the balance between a species and biological stress factors that limit the expression of its potentials. Such a control can be achieved by exploiting the microbial antagonism, hyperparasites and cross protection in the case of virus diseases. The crown gall of stone fruit trees and other crops is caused by the bacterium *Agrobacterium radiobacter* var. *tumefasciens* and can be controlled by *Agrobacterium radiobacter* var. *radiobacter.* Both these bacteria occur in the root zone of the stone fruits, and by dipping and covering the roots with antagonistic bacteria before planting, crown gall infection can be reduced. The reduction of crown

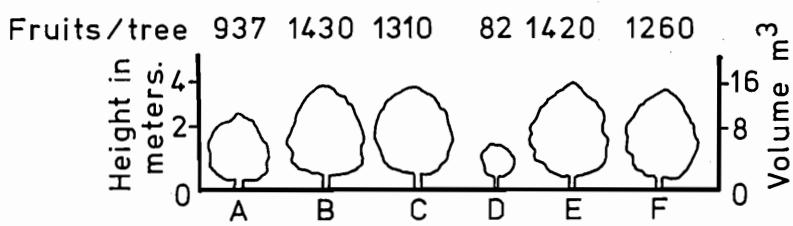
gall infection is mainly due to the secretion of a toxin, which is a type of bacteriocin (Kerr, 1980).

Field experiments conducted in Peru have confirmed the possibility of biological control of potato golden nematode *Meloidogyne incognita* by a fungal parasite *Paeciloyces bilacinus*. Such control operations are neither harmful to humans nor do they pose any environmental hazards. Eggs of the nematode pathogen get parasitized resulting in the death of the embryo and mortality of the female increases due to parasitism (Anon, 1980b). From such biologically controlled fields, seed potato can be had as along with the tuber the parasite would also spread leading to a better control of nematode disease. The fungus suits the requirements of potato cultivation and survives better in acid soils between 20 – 30°C. As potato cultivation in the developing countries of the tropics is mainly in the acid soils of the hills, control of this and other nematodes through fungal parasites is possible (Kerry, 1981).

Since 1960, the Dutch elm disease has destroyed over 20 million elms in Britain alone. The insect vector (*Scolytus scolytus* and *S.multistriatus*) spreads the fungus *Ceratocystis ulmi* to new elms. Biological control of this disease has been achieved through a fungal parasite *Phomopsis oblonga* that reduces the number of offsprings of the vector. In addition, the vector does not prefer the already infected barks and hence intensifies competition amongst the insects in an uncolonized bark (Webber, 1981).

Resistance to virus diseases can be had through cross protection which can be achieved by inoculating a relatively weak or non-destructive mild strain in the nursery, which when becoming systemic would subsequently protect against severe or destructive strains. Cross protection against Tristeza, a virus disease of citrus fruits has been widely followed in India (Figure 17.6.) by supplying immunized lime plants through various state agencies (Anon, 1979). There are several methods and techniques of controlling plant diseases through biological agents. A book on biological control of plant diseases by Baker and Cook (1974) is a testimony for the immense interest shown in managing plant diseases by means other than chemicals.

Figure 17.6. Growth and yield records of cross protected experimental trees with mild strains of Tristeze on acid line. A = uninoculated, B = Infected by very mild strain, C = with mild strain, D = severe strain, E = very mild + severe strain, and F = mild + severe strain
(after Anon, 1979).



Balanced application of fungicides and other chemicals

In addition to the environmental problems caused by the use of pesticides, at times disease severity also increases with spraying. For example, cessation of spraying reduced the pest damage in Malaysian plantations (Conway and Wood, 1964). Similar observations have been made with Coffee Berry Disease (CBD) (*C. coffeanum*). Partial spray against this disease and a mid-way suspension of spray schedule resulted in greater loss than no spraying at all. This is mainly because the spray puts aside the saprophytic population which otherwise would have thrived on the diseased berries reducing the spread of CBD. In the absence of saprophytes the pathogen sporulates more and spreads faster. In literature, there are a number of examples of better disease control achieved through cessation of spraying than with partial spray.

Application of insecticides and weedicides intereact with the plant pathosystem. Reduction in gladiolus scab (*Pseudomonas marginata*) occurs with the application of insecticides such as Aldrin, Lindane or Heptachlor to the soil. Soil application of nematicide Ethoprop at flowering stage or Fensulfothion early in the season lowered the field infection of groundnuts by the fungus *Sclerotium rolfsii*. Use of some fungicides against one pathogen increases susceptibility to other diseases. Benomyl application to control Tikka leaf spot (*Cercospora personata*) significantly increases white mould (*S. rolfsii*) infection. Oscitril, a weedicide for wheat, enhances the severity of take-all disease (*Gauemannomyces graminis*) and eye spot disease (*Cercosporella herpotrichoides*). Application of fungicides eliminates the entomophagus fungi, which help to maintain a balance of the insect pests. It appears that increased or decreased susceptibility to plant diseases as a result of biocide application is because they modify the sensitivity of the host to the pathogen (Sylvestra and Fournier, 1979). It is evident that cropping should be looked at as a system rather than taking control action for each constraint separately.

Mechanization and its influence

In Taiwan, differences in the extent of reduction in the severity of rice blast were observed when sprayed with power sprayers and from aircraft (Ku *et al.*, 1980). Spread of soilborne diseases, that of nematode, is influenced by tractor ploughing, disc type and the direction of operation. Harvesting of root crops such as sugarbeet, potatoes, carrots, etc. involve mechanical digging and turning up of soil. This probably accelerates the rapid spread of nematodes within the field and outside along with the roots and tubers. Similarly, harvesting potato using spinners and other mechanical devices create a distinct pattern of spread of *Globodera rostochiensis* the cyst nematode (Bedi, 1968).

To minimise the cost of harvesting fruits, mechanical tree shakers have been developed, and in the process of shaking trees, pathogens also get liberated. Use of tree shakers led to increased infection of *Ceratocystis fimbriata* in almonds, and the injury thus created gave entry for other pathogen to infect. In cherry orchards, *Monilinia fruicticola* over-wintered on fruits left back after shaking, and as the level

of primary inoculum for the succeeding year was high, epidemics developed during the next crop year (Cowling, 1978).

Disease resistance

Ever since the domestication of crops, plant disease epidemics have become more frequent. In turn, the resisting power of the host was upgraded. With better yield and disease resistance, these lines almost replaced the land races creating a disastrous situation. After Biffen (1905), demonstrated that resistance to yellow rust in wheat followed Mendelian inheritance, interest in breeding for disease resistance increased. This lead to the exploitation of one form of host resistance, till Vanderplank (1963) highlighted the consequences of over-exploitation of such genetic resistance. Resistance to diseases can be broadly grouped into four types.

(a) Vertical;
(b) Horizontal (Vanderplank, 1963);
(c) Cytoplasmic or Extra-nuclear inheritance; and
(d) Cultural resistance (disease escape, cultural practices etc. that have been dealt with earlier).

Vertical resistance

Vanderplank defines that when a variety is more resistant to some races of the pathogen than to others, the resistance is vertical or perpendicular. There are a large number of terms such as specific resistance, race specific resistance, true resistance, monogenic resistance etc. used to convey vertical resistance. Here, resistance to the host pathogen interaction, and susceptibility, are the two expressions. Such resistance reactions are easily recognisable and hence have been used to the maximum by plant breeders.

Vertical resistance is generally oligogenic and dominant though there are exceptions such as the sr 17 of wheat stem rust where resistance is recessive. Correspondingly avirulence of a pathogen is dominant while the virulence is recessive. Flor (1942) proposed the gene-for-gene theory which explains the logic behind vertical resistance. When a race with matching virulence falls on the host with corresponding resistance, the resulting reaction is susceptibility. In short, the host pathogen reaction is something like a lock and key arrangement where only one key is operative.

In the case of wheat there are more than 30 genes identified according to resistance to various stem rust races. A similar number of genes are known to accord resistance against brown rust pathogen also. There are resistant genes against almost all the pathogen. Some genes such as Sr 9 are multiple alleles, while some like Sr 6, Lr 18 of the wheat rusts are temperature sensitive. Also all the genes do not accord resistance to the same extent or magnitude, against a spectrum of races. For example, in India, Lr 14a accords resistance against only 4 out of the prevalent 19 races, while Lr 19 is resistant to all the races. Provoked by such information Vanderplank (1963) proposed the strong and weak gene theory. A weak gene is one which does not exert selection pressure on the pathogen and the withdrawal of which does not also influence the

stablising forces. As a corollary, the strong gene exerts selection pressure on the pathogen, whose withdrawal will encourage stablising forces. The terms, major and minor genes are highly relative as strong and weak genes are. They differ with the prevailing race flora and the background in which the genes are present. North American wheat variety Manitou has Lr 13, a major gene (Samborski, 1977). The same gene when tested against Indian leaf rust races is ranked as a minor or weak gene. The race flora of different agroclimates being diverse, a resistance gene which is strong in one region need not be so under another set of situations.

Vertical resistance simulates a situation similar to that of sanitation and it reduces the initial level of infection (X_O). Races or pathotypes not able to match the host resistance do not get established and hence the level of initial infection gets reduced. Few populations which match would be so few in number that they may not result in greater terminal severity. The reduced X_O increases the time needed for an epidemic, and the host would mature early leaving the terminal severity below the economic threshold. But once the frequency of the matching races are high the X_O level will increase and the benefit of time delay is lost. This is the 'burst' stage of the vicious Boom and burst cycle (Figure 17.3). Because vertical resistance is easy to identify, incorporate and select it has been long used in crop improvement programs and is the reason for repeated Boom and burst cycles.

Even in the case of insects that transmit virus diseases, it has been observed that vertical resistance is operative. Leaf hopper *Nephotettix virescens* which spreads the rice Tungro differentially preferred one host over the other. The leaf hoppers move rather more frequently on susceptible IR 8 than on resistant IR 1. Also, the vector visited the virus affected plants and stayed on them longer than on healthy plants. This partly explains why rice variety IR 8 is more susceptible than IR 1. Probably, host resistance regulates the duration of visit of the vector, and can be exploited in breeding virus resistant rice varieties.

(a) How to identify vertical resistance? Cultivars are frequently bred against the prevalent pathogen flora, but their inadequate screening against other parasitic forms leads to varietal breakdown. The pathogen population is dynamic, and is the very basis of its success in producing new virulences. A continuous monitoring of race flora of *P. oryzae* revealed the dynamic nature of the race flora (Quamaruzaman and Ou, 1970). It partly explains the need to repeatedly evaluate disease resistance, during different seasons and locations. Keeping this in view, multilocation or hot-spot testing of germ plasm and breeders material are done by various national and international agencies. At these locations crop maturity, race flora and disease occurrence should be diverse and the lines that are repeatedly resistant are likely to possess strong vertical resistant genes or gene blocks. Selection for multiple disease resistance is also possible by this procedure. Differential resistance of varieties in multilocation tests shows that their nature of resistance is not identical. When backed by seedling tests where the genetics of virulence is known, resistance genes in the host can be identified. Though the evidence is circumstantial, final proof would come from the cytogenetical and genetical studies.

(b) Management of the vertical resistance genes. Under field conditions, the average

span of a cultivar is just 3-8 years. Once a variety with a particular resistant gene is released, there is a selection pressure on the pathogen and it develops a new matching race. The prevalence of the new matching race increases within a few years. Person (1967) suggests that resistance genes that have lost utility being victims of the boom and burst cycle, should be withdrawn from usage so as to use them subsequently after the pathogen population undergoes a needed genetic shift. With the withdrawal of the previous vertical resistance gene, selection pressure on the pathogen for that gene will tend to stabilise. After a few years, the variety in question would mimic as a resistant variety. In Australia, wheat variety Eureka (Sr 6) was released for cultivation around 1941 but became susceptible to stem rust and by 1946 it went out of cultivation. Promptly Eureka was withdrawn, the frequency of the matching race dwindled, and Eureka mimicked as a resistant type. Eureka was again released for cultivation by 1961 and this was followed by the appearance of four new races. The strains of 1963 were very different from those identified in 1943. Such gene cycling causes a temporal rather than a spatial discontinuity in the genetics of the pathogen population, and increases the utility of vertical resistance genes at our command.

The stability of resistance will increase if more genes, or strong genes can be incorporated. As the total number of strong genes available are few and that the number of minor genes are more, it is better to incorporate several vertical resistance genes in one genetic background. Pyramiding resistant genes curb population shifts of the pathogen, as gaining additional virulence is at the cost of some fitness parameters (Nelson, 1972), and can be exploited to maximise disease resistance. Varieties with many resistance genes have longer agricultural life, as such resistance that lasts longer is 'durable resistance'. Johnson (1981) has defined durable resistance as the one that remains effective while a cultivar possessing it is widely cultivated.

