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SOILS AND WORLD FOOD SUPPLIES[1/]

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INTRODUCTION

It is most appropriate that this international society focus today on soils in relation to the world food supplies. Throughout history, great civilizations have invariably had good soils as one of their chief attributes. The ancient dynasties of Egypt depended on the food-producing capacity of the irrigated fertile soils of the Nile River valley. Likewise, the alluvial soils of the Tigris and Euphrates rivers in Mesopotamia, and of the Indus, Yangtze, and Hwang Ho rivers in India and China were the foundations for flourishing civilizations.

As agriculture continued to progress following these early civilizations, native soil productivity was enhanced by the use of manures and leguminous crop residues, and finally by the application of chemical fertilizers and lime. Differences in soil productivity were narrowed by these practices. Even so, however, the major food-producing areas of the world today are still characterized by naturally productive soils.

POPULATION EXPANSION AND WORLD FOOD SUPPLIES

The significance of soils and their management to world food supplies has never been greater than it is today. In our generation the world has witnessed an unprecedented growth in human population. This, in turn, has forced equally unprecedented attention to meeting the food, fuel and other needs of an expanding population without permitting the deterioration of soils and other natural resources.

The magnitude of the food production problems is seen in population growth statistics. Each year worldwide, there are about 89 million more mouths to feed. Furthermore, six out of seven of these are in the develop-countries, most of which are already pressed to produce enough food to meet today's needs. Projections for the future are of even more concern. The developing countries whose combined population was about 3.6 billion in 1980

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are expected to have nearly 5 billion by the year 2000 (World Bank, 1984b). This will likely rise to between 7 and 8.5 billion by 2050 when 85 percent of the world's population will be living in what are now considered developing countries. While the absolute increases are largest in Asia, the rates of increase are highest in Africa.

These statistics are indeed sobering. They represent a challenge to all who are concerned with the world's capacity to feed itself. They also tell us that we must conserve and wisely manage our soils and other natural resources on which the world's food-producing capacity is largely dependent.

THIRD WORLD PERFORMANCE

As population pressures began to mount in the 1960s, massive starvation and economic chaos in much of the developing world was predicted (Paddock, 1967, and Erlich, 1971). However, unprecedented food-production increases, especially in the developing countries, have refuted these false prophets (Figure 1). Third World agricultural output increased at an historical rate of nearly three percent in the 1960s and 1970s. Three specific examples of remarkable production increases can be seen in India which tripled its wheat production in 10 years; and Colombia which doubled its rice production in 5 years (Brady, 1983).

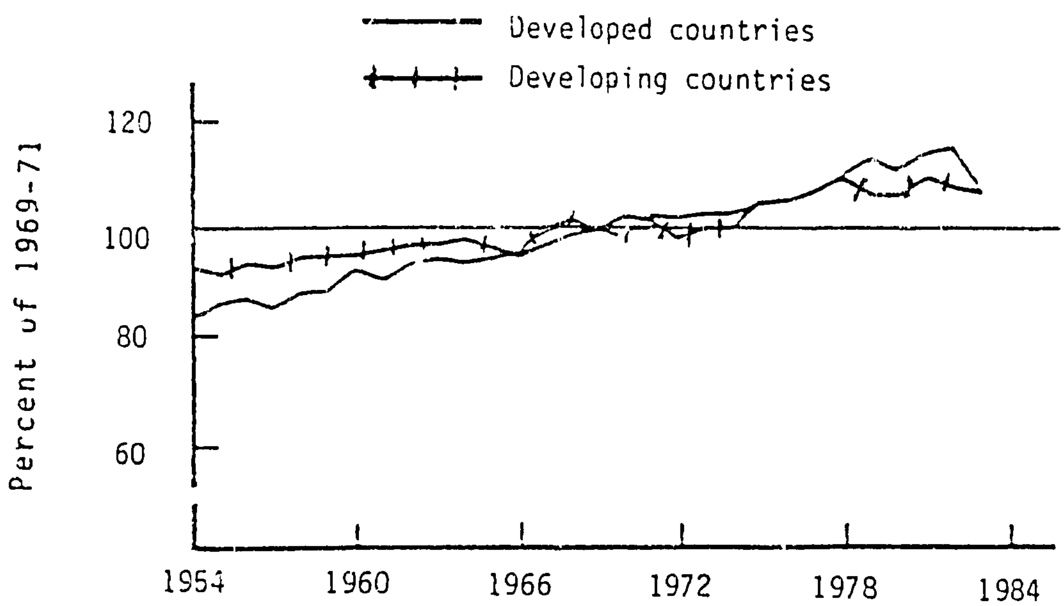

Figure 1. Per capita food production in developing countries from 1954 to 1984. (Kellogg, 1985).

These remarkable rates of increase in agricultural production have even slightly exceeded worldwide population growth rates. As a result, overall per-capita food output increased about 0.3 percent per year in the 1960s and 1970s. (Figure 1). Most of this increase took place in the developing countries. Unfortunately, however, the progress