Mutation breeding approaches for disease resistance aim at creating variability. Mutation merely duplicating genes that are already available is not of greater utility, unless it incorporates higher yields. When a highly susceptible cultivar is used for mutation, only major genes for resistance are likely to be detected (Samborski, 1977). As the host is horizontally susceptible, minor gene mutations would go unnoticed. From the mutation studies of Karchia, a highly rust susceptible Indian wheat variety, a line resistant to all the leaf rust races was identified (Sawhney *et al.*, 1979). It is said to possess Lr 9 in addition to some unidentified gene.

Intergeneric crosses have been attempted to increase the genetic diversity of various cultivated crops. Such transfer of genetic materials from species, distant in the evolutionary scale and the expression of transferred genes are of great interest both from genetics and plant breeding point of view (Bhatia, 1976). Interest in alien gene transfer ranks considerably high in the wheat improvement program as they provide a high degree of resistance to a large number of physiological races of the rust fungi. Sears (1956) transferred the *A. umbellulata* gene conferring resistance to leaf rust to Chinese spring, producing 'Transfer'. And using this in the crossing program, a number of commercial wheat varieties were evolved.

Wheat leaf rust resistance genes Lr 9, 19, 28 and 29 are of alien source and were transferred from *Aegilops umbellulata* and *Agropyron elongatum* respectively and

they accord resistance to all the brown rust races prevalent in India. As the area under such lines is negligible no selection pressure has been exerted on the pathogen to gain virulence against these genes. Like other genes in domesticated crops alien genes can also break down to new races and biotypes once they occupy a large area.

Horizontal resistance

For long, it has been recognised that there exists a type of resistance that reduces the rate of disease spread. It was recognised 70 years ago in the potato *P. infestans* system, and is similar to horizontal resistance. To explain the other type of resistance, that does not react differentially, Vanderplank (1963) coined the word horizontal resistance. This sort of resistance reduces the *r* value, which is a good measure of epidemic development. Such a reduction in the rate of disease spread occurs as a result of interaction at various levels of the disease cycle, such as the infection efficiency, rate of mycelial growth inside the tissues, number of colonies per unit area, amount and duration of sporulation etc. (Parlevleit, 1976). When the nature of slow rusting was evaluated using a number of races no differential reactions were observed (Kuhn *et al.*, 1978). This non-specific resistance is visualised to be uniform against all races and to identify such a resistance Vanderplank (1978) proposed the analysis of variance test. The ranking procedure would add clarity to show the absence of vertical resistance and to demonstrate the presence of horizontal resistance other procedures should be used (Vanderplank, 1978). The horizontal resistance based on correlations is probably governed by many genes. Skovmand *et al.*, (1978) postulated that 2-12 pairs of genes in wheat stem rust, and as many as 3-21 pairs for leaf rust (Gavinlertvatana and Wilcoxson, 1978) govern slow rusting behaviour, or say horizontal resistance. In a genetical study of slow rusting both stem and leaf rust were found in one background demonstrating the possibility of achieving multiple horizontal resistance.

According to Vanderplank (1978) no identification of horizontal resistance is possible but can only be had indirectly through the linked genes. In an attempt to locate a marker gene for slow rusting against wheat stem rust, Skovmand *et al.*, (1978) evaluated a large number of vertical resistance genes. They observed that genes causing slow rusting may be located on the same chromosome as the Sr Tt-1. They also speculate that Sr 6 may be associated with slow rusting per se. These attempts show that both vertical and horizontal resistance can be brought in one background. Most of the crops have a mixed genetical system of both the vertical and horizontal resistance, and the degree of combination may vary with situations. Where horizontal and vertical resistance are mixed, there would be a time delay in the establishment of the pathogen in addition to the reduction in the apparent rate of disease development (Robinson, 1976). In situations where the vertical resistance breaks, still by virtue of horizontal resistance, the rate of disease development would be less, compared to the susceptibles. During such a period it is believed that horizontal resistance would protect the crop from complete ruin. Attempts to incorporate vertical resistance in cultivars led to erosion of horizontal resistance. That is, selection pressure for one type of resistance is at the cost of the other. Vanderplank (1963) discovered this phenomenon in potato variety Vertifolia and named this as the 'Vertifolia effect'.

The agricultural utility of horizontal resistance may last for more years as it does

not exert a selection pressure on the pathogen. But over years the pathogen may erode even this sort of resistance by acquiring a greater number of fitness factors. There is a belief that the horizontal resistance against *P. oryzae*, the rice blast pathogen is not durable (Anon, 1980c). There is also experimental proof to show that horizontal resistance is durable. It is also not clear whether durable resistance (Johnson, 1981) is similar to horizontal resistance (Vanderplank, 1963). While philosophising durable resistance, Johnson has not quantified the durability of resistance. Apparently the duration for which a variety remains resistant under field conditions should constitute a major consideration. At the moment it is very difficult to present a theoretical basis of horizontal resistance as it may change with location, growing conditions, temperature and the time of the year. Though the implications of horizontal resistance on crop improvement is yet to be felt, it will be possibly exploited in future. Thus our future strategy of crop improvement will largely depend upon our ability to encourage stablising forces which can probably be achieved by utilizing horizontal resistance.

Cytoplasmic inheritance of disease resistance

Cytoplasmic male sterility is found in a variety of plants and is being used for hybrid seed production in corn, sorghum, pearl millet, onion, sugarbeet, carrots and other crops. In corn, cytoplasm is the most important factor imparting resistance to race T of *Helminthosporium maydis*. Susceptibility to race T is related to a pathotoxin that acts on the inner membranes of mitochondria which ultimately disintegrates after swelling and increased permeability (Hookar, 1974). The cytoplasmic male sterile lines (Cms) T. P, Q, HA are susceptible to T-race while S and C are resistant. Susceptibility of yellow leaf blight of corn (*Phyllosticta maydis*) that occurs all over the corn growing tracts of the USA, is linked with Cms T cytoplasm. In male sterile lines of pearl millet, ergot (*Claviceps fusiformis*) infection is higher due to the absence of pollen. Also stigma morphology and longevity shows that pollination protects against infection mainly due to a rapid withering of the stigma (Thakur and Williams, 1980).

Difference between reciprocal crosses in rice to two races of *P. oryzae* is attributed to the cytoplasm. Alien cytoplasm in wheat also influences the reaction of stem rust and the triticales are a good example in this respect. Cytoplasmic inheritance also operates against plant viruses. Nagaich *et al.* (1968) in a cross between *Capsicum annum* and *C. pendulum* observed resistance to potato virus X (PVX) to be through the cytoplasm. Extra-nuclear control of disease-resistance should be taken into consideration while exploiting male sterility for purposes of crop improvement.

Tolerance to disease

Tolerance of a variety, the inherent or acquired capacity to endure severe disease (Nelson, 1975), has advantage in yield as is obtained in resistant types. It does not break-down as resistants, but may get eroded with time. Tolerance can be due to the reduced rate of disease development (r), which can be equated with horizontal resistance. Susceptible oat, Clinton, when inoculated with race 216 produces twice the amount of spore compared to the tolerant Cherokee. Vanderplank (1963, 1978) holds

the view that extensive cultivation of tolerant wheat over the central USA would even delay stem rust epidemics. In this respect, he refers to tolerance accorded by slow disease development, which when deployed over a large area may create a time delay with regard to epidemic development.

The physiological traits of grain filling may also contribute towards tolerance. The differential rate in grain filling between susceptible wheats contribute to tolerance, and by reducing evapotranspiration, yield loss can be further minimised (Nagarajan *et al.*, 1980b). Genetical studies with oats and *P.coronata* reveal that tolerance is a quantitative trait, and heritability is between 19 to 38 %(Simons, 1969). Tolerance mechanisms exist in non-cereal crops such as the potato, where with 100% infection of leaf roll virus, variety Cobbler had 53.0% reduction in yield while Chipewa registered a loss of 40.7%. Current literature shows that possibly tolerance and horizontal resistance are two sides of a coin. While tolerance refers to the yield differences between susceptible varieties horizontal resistance relates to the differences in the rate of disease spread among varieties of a crop.

Farm level strategies

Various approaches, cultural, host resistance and operational disease prediction systems in addition to sanitation enable the disease to keep below the economic threshold. Vanderplank (1963) defines sanitation as a process that reduces or completely eliminates or excludes the initial inoculum from creating epidemics. He has shown mathematically that severity levels with and without sanitation, under identical situations, remain proportional. According to him sanitation is unlikely to give any gain when the apparent rate of infection is high.

The pitting disease of banana (*Pyricularia grisea*) survives and spreads from the hanging trash leaf. As a measure of sanitation, when the trash is removed it reduces the terminal severity by 15%. Backed by fungicidal spray, efficient control of the disease can be achieved. Sanitation by way of cleaning the bunds and removing the collateral hosts of rice tungro virus results in a healthier nursery, and when seedlings are transplanted there is a delay in the spread of disease.

The mixed cropping of the traditional farmers of the Indian subcontinent is a subsistence agroecosystem which has been so constituted as to buffer and safeguard against the factors that cause crop failure (Wolfe and Barret, 1980). Such mixed farming practices have many benefits. When tomato and asparagus are grown in a mixed stand, the stubby root nematode *Trichodorus christici* infection of tomato is reduced, compared to that of a pure stand of tomato. The glycosides leached from asparagus roots inhibit the nematode complex (Rhode and Jenkins, 1958). In case high yielding varieties of crops are developed, then mixed cropping in problem areas can be advantageous.

When varieties with a common genetic base occupy large areas, there is no space and time obstacle against the epidemic. Creation of a number of varieties differing in duration and disease resistance will result in varietal diversity at the farm level. It would also minimise the risk of disease spread from one field to another. Multilines

are produced by mixing lines that are morphologically and agronomically similar but possessing differing resistant genes. The concept of multiline popularised by Borlaug (1953) aims to create diversity within a field. With this in view, many national programs have developed and released multilines. In the Netherlands, wheat multilines were developed against *P. striiformis* the major pathogen but succumbed to brown rust (*P. recondita*). According to Zadoks and Schein (1978), those who see a specific goal far ahead are often short sighted with respect to another and, in their eyes, these are secondary problems. Multilines reduce the level of initial infection (X_O), and the apparent rate of infection, if more than 75% of the components are resistant and in lesser proportions the rate is not reduced. Fried *et al.* (1979) maintain that multilines do not reduce significantly the r-value, which means they do not simulate a situation comparable to horizontal resistance. If the multilines even after utilizing many vertical resistance genes create just sanitation, then epidemiologically varietal mixtures would appear better than the multiline approach. Also, there is a degree of sceptism that with the extensive cultivation of multilines, a 'super race' of pathogens would arise. In the absence of real time data, inconclusive theoretical models have been proposed on the question of super race (Groth, 1976).

If a mixture of varieties is grown, the pathogen can co-evolve acquiring greater virulence. Vanderplank (1963) maintains the view that there is always a selection against the unnecessary virulence and hence in a stand of varietal mixtures, the pathogen would face an evolutionary dilemma. It is claimed that there is a negative relationship between greater virulence and efficiency in the process of infection and perpetuation. Indications are that loss of resistance is gradual in a mixture of lines, very similar to that of horizontal resistance, rather than break-down, that is typical of vertical resistance. These observations of Wolfe and Barret (1980) prompt that population dynamics and directional selection of the pathogen can be kept at bay, by advocating carefully planned varietal mixtures. Such mixtures can be well constituted to have resistance to a number of diseases, and being a non-conservative, dynamic system, yield of each constituent line can be increased substantially. Average yield of varietal mixtures increased by 6.5% compared to that of the components. Such beneficial interactions can be exploited to improve the yields further if varietal mixtures are advocated as means of disease management.

Regional strategies

Some of the air-borne pathogen such as the cereal rusts get disseminated over long distances and the primary inoculum, if it gets established, initiates disease spread. The defined route between the source and target of these pathogen known as the '*Puccinia* path' can extend over hundreds of kilometres. If varietal uniformity occurs all along the *Puccinia* path the spread of disease is rapid. This path can be divided into different agro-ecological zones and between them gene deployment is possible. In doing so, vertical resistance genes can be better utilized. Gene deployment can be defined as a 'centrally planned, properly executed, strategic use of vertical resistance genes over a large geographical tract to minimise the risk of an epidemic or pandemic

of plant disease'. Deployment or erecting genetic barriers along the path creates a space and time obstacle against the pathogen. Cycling the pathogen between incompatible hosts along the *Puccinia* path has been recommended in the USA as a means of controlling oat crown rust. In the United States, there exist gene deployment potentials against *Macrosteles fascifrons*, the vector of aster yellows, a mycoplasmal disease and for curly top of sugarbeet, a virus disease transmitted by the hopper *Circulifer tenellus* (Browning *et al.*, 1969). The spring and winter wheats in north America possess different stem rust resistant genes. Vanderplank (1978) attributed this unplanned gene deployment as a reason for the poor wheat stem rust development along the US-Canadian belt. In India, wheat rusts spread over long distances and gene deployment has been recommended to control this disease (Nagarajan and Joshi, 1980). The release of several wheat varieties unintentionally led to gene deployment in the Indogangetic plain which avoided a possible epidemic by the brown rust of wheat (Nagarajan *et al.*, 1980a).

The gene deployment approach is a disease management strategy of a regional nature, and the execution of which needs effective participation of the state, the cultivator and the researcher. To make gene deployment a success, which is a calculated long duration strategy, the pathogen variability all along the path should be continuously monitored. Such a monitoring to keep ahead of the pathogen would enable farms to avoid possible epidemics and failures. The average span of useful life of a cultivar under farm conditions is between 3-8 years. If the varietal mosaic is kept in a dynamic state by means of quick varietal change, then the pathogen co-evolution can be kept at its minimum. A quick varietal reshuffle, sanitation and eradication of *Barberris* avoided a possible epidemic of stem rust in USA (Roelfs and Rowell, 1973). Nagarajan *et al.* (1980a) concluded that a possible epidemic in India during 1976 was averted or delayed due to quick varietal change that occurred between 1973-75. While in Pakistan, a continuation of the Indo-Gangetic plain, there was a severe brown rust epidemic (Hassan, 1978). It was mainly because during 1976-77 crop year the 15 million acres of wheat in Pakistan were planted with the highly susceptible Mexipak, Chanab-70, Barani-70 and other wheats. During that season stem and leaf rust exploded as a time-bomb while due to varietal dynamics and quick change the Indian crop was relatively free, and produced a record harvest (Borlaug and Hepworth, 1978). In most of the developing countries, due to capital and organizational constraints extensive chemical control is not operative. Quick varietal change and proper management of host-resistance need to be utilized further for the benefits of the poor.

THE TREND

Emerging plant disease problems

With crop improvement approaches, changed varietal patterns and cropping systems, some of the minor pathogens have tended to become major. The rapid spread of coffee berry disease caused by *C. coffeanum* in the western and southern coffee producing area of Ethopia is closely related with the large-scale planting and wide distribution of the Harar variety (Gassert, 1979). The Karnal bunt of wheat caused by *Neovossia indica* seldom became problematic in the past though it has been known to occur in India for more than 50 years. Suddenly from 1973 onwards it has become more common and severe, and hence can no longer be categorised as a minor disease. This change in the patho-system behaviour is probably because the land varieties and other improved tall wheats were replaced by Mexican dwarfs. Vanderplank (1963) is of the opinion that resistance gets eroded when the host is bred and evolved in the absence of the pathogen. Apart from this being one of the reasons, changes in the agronomy, cropping cycle, crop phenology and micro-meterological conditions might have also played a role. When the Niphad wheats bred for resistance to stem rust were released for extensive cultivation in Maharashtra and Gujarat (India) the unknown and minor disease *Alternaria* blight knocked off these varieties. Popularity of the oat variety Victoria in the United States resulted in the Victoria blight caused by *Helminthosporium victoriae*. The variety Victoria was singularly susceptible to this pathogen because of which a minor or an unknown pathogen became a major one. The rice brown leaf hopper and the associated virus diseases in South and South-East Asia; powdery mildew of wheat (*Erysiphe graminis tritici*) in western Europe; *Septoria tritici* blight of wheat in North Africa and Mediterranean countries are in an upward trend (Saari and Wilcoxson, 1974). The bunchy top of banana which is a viral disease and the coconut wilt of an unknown etiology are some of the problems becoming very serious in India. It is difficult to define the reasons and conditions for the above instances of disease spread but it appears to be a part of human activity. All these show that a systems approach in crop production should be encouraged, if the problem of minor pathogens acquiring importance is to be minimised.

Training of future manpower

Prosperity of a nation depends greatly on the proper utilisation of material and human resources through industrialisation. The human material or manpower for this purpose demands training in technical skill. Studies at the Delhi School of Economics and elsewhere show that educational differences affect agricultural productivity and schooling should be an essential constituent of agricultural programs. As most of the developing nations are dependent on agriculture, there is scope to recase the educational curricula of primary schools, so as to interest children in crops and farming practices (Swaminathan, 1970).

Training extension workers, field staff and progressive farmers in the maintenance of plant protection machinery, decision making and plant protection operations needs to be intensified. The success of the Taiwanese co-operative plant protection programme cited earlier, is primarily due to the involvement of progressive farmers. In addition to providing the needed man power for better crop protection, there is need to conceptually unify the whole subject of plant pathology and crop protection. This will then lead to better crop production, by improving farm level decision making (Butt and Royle, 1980).

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Building National and Global Nutrition Security Systems

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INTRODUCTION

IT IS BELIEVED that the first human form was born over 25 million years ago. The remains of hominids like Zinhanthropus, one of the earliest known tool makers, were discoverd by Drs. Louis Leakey and Mary Leakey at Olduvai Gorge in northern Tanzania. Since then, the brain power of the human species, *Homo sapiens,* has gradually grown. Surprisingly however, human beings remained hunters and gatherers of food, living on native flora and fauna, for a very long time. It was only 10,000 to 12,000 years ago that the process of domestication of plants and animals began, leading to the birth of agriculture as a profession. Thus, if the human race as an identifiable species is equalled to a 24-hour day, human beings have been farmers for less than 4 minutes.

Agriculture facilitated settled life and stimulated the growth of human settlements, particularly adjoining sources of water. Crop failure due to adverse weather and/or pest epidemics often caused famine and hardship. In fact, the fate of several past civilizations was determined by the ability of governments to maintain food supplies. Some well known examples are the decline of the Roman Empire and the ancient civilizations of the Indus valley.

Providing to all citizens their daily bread has been a major goal of all governments. Amartya Sen (1981) has made a penetrating analysis of government policies in relation to prevention of famines, taking as examples some of the important famines of the present century, such as those which affected Bengal during World War II and more recently, Ethiopia, the Sahelian countries in Africa and Bangladesh.

Advances in preventive and curative medicine and in environmental hygiene and nutrition led to a steep fall in death rates after World War II, and thence to a rapid growth in population, particularly in developing countries. According to recent predictions, the human race numbering 4,400 million in 1980 will increase by some 1,800 million to reach 6,200 million before the end of the century. No less than 92% of this increase will occur in the developing countries of Asia, Africa, and Latin America. By the year 2000, the annual increase in population will be about 95 million, in contrast to 80 million in 1982.

About 40% of the population in developing countries are under the age of 15. This

has implications both for population stabilization and employment generation. It will thus take several decades more before the population increase drops from the present 2-3% to below 1%, which is a long term necessity. Meanwhile, the immediate task is to develop the capacity to feed adequately over 6,000 million persons in A.D. 2000. It is in this context that the mechanics of building an effective and enduring national and global food and nutrition security system assume importance.

FOOD SECURITY: EVOLUTIONARY STEPS IN RECENT DECADES

At the First International Conference on Food and Agriculture convened by President Roosevelt in 1943 in Hot Springs, Virginia, USA, it was resolved that "this conference, meeting in the midsts of the greatest war ever waged, and in full confidence of victory, has considered the world food problem of food and agriculture and declared its belief that the goal of freedom from want of food suitable and adequate for the health and strength of all peoples, can be achieved."

At the Second World Food Congress held 20 years later in Washington in June 1963, President J.F. Kennedy declared "so long as freedom from hunger is only half achieved, so long as two thirds of the nations have food deficits, no citizen, no nation, can afford to be satisfied. We have the ability, as members of the human race, we have the means, we have the capacity to eliminate hunger from the face of the earth in our lifetime. We need only the will."

Again, at the World Food Congress held in Rome in November 1974, it was resolved that the problem of hunger and malnutrition should be solved by 1985. The United Nations Assembly, in a resolution on the Third United Nations Development Decade, declared in 1980 that hunger and malnutrition should be eliminated as soon as possible and certainly by the end of the century.

At the World Food Day Colloquium held on 16 October 1982 at the FAO Headquarters in Rome, the eminent panelists drawn from different parts of the world made the following statement: "We believe that it is indeed possible to end world hunger by the year 2000. More than ever before, humanity possesses the resources, capital, technology, and knowledge to promote development and to feed all people, both now and in the forseeable future. By the year 2000 all the world's people and all its children can be fed and nourished."

"Only a modest expenditure is needed each year – a tiny fraction of total military expenditures which amounts to about $650 billion a year. What is required is the political will to put first things first and to give absolute priority to freedom from hunger."

Thanks to good harvests during the last few years, world cereal stocks in 1984-85 are expected to be about 294 million tons. This represents an increase of 28 million tons as compared to the stocks in 1983-84. At 18 percent of estimated world consumption, they meet the minimum requirements for global food security. In spite of such grain mountains in some countries, the queues for grain rations and for free or sub-

sidized food grains are becoming longer in many developing countries. It has been estimated that in Southeast Asia alone over 300 million children, women, and men may be going to bed hungry. The situation in parts of Africa is even more serious. Drought, desertification, and man-made calamities have added to the problems caused by an imbalance between growth rates in food production and population.

In January 1985, the aggregate cereal production in 21 African countries was estimated by FAO at 22.7 million tons, some 20 percent below the average annual production for the previous five years. According to the FAO study "Agriculture: Toward 2000," at least 600 to 650 million people are likely to be seriously undernourished by the end of the century. In other words, about 300 million tons of grain stocks and over 500 million hungry people are co-existing in our planet today. Thus, hunger is not related only to adequacy of food supplies. Access to supplies is equally important. This is the principal lesson of the Great Bengal Famine of 1943 when several million people died due to starvation, although more equitable distribution of the available food would have made such deaths unnecessary (Sen, 1981). Consequently, FAO (1983) has enlarged its concept of food security so as to include the following components:

(a) The *ultimate objective* of world food security should be to ensure *that all people at all times have both physical and economic access to the basic food they need.*

(b) *Food security should have three specific aims,* namely ensuring production of adequate food supplies; maximizing stability in the flow of supplies; and securing access to available supplies on the part of those who need them.

(c) Action will be needed on a wide front including all factors that have a bearing on the capacity of both countries and people to produce or purchase food. While cereals will continue to be the main focus of attention, action should cover all basic foodstuffs necessary for health. Agricultural and rural development, food production, food reserves, the functioning of national and international cereal markets, the foreign exchange needs of importing countries, trade liberalization and export earnings, the purchasing power of the poorest strata of the population, financial resources and technical assistance, the flow of food aid and arrangements to meet emergency needs; these are some but by no means all of the specific areas where action is needed to enhance food security.

FOOD SECURITY VERSUS NUTRITION SECURITY

Although FAO has revised its concept of Food Security in 1983 on the lines indicated above, we still need to enlarge this concept so as to promote nutrition security in all countries.

During the last 10 years there has been a growing appreciation of the multi-faceted nature of the nutrition problem. In the past, malnutrition was often regarded as something similar to a communicable disease. Today, nutrition is no longer viewed in isolation and consequently it is not just the Ministries of Health that are considered responsible for combating malnutrition.

There may be many reasons for the incidence of malnutrition, of which the following are some of the more important.

1. Adequacy and stability of food production and supply with a view to ensuring reasonable prices and to avoiding panic purchase by affluent consumers and distress sales by poor farmers.
2. Lack of safe drinking water and the resulting infection.
3. Household income: poverty resulting in inability to buy the needed quantities of food is now known to be a major cause of malnutrition. In fact, in several countries and in several regions within large countries, the nutrition problem can be better stated in terms of person-years of job opportunities rather than in terms of tons of food grains.
4. Composition of intra-household income and nature of family budget management and women's time allocation.
5. Consumer price of food commodities.
6. Nutrient composition of the foods consumed in relation to the need for balanced diet.
7. Energy expenditures by the working population, particularly unskilled labour.
8. Illiteracy and inadequate efforts in nutrition education.
9. Cost, risk, and return structure of farming systems.
10. Poor post-harvest technology and ill-developed food delivery systems for the rural and urban poor and for people living in remote areas. Inadequate grain drying and poor storage can lead to a greater incidence of liver ailments arising from mycotoxins in food.

An important factor which is receiving increasing attention is an understanding of the precise nature of the nutrition problem. It is now widely accepted that in countries where a cereal like rice or wheat is a staple, inadequate consumption of calories is the basic cause of malnutrition. Generalized concepts on quantitative guidelines for minimum quantities of food required by children and adults are currently undergoing changes because of the progress in our understanding of the physiological and biochemical causes of malnutrition. The ability of human beings to adapt to a wide range of dietary situations is now recognized. Professor P.V. Sukhatme in this book, Professor P.R. Payne and several others have shown how a clear understanding of the basic processes of human adaptation to different nutrition levels is essential for developing an effective strategy for assuring to every child, woman or man the

minimum levels of nutrition required for an adequate level of physical and mental performance.

Disillusionment with many of the conventional types of nutrition intervention programmes has generated interest in finding effective low-cost remedies to the major nutritional maladies of each area. Many externally supported nutrition intervention programmes collapse as soon as the external inputs are withdrawn. How can a methodology be developed for overcoming malnutrition where external help, if any, will be self-eliminating and not self-perpetuating? The answer lies in agriculture and nutrition coming together in a meaningful manner. FAO's enlarged concept of food security involved steps for promoting both physical and economic access to food among all sections of a country's population. This concept provides a mechanism for provides a mechanism for developing enduring national nutrition security systems. Introduction of the nutrition security concept will facilitate such integration.

The following are essential components of a national nutrition security system:

1. *Food security* resulting in adequacy and stability of food supplies and economic and physical access to food.

2. *Drinking water security* resulting in a reduction in the intestinal load of infections and in the incidence of diarrhoea, hepatitis, etc.

3. *Minimum income security,* resulting in all citizens having the requisite purchasing power for balanced nutrition. Depending upon needs and possibilities, steps to ensure minimum income security may take the form of "Food for Work" and "Food for Development" programmes for unskilled and skilled labour, crop and livestock insurance for small farmers and share croppers, mid-day meal and supplementary feeding programmes for children, and various other forms of social security measures for both economically handicapped farmers and consumers. The rights to food and to work have to become correlated rights. Developing countries cannot afford the advanced social security measures adopted by developed countries. Nevertheless, they have to realize that freedom from hunger can be achieved only by winning the battle against unemployment.

4. *Nutrition intervention,* leading to insulating old and infirm persons, pre school children and pregnant and nursing mothers from under- and mal nutrition. Nutrition intervention programmes may also take the form of oral administration of Vitamin A and other special programmes to cater to specific needs.

5. *Nutrition education* culminating in a widespread awareness that every family and every local community can and should solve its nutrition problems. Also, simple local solutions may often be the most economical and speedy method of overcoming the nutritional maladies of an area.

6. *Population stabilisation.* In the ultimate analysis, a proper balance between population growth and resource availability is essential for improving the quality of life including nutrition. Hence, population education and

stabilization programmes have to become an integral part of a nutrition security action plan.

Given an appropriate blend of improved agricultural technologies, effective delivery systems and services and government policies designed to stimulate both production and consumption, enduring national nutrition security systems can be built within this century. The different steps involved in building national and regional nutrition security systems follow.

Malady-remedy analysis

The first step in developing an effective nutrition security system will be the undertaking of a malady-remedy analysis at the level of the village and district by interdisciplinary groups. This would enable the development of appropriate agricultural and public health programmes designed to provide remedies to the specific nutritional problems of the area. In order to enable local action groups to conduct such analyses in a purposeful manner, there is need for organizing training programmes on the methodology of identifying the constraints responsible for the gap between current and desired levels of nutrition. An urgent need is the development of methodologies for malady-remedy and constraints analyses.

After the maladies are identified, solutions will have to be found. The maladies can be classified into (a) those which can be solved by the local community through individual or/and group action, and (b) those which require intervention and support programmes sponsored by government and/or voluntary agencies.

Nutrition based land and water use planning

Land and water based occupations involving crop and animal husbandry, fisheries, and forestry are the most important sources of food, jobs, and income in many developing countries. If nutrition, employment, and income are to have a mutually beneficial feedback relationship, a beginning should be made to promote scientific land and water use planning in each agro-ecological area. The land and water use plans developed by professionals in full consultation with the farmers and fishermen of the area will have to be based on principles of ecology, economics, energy conservation and employment generation. The nutritional malady-remedy analysis data would help in providing solutions to several problems through appropriate shifts in crop planning. For example, cereal-legume rotations or intercropping can help to provide a balanced diet where cereals alone are grown and consumed. Intercropping and mixed cropping can help to provide in rainfed areas the ingredients necessary for balanced nutrition. To facilitate such a reorientation in land and water use planning, farming systems research programmes should include a nutritional dimension. Both productive and post harvest technologies will have to be examined. The qualitative deterioration of food grains and other agricultural commodities will have to receive

as much attention as the quantitative aspects of food losses. With the spread of photo-insensitive and period-fixed varieties of crops, problems of grain drying are becoming more important. Work on the estimation of mycotoxins in food is inadequate in developing countries. Many liver ailments could result from mycotoxicosis. Improved post-harvest technology would also help to provide greater opportunities for livestock production through appropriate fortification of biomass for use as animal feed. Farming systems research, hence, should cover both production and post-harvest operations in an integrated manner.

Monitoring and short term intervention programmes

Local level nutrition planning and monitoring groups will have to assess the extent to which the major nutritional maladies can be remedied through a restructuring of land and water use. Problems which cannot be readily solved through local shifts in farming systems will need external assistance. At least in this manner, the nature of the nutrition intervention programmes needed can be articulated fairly precisely.

A Nutrition Planning and Monitoring group in each area can be an integral part of a rural development agency so that nutrition becomes a major area of concern in rural development programmes.

VULNERABILITY OF FOOD PRODUCTION SYSTEMS

The vulnerability of the world food production systems arises from the following factors:

1. Very few countries have sufficient surplus grain stocks for provision to others, either on commercial or concessional terms. The most important source of surplus grain stocks at present is North America.

2. In spite of all the scientific progress made in capture and culture fisheries, over 90% of the world's food supply comes from the land. Although the flora of the world has over a million species, only about 30 of them make a significant contribution towards human nutrition. Wheat, rice, and maize are the dominant food crops of the world. If one or more of these crops are damaged by weather abnormalities and/or pest epidemics, the world food production becomes critical. In fact on a global scale, about a 10% increase or decrease in food grain production can make all the difference between an uncomfortable glut and acute scarcity at current levels of consumption.

3. From the early 1970s, the rapid escalation in the price of fossil fuel led to an increase in the cost of important agricultural inputs like fertilizer, gasoline, and diesel. Consequently, crop land is also looked upon as a source of producing energy. There are thus competing demands for scarce land resources. Further, the widespread damage now taking place in natural eco-systems due to deforestation,

soil erosion, and desertification will make vertical growth in productivity the only possible method of improving production. In the tropics and sub-tropics, however, multiple cropping will be another method of increasing the gross cropped area.

4. While the cost of production is going up, farmers usually suffer whenever there is a bumper harvest. The growing stocks of food grain are tending to reduce the international commodity market prices of food grains and other agricultural products (Table 18.1). Many developing countries are experiencing serious balance of payment problems as a result of a steady decline in the price of the agricultural commodities they export. Consequently, the share of developing countries in the world trade in agricultural production is tending to go down. While the share of developing countries in agricultural exports was 36% in 1977, it came down to 28% in 1981. In 1983, the volume of agricultural trade rose by only 1 percent, which was far below the average rates of growth in the 1960s and 1970s. In dollar terms, exports of agricultural, fishery and forestry products actually declined by 1 percent. Because of a low margin of profit, small farmers in developing countries have very little resources to invest on the land. The capital requirements for the modernization of agriculture are not available in most developing countries.

5. In the pre-modernization state of agriculture, weather aberrations and pest epidemics were largely responsible for year to year undulations in production. Once the process of modernization involving the use of purchased inputs set in, marketing opportunities assumed importance. Under such conditions, public policies followed by governments, both to stimulate production and improved consumption by the poorer sections of the population, play a dominant role in influencing farmers' decisions on land and input use. Thus, weather, pest epidemics, and public policies now influence the stability of production.

PROGRESS IN BUILDING GLOBAL AND NATIONAL FOOD SECURITY SYSTEMS

Since the World Food Conference held in Rome in 1974, several steps have been taken to develop a global food security system to insulate humankind from mass starvation due to either widespread crop failure or wide gaps between demand and supply. These fall into 3 broad areas of action, namely: (1) identification of famine indicators and establishment of a global famine early-warning system; (2) creation of an adequate food security reserve; and (3) long-term policy changes leading to both more production and more equitable distribution of food and of resources necessary for this purpose. Following are some of the more significant steps:

1. *A Global Information and Early Warning System* was initiated in 1975 by the

Table 18.1 Export prices of selected crops ($ per m.t.)

	US Wheat[1] No.2 Hard Winter Ord. Prot.	Maize[2] US No.2 Yellow	Rice[3] Thailand	Soybeans[2] No.2 Yellow
1983 - September	159	148	298	323
October	154	148	286	311
November	153	147	282	311
December	154	143	273	298
1984 - April	158	148	255	300
May	154	146	253	321
June	150	147	256	293
July	149	143	273	253
August	155	139	272	248
September	157	131	254	238
October	155	122	251	239
November	155	117	231	234
December	151	114	224	221

[1]*Export price, f.o.b., Gulf Ports US*
[2]*Export price, delivered, US Gulf Ports*
[3]*White Rice, 5 per cent f.o.b. Bangkok*
Source: FAO, Commodities and Trade Division

Food and Agriculture Organization (FAO). The system provides data to help initiate suitable preventive and remedial measures to overcome the difficulties that may arise if famine potential develops. About 100 countries participate in it. The system has proved itself on many occasions – as during the African food emergency of 1983-84 – to be an essential link in the world's food security network. Although FAO provides the early warning system, national governments must develop a mechanism for timely action.

2. *The International Emergency Food Reserve (IEFR)* was started in 1975 and has distributed 1.8 million tons of food grains and about 150,000 tons of other foods to stricken people until 1982. IEFR's annual target is 500,000 tons of cereals. The African food crisis has highlighted the need for an expanded IEFR.

3. *The International Fund for Agricultural Development (IFAD)* was established in 1977 to promote an increased flow of external resources for food production and rural development. IFAD had committed $1,400 million for projects and programs in 100 developing countries until 1982. It has recently experienced difficulties in replenishing its resources to help poor farm families.

4. *The World Food Council (WFC)* was established by the United Nations General Assembly in December 1974 to provide "coordination and follow-up of policies concerning food production, nutrition, food security, food trade, and food aid, as well as other related matters, by all the agencies of the United Nations system." It is enjoined to "review periodically major problems and policy issues affecting the world food situation, and the steps being proposed or taken to resolve them by Governments, by the United Nations system and its regional organization" and recommend remedial action. WFC is an organ of the United Nations and reports to the General Assembly through the Economic and Social Council.

The WFC organizes an annual ministerial level conference to review the global food situation and develop regional and national food security systems. Its major goal is to raise the political priority for food.

5. *The International Wheat Council (IWC).* The International Wheat Agreement 1971 consists of two separate legal instruments: the Wheat Trade Convention 1971 (as extended) and the Food Aid Convention (as revised in 1980 and subsequently extended). The Wheat Trade Convention is administered by the International Wheat Council and the Food Aid Convention is administered by the Food Aid Committee. The Food Aid Committee (membership of which is limited to contributor countries) does not have its own secretariat but is serviced by the IWC secretariat.

6. *The Food Aid Convention (FAC)* was enlarged in 1980 and has a target of 10 million tons of food grains.

7. *The International Monetary Fund Compensatory Facility* was established in 1981 to provide assistance to nations which must import additional food grains to feed their population. This new financing mechanism has made credit up to $300 million available to 5 developing countries until the end of 1982.

8. *Other FAO Programs* such as the Food Security Assistance Scheme, International Fertilizer Supply Scheme, and Action Program for the Prevention of Food Losses also provide help to needy countries.

9. *World Food Program (WFP)* was started in 1963 jointly by the UN and FAO. Since it commenced operations 20 years ago, WFP has committed more than $5 billion of assistance to over 1,100 development projects in 114 developing countries. In addition, WFP has provided more than $1 billion of food aid to almost 600 emergency operations in 103 countries. In total, this assistance has helped 170 million people. During 1984, WFP undertook massive operations in the drought ravaged countries in Africa. Thus, WFP has become a very meaningful multilateral development assistance organization. WFP is not only helping to alleviate human distress, both in normal times and during emergencies, but it is also increasingly helping to prevent distress sales of food grains by small farmers by making purch-

ases from its own resources in developing countries. However, the fact that WFP has been able to assist only 170 million people during 1963-83, in contrast to an estimated 500 million people suffering from hunger today, underlines the urgent need for similar initiatives at the national and regional levels.

10. *Regional Food Security.* A good example of regional food security is the recently established ASEAN Food Security Reserve Agreement. Several other regional mechanisms to plan and establish food reserve are under discussion and development.

11. *National Food Security Programs.* Food programs have been initiated in 72 countries of which 60 are developing nations. The United States has established a Food Security Wheat Reserve of 4 million tons to meet emergency needs. The U.S farmer-owned reserve and large national buffer stocks of food established by major food deficit countries such as China, India, Indonesia, and Japan have also contributed to world food security. India had a grain reserve of over 22 million tons in 1984. National early warning systems are being slowly improved, and devices have been introduced into bilateral grains contracts to limit large-scale preemptive buying.

The preceding measures indicate a positive movement toward achieving world food security. A new General Agreement on Tariff and Trade (GATT) committee has been set up to recommend methods of achieving greater liberalization in agricultural trade. If this committee can devise a pattern of trade that will increase the flow of resources to the agricultural and rural sectors of developing countries, it will have done a great service to the cause of building national food security systems. Prospects for success in this field are unfortunately not yet in sight.

While it will be imprudent to underestimate the long term significance of the above developments in the field of food security, it will be equally unwise to overlook the fact that none of these steps have been able to make a significant dent on the problem of undernutrition and hunger among the poor in developing countries.

Efforts in providing safe drinking water are also not adequate in many developing countries. This is why there is need to change the concept of food security into one of nutrition security.

There is considerable debate among technologists and ecologists about the human carrying capacity of the earth. Hence, before dealing with the various steps essential for achieving freedom from hunger, it will be worthwhile to examine briefly the global agricultural balance sheet.

GLOBAL AGRICULTURAL BALANCE SHEET

Land

Crop land, range land and fisheries constitute the three major source of food. The 6 million tons of marine protein consumed annually and the 6 million tons of beef and mutton protein produced each year on range lands will each correspond to 250 million tons of grain equivalent (Mtge) in primary terms (Gilland, 1983). In 1984, crop land provided about 1,780 million tons of cereals, over 450 Mtge of non-cereal crops and 300 Mtge of rotation grasses and harvested roughage. The 1984 gross primary production is about 3,000 Mtge, of which crop land provided 80% and range land and fisheries, 10% each. Even with modern aquaculture techniques, it seems unlikely that the 80:10:10 proportion in the respective contribution of crop land, range land, and fisheries will change very significantly during the remaining years of this century. In fact, the contribution of crop land is likely to go up with yield improvement in major crops. Inland and coastal aquaculture techniques can help to enhance the contributions of the fisheries sector if many of the problems in processing, storage, transport, and marketing can be solved.

The arable area including land under permanent crops in the world was about 1.45 billion ha in 1980. About 50 million ha were under non-food crops and the remaining 1.40 billion ha constituted the food producing area. Estimates relating to the maximum attainable world average crop yield vary. Buringh *et al.*(1975) estimated a theoretical maximum global production potential of 50,000 Mtge per year, based on the assumption that an average yield of 14.6 tge per hectare can be obtained in a maximum arable area of 3.4 billion hectares. In a subsequent study, Buringh and van Heemst (1977) suggested more realistic estimates. Based on the view that the area available for high input cultivation may be about 1.4 billion ha and that a realistic average yield limit may be 7.3 tge per hectare, they proposed a production limit of 10,200 Mtge per year.

Revelle (1976) worked out a maximum global production limit of 11,400 Mtge based on the assumption that an average yield of 5 tge per hectare can be obtained on a net arable area of 2.3 billion hectares. A major reason for the difference in the estimates of Buringh and co-workers and of Revelle is the assumption by the former that the humid tropics can become twice as productive as the temperate zones. Revelle, however, holds the view that large-scale high-yielding agriculture is not possible in the humid tropics except in Java and a few other areas with deep, recently weathered soils. Also problems of pests, pathogens, and weeds as well as of leaching and fertilizer loss place serious limitations on average yields in the humid tropics.

Gilland (1983) has concluded that the maximum primary production potential from crop land, range land, and fisheries may be of the order of 7,500 Mtge. If an ideal per capita requirement of 1 tge per year is assumed, 7.5 billion people can be sustained at satisfactory nutrition levels on the earth. At present on a global average, about 3 persons survive on 1 tge per year, the range being 1 person per 1 tge in the affluent countries to 6 persons per 1 tge in the poor, densely populated nations. If the

world population could stabilize itself at about 10 billion by the middle of the 21st century, there is still chance of meeting the per capita food needs at a substantial level of utilization of natural resources.

Water

Although water is one of the most abundant substances on earth, only 2.7% of the total 1.4 billion $km^3$of water is fresh water. Of this, only about 23% is available for sustaining life, the rest being frozen in ice caps and glaciers. Nevertheless, some estimates (Biswas, 1983) reveal that even without drastic conservation measures, only one-sixth of the potentially available water may be used by the year 2000 (Table 18.2). Therefore, water availability by itself may not be a problem except in arid and semi-arid areas. What is of greater concern is the poor water use efficiency in many irrigation projects as well as the heavy conveyance losses.

Table 18.2. Water availability

	1973	2000
Estimated world population (million)	3,860	6,500
Potential annual availability of water (m^3/person)	10,400	6,200
Prospective annual demand for water (m^3/person)	1,000	1,000

Source: Biswas, 1983

Timber

In 1979, the production of roundwood was about 3 billion cubic meters from about 2,400 million hectares of commercial forests. Windhorst (1979) has estimated a theoretical maximum sustainable production of 9 billion cubic meters per year, i.e. about 3% of the timber stand of 300 billion cubic meters. This level of productivity can be obtained only if all the trees were felled at the optimum age and there were no losses from insect attack, diseases, fires, and storms. Further, the area under tropical forests is declining at a rate of about 6 million hectares per year (Fontaine, 1981). Hence, the present per capita production of 0.7 cubic metres or 4,200 kcal per day on an energy basis is likely to decline after the world population reaches the 7 billion level.

Major nutrients

World consumption of the three major plant nutrients – nitrogen, phosphorus, and potassium – was 60, 14 and 20 million tons respectively in 1980-81. To produce more food, there will be need for stepping up considerably the current levels of consump-

tion of N, P, and K. As long as adequate energy is available, there need be no shortage of nitrogenous fertilizers. Also, biological methods of nitrogen fixation will probably be used to a much greater extent in the coming years.

Potassium reserves are of the order of 66 billion tons. Also, when exploitable reserves on the land are exhausted, potassium can be extracted from sea water, in which the K concentration is about 380 parts per million. The total amount will be of the order of 520 trillion tons. Magnesium, which is present in sea water at a concentration of 1,290 parts per million, is already being commercially extracted.

Phosphorus could become a key limiting factor in a few centuries. The present estimate of economically exploitable reserves of phosphate rock is about 76 billion tons. In 1981, global phosphate rock production was 143 million tons. At an average P content of 15%, the world P production at present is about 20 million tons. About two-thirds of this quantity is used for the manufacture of phosphate fertilizer. With technological advances, it may be possible to recover P from rocks containing small quantities. The average concentration of P in sea water is only 0.06 parts per million. Hence, phosphorus management and recycling deserve serious attention from a long term point of view. Immediately, prevention of extensive soil erosion will make a major contribution to scientific soil health management.

NEED FOR NATIONAL NUTRITION SECURITY SYSTEMS

It is now clear that an effective global food security system may emerge only if all countries pay greater attention to the building of strong national food security arrangements. The five major grain exporting countries – the United States, Canada, Australia, Argentina, and France – produce over 25% of the world's cereals and export over 40% of production. Their annual per capita grain production of 1,100 kg is four times that of the rest of the world. Their combined grain exports of 170 million tons constitute an important factor in avoiding famines in many countries. If dependence on them continues at the current level, they will have to export at least 220 million tons by the year 2000.

Dependence on grain imports for feeding their population by developing countries endowed with a large untapped agricultural production potential will not only create balance of payments and other economic problems but will also add to problems of unemployment and underemployment. Importing food by keeping the local rural population at low levels of productivity will be equivalent to importing unemployment and poverty. Hence, steps to build strong national nutrition security systems will not only be helpful in providing food and nutrition to a country's population but will also help to generate more jobs and income in rural areas. Because of several linkages between agriculture and industry, priority to the farm sector stimulates industrial growth.

Agriculture supplies the raw materials for employment-intensive industries. Agriculture stimulates and sustains industrial output through rural household

demands for consumer goods and services. Agriculture influences industry through government savings and public investment. Agricultural growth requires fertilizer, machinery, tools, and energy.

The International Food Policy Research Institute (IFPRI) has attempted to quantify the impact of such linkages. Using a macroeconomic model, it has been estimated that from 1961 to 1972, a 1% increase in agriculture in India generated a 0.5% increase in industrial growth. Agriculture increased national income by 0.7%.

Poor people spend most of any additional income on food. In India, studies show that the poor spend 60% of increments to income on grain and almost 80% on total food products. Food and employment are intimately related through the multiplier effects of agricultural growth and development.

Technological change in agriculture can stimulate growth in income and employment in many sectors of the economy. It raises the incomes of farmers, who devote a larger share of their additional income to locally produced goods and services. IFPRI research in Malaysia, Bangladesh, and India has shown that from 40 to 80% of increments to farmers' income is spent on such local "tertiaries" as housing, entertainment, and services. Such tertiaries create more employment.

In a recent study in Malaysia, it was found that each additional dollar of value an irrigation project created in the paddy rice sector indirectly generated an additional $0.83 of value in the non-rice economy. Of this $0.83, about two-thirds was attributable to final household demand linkages and only one-third to increased demands for paddy intermediaries. Thus, there are symbiotic linkages in the growth of all the three major factors of an economy – agriculture, industry, and services. Agricultural growth necessitates better rural communication, and better communication helps to minimize the gap between the city and the village in technological evolution.

COMPONENTS OF A NATIONAL ACTION PLAN

An effective national plan for nutrition security system must include the following (Swaminathan, 1982):

(a) ecological security to protect the basic life-support systems upon which sustained agricultural improvement depends;
(b) technological security to ensure that yield improvement is coupled with production stability;
(c) grain reserves, safe storage, and improved postharvest technology;
(d) trade security – both national and international;
(e) social security to provide purchasing power to the urban and rural poor through greater opportunities for gainful employment;

(f) drinking and irrigation water security;
(g) nutrition education; and
(h) population stabilization.

A National Nutrition Security System should give concurrent, integrated attention to both production and distribution of food. Above all, a nutrition security system must ensure that the short-term goals of agricultural development do not endanger long-term prospects for producing more food from the available land and water resources. As mentioned earlier, success in population stabilization will ultimately determine the fate of nutrition security programmes.

Improving production

Until the beginning of this century, agricultural production increased largely through area expansion. In countries like Japan, there has been a steady improvement in the yield of crops like rice during the last 10 centuries, thanks to the development of techniques for soil fertility restoration and enrichment as well as irrigation. During the present century, major advances have taken place in four broad areas – genetic improvement, chemical technology application, engineering including irrigation water management and above all, integrated systems of farm management. These scientific advances, when supported adequately with appropriate government policies, lead to sustained progress in food production.

Taking mainly rice as an example, I would like to illustrate some of the major scientific ingredients which have gone into the improvement of yield coupled with stability of performance.

Increasing and stabilizing rice production in irrigated areas

Developing countries are making considerable investments on bringing more land under irrigation. Most of the rice cultivated in China is irrigated. In India, nearly 2.5 million hectares are brought under irrigation each year. In the Philippines, about 100,000 hectares are added to the irrigated area every year. Therefore, a priority area of researchy relates to the optimum use of water so that the yield per liter of water can be maximized. In this context, much research has been done on all aspects of water delivery and on-farm management of water. Methods of achieving equitable distribution of water in the head and tail ends of a command area have been developed.

Prior to the introduction of the Dee-gee-woo-gen and Norin dwarfing genes in rice and wheat respectively, lodging was a serious problem under conditions of good soil fertility. This is why varieties of rice and wheat possessing a semi-dwarf and non-lodging plant type became popular with farmers very speedily. The first high yielding rice variety developed by IRRI by crossing Peta, a tall strain from Indonesia, and Dee-gee-woo-gen resulted in the variety IR8. Soon it was found that when the ecology of the rice field is changed by the application of more water and fertilizer, the threat to yield caused by the triple alliance of weeds, pests, pathogens could become serious. Small farmers obviously can invest on inputs only when risks are low. Therefore, high yielding varieties characterized by stability of performance were needed. IRRI, hence, introduced in its breeding programs the following approaches in order to com-

bine good yield potential with multiple resistance to pests and diseases:

(a) continuous identification of new genes for resistance to each of the major diseases and insects;
(b) sequential releases of improved germplasm with different major genes to combat new races of diseases and biotypes of insects;
pyramiding of two or more genes into the improved rice germplasm using pedigree method or population breeding approach
(d) gene rotation to reduce the chances of development of races or biotypes;
(e) development of multi-line varieties;
(f) development of several varieties for a region with different genes for resistance;
(g) development of varieties with horizontal resistance;
(h) wide hybridization combined with disruptive mating to incorporate genes for resistance from wild germplasm;
(i) Use of cell cultlure techniques to develop resistance to toxins produced by major fungal and bacterial diseases.

The pedigree of IR36 which is now cultivated in over 10 million hectares in Asia is an index of the power of the breeding strategy designed to bring about a pyramiding of major genes for resistance. IR36 includes in its ancestry 11 different varieties from 6 countries and a wild specie, *Oryza nivara.* IRRI breeders have been able to combine in recent years multiple resistance to pests with earliness and good yield potential (Table 18.3). Earliness enables multiple cropping wherever there is irrigation.

To make broad based breeding work possible, there is need for the collection, conservation, and evaluation of rice genetic resources. IRRI has, therefore, established an International Rice Germplasm Center. At present, over 75,000 strains are available in this collection. This is estimated to represent about 60% of the world's genetic variability in rice.

All the collections are systematically screened for nearly 40 different characters under a Genetic Evaluation and Utilization (GEU) program.

A great advantage of regional and international collaborative research is the possibility of identifying breeding material suited to different ecological conditions. Under the International Rice Testing Program (IRTP), the best available varieties from all rice growing countries are tested in common trials at many locations. Consequently, varieties developed in one country have been found to be suitable for release in some others (Table 18.4). International cooperations also helps to screen segregating material at "hot spot" locations for major pests and diseases as well as adverse soil factors. Thus, IR36 is the product of selection at a hot spot location for tungro virus in Indonesia, for gall midge in India, and for other pests in the Philippines.

After the release of high yielding varieties of rice, the production and productivity of rice have gone up considerably in several countries of Southeast Asia. For example, in the Philippines, rice production has been more than doubled between 1960-1980. What is even more significant is the doubling of the yield per hectare. This is particularly important in Asia where ratio of land to people is at present 0.21 hectare per person. The progress made by Indonesia in increasing rice production from about 10 million tons in 1970 to over 25 million tons in 1984 is another outstanding example

Table 18.3. Disease and insect reactions of IR varieties in the Philippines

Variety	Growth duration (days)	Blast	Bacterial blight	Grassy stunt	Tungro	BPH biotypes 1	BPH biotypes 2	BPH biotypes 3	GLH	Stem borer	Gall midge
IRS	140	MR	S	S	S	S	S	S	MR	MS	S
IRS	130	S	S	S	S	S	S	S	MR	S	S
IR20	125	MR	R	S	MR	S	S	S	MR	MR	S
IR22	125	S	R	S	S	S	S	S	S	S	S
IR24	120	S	S	S	S	S	S	S	MR	S	S
IR26	130	MR	R	S	MR	R	S	R	MR	MR	S
IR28	105	R	R	R	R	R	S	R	R	S	S
IR29	115	R	R	R	R	R	S	R	R	S	S
IR30	110	MS	R	R	R	R	S	R	R	MR	S
IR32	140	MR	R	R	R	R	S	R	MR	MR	S
IR34	130	R	R	R	R	R	S	R	R	MR	S
IR36	110	R	R	R	R	R	R	MR	MR	MR	R
IR38	125	R	R	R	R	R	R	MR	R	MR	R
IR40	120	R	R	R	R	R	MR	S	MR	MR	R
IR42	135	R	R	R	R	R	R	S	MR	MR	R
IR44	130	MR	R	S	R	R	R	MR	MR	MR	S
IR46	130	R	R	S	R	R	S	R	MR	S	S
IR48	140	MR	R	R	R	R	R	S	MR	S	S
IR50	105	MS	R	R	R	R	R	MR	R	MR	S
IR52	115	MR	R	R	R	R	R	MR	R	MR	-
IR54	120	R	R	R	R	R	R	S	R	MR	-
IR56	110	R	R	R	R	R	R	R	R	MR	-
IR58	100	R	R	R	R	R	R	R	R	MR	-

Source: IRRI

Table 18.4. IRTP entries released in different countries, 1982–84

Country	Designation	Origin	Name given	Year released
China	Chianung sen yu 23	Taiwan (China)	*	1982
	Chianung si-pi 661020	Taiwan (China)	*	1982
	Suweon 290	Korea	*	1982
	BG90–2	Sri Lanka	BG90–2	1983
Vietnam	IR9224–73–2–2–2–3	IRRI	OM33	1983
	IR8423–132–6–2–2	IRRI	*	1983
India	HPU734 (IR579)	IRRI	Himalaya–1	1982
	HPU71 (Pusa 33)	India	Himalaya–2	1982
	IRI3427–45–2	IRRI	Bharathithasan	1983
	BG90–2	Sri Lanka	Pant Dhan 4	1983
	CO43	India	*	1983
	CO44	India	*	1983
Nepal	IR3941–4–Plp2B	IRRI/India	Kanchen	1982
	IR2298–Plp–3–2–1	IRRI/India	Himali	1982
	Mala/J15	Bangladesh	Mallika	1982
Pakistan	IET4094	India	DR-82	1984
	IR2053–261–2–3	IRRI	DR–83	1984
Tanzania	BG90–2	Sri Lanka	*	1984
	IET1444	India	*	1984

**Not available*

of the role modern technology can play in improving production and yield provided the technological package is supported by appropriate packages of services including credit and public policies particularly in the area of pricing and marketing.

The new varieties of rice and wheat are insensitive to the photoperiod; hence, they can be cultivated at different times of the year provided water is available and temperatures are favourable. Hence, plant breeders have introduced productivity per day as an important criterion in selection programs. New crop rotations have consequently become possible. Multiple cropping involving different crop combinations chosen on the basis of their yield potential as well as on marketing opportunities are now being introduced. Rice-wheat rotation has become popular in several parts of India and Bangladesh. Consequently, wheat production has gone up very considerably in Bangladesh and in the West Bengal State of India.

Increasing production under unfavourable environmental conditions

Large areas under rice are either drought prone or flood prone. In recent years, considerable emphasis has been placed on breeding varieties for rainfed upland conditions. The growing conditions in such areas can be classified into distinct categories depending upon the number of months when rainfall is received, the moisture holding capacity of the soil, and other soil factors such as alkalinity and salinity.

The technology for stabilizing production under adverse weather conditions include:

(a) crop life-saving techniques;
(b) alternative cropping strategies to suit different weather models;
(c) compensatory production programmes in irrigated areas.

In flood prone and deep water (50cm and above of standing water) areas, there is need for varieties which can stand submergence and which can divert a larger proportion of the dry matter to grains. At present, the harvest index (i.e., the proportion of total dry matter used for producing grains) is very low in deep water rices (Table 18.5). Hence, a better partitioning of the dry matter will have to be achieved in order to increase the grain yield potential. Also under such conditions, it is possible to combine rice cultivation with aquaculture. This will call for the cultivation of varieties with a high degree of pest resistance so that the application of chemical pesticides with long residual toxicity can be avoided.

Table 18.5. Comparison of grain yield, total dry matter production and harvest index between irrigated and deepwater rices

Water regime	Variety	Total dry matter (t/ha)	Harvest index	Grain yield (t/ha)
Irrigated lowland	IR36 (dry season)	13.7	0.45	7.13
	IR36 (wet season)	11.2	0.44	5.74
	Deepwater	Kwian Hak	13.3	0.25
3.29				
(floating rice)	Pin Gaew 56	12.2	0.19	2.31
	Hing Hoy	23.2	0.10	2.23

Source: IRRI

Problem soil areas. Over 86 million hectares in South and Southeast Asia suffer from various soil health problems. In addition to problems of salinity and other adverse factors, nearly 70% of the rice lands in this region suffer from nitrogen deficiency. Unfortunately, however, there is considerable loss of the applied fertilizer during the monsoon season. Formerly, it was believed that much of this loss is due to leaching and denitrification. However, recent experiments carried out jointly by IRRI and the International Fertilizer Development Center (IFDC) have shown that a considerable proportion of the loss may be due to ammonia volatilization. Through appropriate placement procedures, the volatilization losses can be greatly minimized and even eliminated. For doing this on a large scale, suitable fertilizer placement equipment will be needed.

In addition to mineral fertilizers, it is possible to harness various organic and bio-fertilizers such as Azolla, blue green algae, straw, waste materials, and legume nitrogen. Azolla is already used fairly extensively in China and Vietnam. Experiments carried out at IRRI have shown that if the following three conditions are followed, Azolla application would save to some extent expense on mineral tertilizer:

(a) adequate phosphorus availability in the soil;
(b) effective control of Azolla pests, whenever necessary;
(c) Favourable labour wage rate.

The scope for introducing nitrogen fixing genes in rice through genetic engineering techniques is being explored. However, this pathway of minimizing the need for mineral fertilizers is not likely to become available for commercial use during this decade.

Technologies for small farmers. The question is frequently asked whether high yielding varieties of rice, wheat and other crops have built-in characteristics of social discrimination. Carefully conducted studies, however, have shown that the technology is beneficial irrespective of the size of the farm holding. The scale-neutrality of technology is important, since a majority of farmers in many developing countries have small holdings (Table 18.6). A small farm in the tropics and sub-tropics has a good production potential since it affords the possibility of intensive agriculture. However, the small farmer with often fragmented landholdings suffers from several handicaps. The average yields hence tend to be low (Table 18.7). The handicaps are partly economic and partly technological. For example, technologies such as winter harvesting, water shed management, and integrated pest management can be adopted efficiently only by a group of small farmers working together. It is in this context that the pattern of land ownership and management becomes exceedingly important. Countries like China where land is socially owned are introducing techniques for combining social ownership with individual initiative and incentive. In the case of individually owned lands, there is need for combining individual initiative and enterprise with social or group action in fields of activity such as water management, crop protection, and post-harvest technology. Unless small farm management receives greater attention from the point of view of improving its operational efficiency and economy, it will by very difficult to improve the financial well-being of small farmers.

Table 18.6. Percent distribution of holdings by size of total area, selected locations

Location	Census year	Farm size in hectares					Total No. all farm holdings (000) [a]
		Under 1 ha	1 ha and under 2 ha	2 ha and under 5 ha (percent)	5 ha and under 10 ha	Over 10 ha	
Africa							
Ivory Coast	1974	9.4	16.4	38.0	24.9	11.3	550
Liberia	1971	52.7	23.7	16.1	3.1	4.1	122
Sierra Leone	1970	37.8	26.9	29.7	5.6	-	286
Tanzania	1971	58.1	23.1	13.5	2.1	3.2	2434
Zaire	1970	41.5	38.3	18.9	1.0	0.3	2538
N & C America							
Dominican Rep.	1971	32.1	20.0	24.9	11.1	11.9	305
El Salvador	1971	41.8	18.6	13.5	5.0	6.2	318
Honduras	1974	17.5	20.0	26.7	14.4	21.4	195
Mexico	1970	25.0	11.1	15.1	10.0	30.3	1020
United States	1969	2.6	1.4	3.3	5.8	86.9	2730
South America							
Brazil	1970	8.1	10.0	18.6	14.6	48.7	4906 [b]
Colombia	1970	22.8	15.1	21.6	13.6	26.9	1177
Ecuador	1974	26.0	16.0	22.7	10.6	22.6	519
Peru	1972	34.8	18.8	24.4	11.0	11.0	1391
Venezuela	1971	4.5	11.5	26.4	17.0	39.2	288
Asia							
Bangladesh [c]	1978	73.1	7.9	5.2	2.4	-	15315
Burma [d]	1979	-	61.4	24.1	11.8	2.7	4270
India	1976	54.5	18.1	17.8	6.6	3.0	81569
Indonesia	1973	70.4	18.1	9.4	1.5	0.6	14375
Iran	1960	26.2	13.7	25.3	18.1	16.7	1877
Iraq	1971	11.3	11.2	18.1	21.5	29.1	591
Japan	1970	68.0	24.0	6.5	1.3	0.2	5354
Korea, South	1970	66.1	26.4	6.7	-	-	2421
Nepal	1971	76.8	11.1	8.5	2.1	0.7	1722
Malaysia, W.	1960	45.3	22.1	25.5	6.0	1.1	450
Pakistan	1971	13.8	14.3	39.9	21.1	10.9	3762
Philippines	1971	13.6	27.4	43.8	10.4	4.8	2354
Sri Lanka	1973	70.6	16.9	9.9	1.3	0.7	1645 [e]
Thailand [f]	1963	18.5	29.4	27.5	19.2	5.4	3214
Europe							
Italy	1970	31.9	18.9	24.6	13.0	11.2	3607
Hungary	1972	85.9	6.0	2.5	0.4	0.3	803
Oceania							
Australia	1970	0.4	1.2	6.0	5.2	87.2	250

a Percentage total may not add up to 100; excludes holdings without land
b Excludes 18, 377 holdings not reported
c Size categories are: (in ha) under 1.2; 1.2 under 2.02 under 4.05 and over 4.05
d Size categories are: (in ha) under 2.02; 2.02 under 4.05; 4.05 under 8.09 and over 8.09
e Excludes 2,012 holdings not reported

f. Size categories are: (in ha) under 0.96; 0.96 under 2.4; 2.4 under 4.8; 4.8 under 9.6; and over 9.6
Sources: General source: FAO 1970 World Census of Agriculture, Analysis and International Comparison of the Results, (Rome, 1981). For Bangladesh: Bangladesh Bureau of Statistics, The Yearbook of Agricultural Statistics of Bangladesh 1979–80, (Dacca, 1980).
For Burma: Report to the Pyithu Hluttaw on the Financial Economic and Social Condition of the Union of Burma for 1981/82, Ministry of Planning and Finance, 1982.
For India: Directorate of Economics and Statistics, Ministry of Agriculture, Indian Agriculture in Brief 1982 (New Delhi 1982).
For Iran, Malaysia, W. and Thailand: FAO Report on 1960 World Census of Agriculture (Rome, 1968).

Table 18.7. Average yields of rough rice (paddy) grown under irrigated and rainfed conditions, selected locations in Asia

Location	Year	Irrigated (mt/ha)	Rainfed (mt/ha)	Total Yield[a] irrigated	Percent rice area (%)
Bangladesh	1981/82	3.63	1.56	1.96	12
Burma	1976/77	3.50	1.50	1.90	9
Philippines	1981/82	2.95	1.91	2.36	49
Sri Lanka	1975/76	1.00	0.70	0.85	57
Thailand	1974/75	2.52	1.61	1.86	27

[a]/Includes yield of upland rice.

Sources:
Bangladesh: R.W. Herdt and C. Capule. Adoption, Spread and Production Impact of Modern Rice Varieties in Asia (IRRI, 1983).
Burma: R.W. Herdt and R.H. Bernsten. Rice Production and Research Development in Asia. IRRI Ag. Economics Department Paper 80–18, 1980.
For total area and total yield – USDA Foreign Agriculture Circular, Grains FG 22–82, September 1982.
For total rice area irrigated – Burma Settlement and Land Records Department (unpublished mimeo).
Philippines: Bureau of Agricultural Economics. Palay yield per hectare by crop type and variety by region, Philippines, 1982 (unpublished mimeo).
Sri Lanka: Department of Census and Statistics. Paddy Statistics, Extent Sown and Harvested and Average Yield Maha 1975/76 and Yala 1976 (unpublished mimeo, 1976).
Thailand: Royal Irrigation Department, Ministry of Agriculture and Co-operation, Bangkok, 1975 (unpublished mimeo).

Generating more opportunities for on-farm and off-farm employment

The other area which requires attention is the enhancement of the employment potential of agriculture. A majority of people in developing countries depend on land and water-based occupations such as agriculture, animal husbandry, fisheries, and forestry for their living. Human labor is still the most important component of labor in many developing countries. Here again studies have shown that modern varieties will enable more labor to be used. This is particularly so in areas characterized by multiple cropping. A proper assessment of the employment impact of new technology should be done and it should be ensured that labor diversification and not labor displacement occurs following the introduction of new technology. Particular attention

should be given to new technologies for women-specific occupations being subjected to an employment impact analysis prior to their introduction. Examples of new technologies which are labor intensive are:
(a) hybrid rice in India;
(b) hybrid cotton produced from hand emasculated and pollinated seeds in India;
(c) cultivation of potato from sexual seeds.

Also mixed farming techniques involving crop-livestock integration and aquaculture and agriculture techniques should be promoted. There are considerable opportunities for 3-dimensional crop planning involving the optimum use of cubic volumes of air and soil. Post-harvest technology and biomass utilization are areas which can provide considerable opportunities for the preparation of value-added products from every part of both plants and animals.

If during 1984, about 1,780 million tons of cereal grains were produced, the same cereal plants produced another 3,500 million tons of other plant parts. What are we doing to improve the utilization of this biomass? Advances in chemical engineering and technology have helped in standardizing methods which could provide value-added products from every part of a plant or animal. I would like to illustrate this by citing a few of the possibilities now open for the better utilization of rice biomass.

1. *Rice straw* – as a source of manure for soil incorporation, a substrate for mushroom culture, a source of balanced animal nutrition for stall-fed animals (rice straw can be subjected to alkali digestion and enriched with urea and molasses), a source for the generation of biogas and composting, and as a cellulosic raw material for paper manufacture.
2. *Rice bran* – extraction of edible rice bran oil for human use, use of bran oil in the manufacture of soaps and other products, use of deoiled rice bran for poultry feed, and fortification of deoiled rice bran to impove animal nutrition.
3. *Rice hull or husk* – as energy for grain drying and charcoal production, for animal feed after appropriate fortification, use of rice hull ash for soil incorporation and hollow building blocks, and as a source of solar grade silicon for use in the manufacture of photovoltaic systems.

Similar analysis can be made in the case of all crops and animals. An optimum blend of production and post-harvest technologies could help to improve rural income.

Improving nutrition

Recent research indicates that malnutrition and poverty are positively correlated. In several countries, the nutrition problem can be stated more aptly in terms of person-years of employment or units of purchasing power rather than in tons of grain. The job famine seems to pose a greater threat to the nutrition status of poor families than the scarcity of food in the market.

Several medical problems have their roots in nutritional deficiencies or imbalances. Xerophthalmia caused by Vitamin A deficiency is estimated to cause blindness in a quarter of a million children every year. Goiter arising from a shortage of iodine

in the diet is believed to affect about 200 million people. In an FAO analysis made in 9 countries anaemia predominantly caused by iron deficiency has been found to affect 42% of children under 5. The problem of nutrition has thus many facets – socio-economic, medical, as well as strictly nutritional. Hence, the precise action plans designed to eliminate malnutrition will have to be tailored to suit the situation prevailing in each country and in large countries, within regions of each country.

Compounding these problems is the current economic situation in the world. The poorest nations which depend largely on agricultural export earnings to balance their trade budget are facing serious problems arising from a steep fall in the prices of the commodities they export, together with a steep escalation in the prices of the goods and fuel they import. Small farmers are unable to escape the poverty trap in which they are caught by low productivity and high input cost. Increased production and trade which are vital for world food security are both being adversely affected.

In countries where a cereal is the staple, malnutrition can be more accurately described as undernutrition or calorie deprivation. Under-nutrition may frequently be combined with infection and parasitic diseases that reduce the capacity of the body to utilize effectively the energy and nutrients of whatever food may be consumed. Basically, this condition, referred to as protein-energy malnutrition, is most widely prevalent in children belonging to the economically handicapped sections of the population. The poor suffer not only from inadequate intake of food but also from lack of access to clean drinking water and from unhygienic living conditions. Their children often take food containing mycotoxins and suffer from liver damage. Thus, they are doubly hit. Provision of clean drinking water is unfortunately not given the priority it deserves.

Another serious problem faced by the poor is the need for children to start working for low wages early in their life. In fact, in many developing countries, childhood is a luxury the poor can ill afford. Household responsibilities come early causing a set-back to the child's educational career. Programs intended to improve the nutrition of this section of the population should simultaneously have an integrated mix of health, nutrition, and education aspects. Unfortunately, the responsibility for these programs tends to get divided among different government departments and hence, integrated child care services exist more in rhetoric than in reality.

An often neglected problem in the area of nutrition and development relates to sex differences in the incidence of malnutrition. In many poor countries the female child tends to get less attention from the nutritional and educational angle than the male child. This results in some cases in a decline in the proportion of females in the population, as in parts of India. Rural women also tend to be overworked, a phenomenon referred to as "double day." They are often employed in low-paid or unpaid activity like fetching fuel, fodder, and water. The mean participation sex-ratio (1000 x F/M) of women in economic activity is also frequently low. Thus, only a systems approach to the problems of nutrition and development can result in meaningful programs which will become self-replicating in their impact.

Solutions to the problems arising from malnutrition have to be developed both from a short-term and a long-term perspective. There have been many short-term solutions such as the World Food Programme at the global level and the Food for Work,

Mid-Day Meals and similar programs at the national level. An integrated strategy involving an appropriate blend of free supply of food to needy pre school children, pregnant and nursing mothers and old and infirm persons and a Food for Work Program for all able-bodied persons can insulate the poor from hunger in the short term. The world has the capacity to initiate such a programme immediately if there is the political will to do so. To banish hunger and malnutrition in the world and in that process accelerate national development, about 100 million tons of food grains will be needed for launching a global "Food for Development 'Program," i.e. one third of the 1984 grain reserves in the world.

In the long term, only accelerated economic development based on sustainable patterns of growth and relevant education can eliminate malnutrition, for even if there is sufficient economic growth there could still be malnutrition arising from ignorance or poor environmental hygiene. This is where education and particularly the mass media can play a key role in stimulating appropriate government and people's action. For the children of the poor, there is an economic stake for the family in not sending the child to school. We should reverse the situation and create an economic stake in sending the child to school. Many innovative approaches of this kind will be needed for developing effective nutrition policies.

Land use planning

Above all, there is need for adding a nutritional dimension to land use planning in every country. Today, land use is predominantly based on considerations of economics and in the case of small farms on home needs. We should work for the addition of ecological and nutritional dimensions to land and water use planning. Simple botanical remedies such as small kitchen gardens can help to overcome the nutritional maladies of the people living in a village. Inter-cropping of cereals and legumes could provide ingredients for home-made weaning foods and help to achieve a balanced diet. A disaggregated and location-specific analysis of the nutrition problem and decentralized approaches to solving such problems can alone lead to speedy and enduring progress.

GREEN REVOLUTION BALANCE SHEET AND SUSTAINABLE AGRICULTURAL DEVELOPMENT

The green revolution era began in several developing countries of Asia and Latin America in the late 1960s. The term has been used to denote accelerated progress in the production of cereals, partcularly wheat and rice. It will be useful to look back and construct a balance sheet.

Benefits

The first important benefit of the Green Revolution particularly in rice and wheat has been the generation of self-confidence among farmers, extension workers, scientists, and political leaders in their ability to bring about rapid improvements in food production. Since self-confidence is a basic requisite for success in any area of human endeavor, this is a great gain.

Second, the spread of new technologies in the countryside leads to a demand for inputs and infrastructure such as rural roads, power supply, marketing arrangements, and assured irrigation that political priority for the farm sector gets increased.

Third, farmers and farming gained greater social prestige and recognition. Before the advent of new technologies, agriculture, particularly the cultivation of food crops, was regarded as a profession which requires only brawn and no brain. Therefore, the educated and intellectual classes did not prefer farming as a profession but sought jobs in urban areas. Similarly, agricultural colleges and universities did not attract the brighter students, who tended to prefer other fields of studies like medicine, engineering, commerce, etc. From the seventies, this position is changing in many developing countries since many young students find scientific agriculture and rural professions not only remunerative but also intellectually satisfying. The art and science of farm management are getting integrated. Farmers' associations and unions are becoming increasingly articulate and are able to get their views heard by political and administrative authorities.

Fourth, agrarian reform started attracting serious attention. New technologies made land-based occupations attractive and therefore the pressure on political leaders for equitable land rights and laws have increased.

Fifth, rural development starts receiving serious attention since when agriculture moves from a subsistence level to a market-orientated one, rural communication, rural electrification and other areas of rural infrastructure development become an economic and social necessity.

Sixth, in the countries of South and Southeast Asia where the Green Revolution Technology took roots and started making an impact, production increased largely through improved productivity. In many rice growing developing countries, land and not labor is the most serious constraint. Land is also constantly required for nonagricultural uses and is hence a shrinking resource for agriculture. Therefore, the only pathway open to many developing countries for improving food production is higher productivity and cropping intensity. Before the introduction of high yield technology, production gains in many countries came largely through area expansion, which was one of the factors responsible for forest denudation. Productivity improvement in recent years has led to a considerable saving in the land required for producing food for the growing populations.

Seventh, the Malthusian prediction on famines arising from an adverse relationship between population growth and food production has so far not come true in most parts of Asia and Latin America. The situation is different, however, in countries of Sub-Saharan Africa (Figure 18.1). The Green Revolution Technology thus has provided the breathing spell necessary for national policies to have an impact on adjust-

Figure 18.1. Trends in per capita food production in Asia, Latin America, and Sub-Saharan Africa, 1961–65 average and 1965–1983. Source: FAO

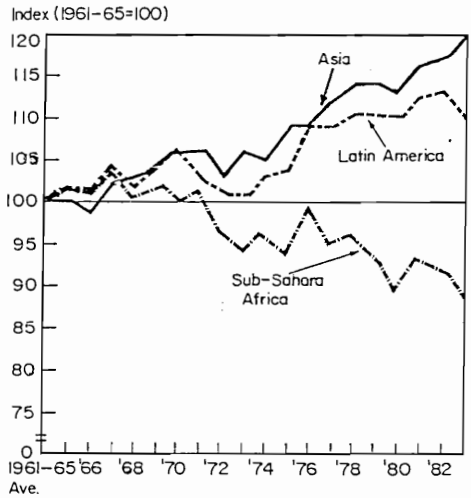
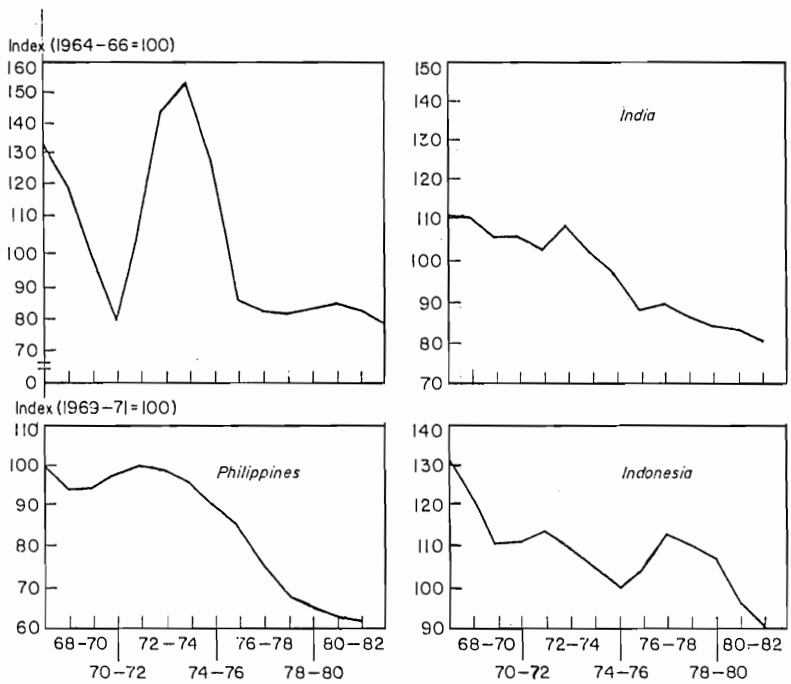


Figure 18.2. Trends in real world rice price and in rice price to consumers in selected, formerly rice importing countries.



ing population growth to the resource potential of each country.

Finally, an important outcome of the rate of increase in food production keeping above population growth rates has been a relative stability and even decline in the price of important food grains such as rice (Figure 18.2). This has enabled the economically handicapped sections of the population to improve their calorie intake, thereby preventing a further growth in the number of undernourished people.

Concerns

While the above represent some of the important benefits from the high yield technology developed and introduced jointly by international and national research systems since 1960, we cannot overlook the fact that some serious doubts and concerns have been expressed about the sustainability of this pathway of agricultural advance. The major goal of agricultural research is to work for improving the productivity, profitability, stability, and sustainability of the major farming systems of each country. Therefore, the concerns expressed since the early 1970s on the sustainability of the production techniques associated with the green revolution need careful consideration. These concerns can be grouped into the following five major categories:

Economics

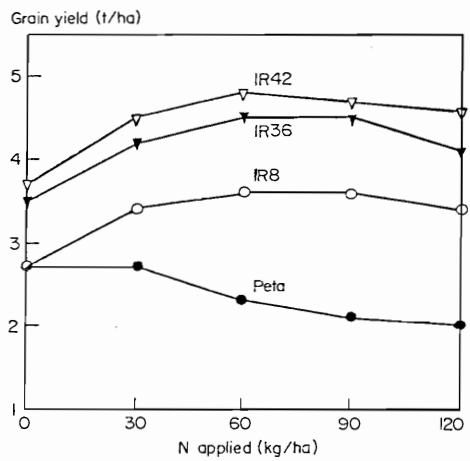
The first among them is *economic factors*. The cost, risk, and return structure of agriculture influences greatly land and water use planning, varietal choice, and input application levels for small farmers. In most developing countries, effective crop insurance schemes do not exist. If crops are damaged by natural calamities like typhoons, cyclones, floods, and drought or by pest epidemics, financial institutions and governments may agree to the rescheduling of debts and waiving of interest. They are not in a position to write off the debt. Therefore in disaster-and risk-prone areas, farmers will choose not to apply purchased inputs as far as possible. Following the escalation in the cost of fossil fuels in the early 1970s, inputs like fertilizers and pesticides having petroleum products as feed stocks became more expensive. While the input prices went up, the output prices did not register a commensurate rise. The terms of trade became adverse in many countries with farmers paying more for the goods they buy and getting less for the products they sell. Therefore, the ratio between input and output prices became a major determinant in the level of nutrient supply to crops and consequently of yield.

Though it is true that high yielding varieties of rice and wheat can express their full yield potential only under conditions of adequate nutrient supply and soil and plant health care, the view that they can perform better than the earlier tall varieties only if they are given large qualities of fertilizer is not correct. In fact, the new high yielding strains give more yield than the earlier tall varieties of rice at all levels of nutrient supply (Figure 18.3). The reason for this is their ability to partition more of the dry matter for grain and less to straw and other parts of the plant. In other words, if a tall variety and a semidwarf variety both make 10 tons of dry matter under similar soil fertility conditions, the tall strain may give 2 to 3 tons of grains and 7-8 tons of the remaining plant parts. On the other hand, semidwarf high yielding varieties may give

4-5 tons of grain and 5-6 tons of other plant parts. The other reason why carefully tested and selected high yielding varieties perform better than traditional varieties under many situations is the broad spectrum of resistance to pests and diseases and soil stresses possessed by the new strains (Table 18.8). Therefore, under resource-scarce conditions, what is important is the identification and popularization of varieties which can give maximum yields with the available resources. Before the advent of high yielding varieties, land and water use patterns were largely based on the needs of both the farmer's family and the immediate neighborhood. However, when production and productivity increased, farmers had surplus produce for the market. Under such conditions, farmers' decisions on investment on inputs are influenced by the market environment. Government policies in input and output pricing then become crucial to sustaining the interest of farmers in improved technologies. Farmers' decisions on technology choice and adoption will always be based on the net return per hectare as well as security of that return and not by gross yield per hectare.

Figure 18.3. Grain yield response of 4 rices to different levels of nitrogen. Data are average for IRRI and three experiment stations of the Bureau of Plant Industry (Maligaya, Bicol, and Visayas) 1976–1984 wet seasons.

Data source: IRRI (Agronomy Department)



Equity

The second group of concerns relates to *equity issues*. Some of the issues involved are the relative benefits derived by small and large farmers, the fate of landless labor, and the impact of new technologies on the income and well-being of women. It is now widely recognized that new technologies by themselves tend to be scale neutral, i.e., all farmers irrespective of the size of their holding can derive economic benefit from them provided they have access to the needed inputs. However, high yield technologies are not resource neutral. In other words, more inputs are required for higher ouput. A certain degree of resource neutrality can be introduced by substituting non-monetary inputs for purchased inputs. There is however a limit to which such

Table 18.8. Elite breeding lines with superior grain quality and multiple disease and insect resistance

Breeding line	Growth duration (days)	Amylose content (%)	Reaction to							
			BL	BB	RTV	GSV	GLH	BPH biotypes		
								1	2	3
IR21820–154–3–2–2	130	23	MS	R	R	R	R	R	R	S
IR31802–48–2–2–2	107	22	MR	R	R	R	R	R	R	R
IR31851–63–1–2–3–2	108	22	R	R	R	R	R	R	R	R
IR31868–64–2–3–3–3	110	22	R	R	R	R	R	R	R	S
IR32429–47–3–2–2	105	23	R	R	R	R	R	R	R	R
IR28228–12–3–1–1–2	135	24	MR	R	R	R	R	R	R	R
IR28150–84–3–3–2	135	23	MS	R	R	R	R	R	R	R

BL = blast; BB = bacterial blight; RTV = tungro virus; GSV = grassy stunt virus; GLH = green leafhopper; BPH = brown planthopper.

a substitution is possible particularly when a vertical growth in productivity is the only available method for increasing production. Therefore, government policies rather than scientific work will have to provide the tools for enabling all farmers irrespective of the size of their holding, input purchasing and risk-taking capacity, and social status to derive economic benefit from new technologies. Similarly, the adverse impact of modern technology on rural women can be avoided through a careful study of the potential consequences of new technologies for women and men before they are widely popularized.

Employment

The third group of concerns relates to the impact of new technology on *employment.* Developing countries with large rural populations have already serious problems of unemployment and underemployment. This is reflected in the unplanned migration of rural poor to towns and cities seeking opportunities to earn their daily bread. Therefore, technologies which reduce labor use will have to be concurrently accompanied by the creation of alternative avenues of employment. Unless job elimination and job creation are concurrent events, considerable human hardship can be the outcome from the adoption of technologies which substitute capital and machines for human labor. In several countries of Asia, undernutrition or calorie inadequacy is the major nutritional problem. This in turn tends to be more related to inadequate purchasing power rather than to the lack of an adequate supply of food in the market. Hence, an employment revolution is important for families without assets in the form of either land or livestock to derive economic and nutritional benefit from the green revolution. New technologies should hence be subjected to an employment impact analysis before they are recommended for large scale adoption.

Energy

The fourth group of issues relate to the *energy requirements* of the green revolution technology. If the pathway of productivity advance chosen requires increasing consumption of non-renewable forms of energy, the technology will become self-defeating in the long run since a finite source of energy can not be exploited in an exponential manner. The question hence arises as to how far renewable sources of energy can provide substitutes for fossil fuel-based energy.

Ecology

The final group of factors which are causing concern relate to the *ecological impact* of new technology. These cover areas like the erosion and loss of plant genetic resources, vulnerability to pests and disease epidemics arising from genetic homogeneity, destruction of soil fertility and soil erosion, and pollution caused by the use of toxic chemicals and high doses of fertilizers. It is possible today to integrate considerations of ecology, economics, employment generation, energy conservation, and social equity in technology development and transfer. This will however call for a systems approach in the organization of research and extension programmes.

We thus have now the technical capability to build enduring national and global nutrition security systems based on sound scientific principles where the short and long term goals of development are in harmony with each other. What we often lack is the requisite blend of political will, professional skill, and farmers' participation. We live in this world as guests of green plants and of the farmers who cultivate them.

If farmers are helped to produce more, agriculture will not go wrong. If agriculture goes right, everything else will have a chance for success.

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Recent times have borne witness to unprecedented problems of food supply and nutrition in both qualitative and quantitative terms.

It is therefore surprising to learn that the global food scenario reveals uncomfortable gluts of food grains and animal products in certain countries, and that the global surplus of food stocks reached nearly 300,000,000 tons by the end of 1985. The problems in the area of food scarcity and deprivation are both of a distributive and productive nature. Despite massive international aid, distribution remains a major problem both in terms of international transfers of food and agricultural know-how and primary resources, and also within the still inadequate economic systems of certain developing countries. Production of adequate food supplies in many developing countries is also a major problem, due to a lack of primary resources such as good land and fertilizers, lack of irrigation and many external environmental stresses and factors.

This book proposes that the world's nutrition, and especially the balance between areas of glut and areas of scarcity, could be resolved by the end of this century. The different chapters provide information relevant to an international agricultural system based on principles of ecology, efficiency and equity.

Global Aspects of Food Production does not paint the dismal picture so characteristic of much writing about the global food situation, but instead a picture of hope which approaches the solution to food scarcity and deprivation with an optimism born of the authors' deep understanding of the underlying causes of dislocations in the food production and distribution chain. Theirs is no pollyanna perspective, but a reasoned, documented approach leading to recommendations that, if followed, would ensure adequate food supplies to all countries by the end of this century.

There is no similar book that brings together comprehensive information on all aspects of global food production, and one which enlarges the concept of food security so as to promote the growth of national, regional and international nutrition security systems.

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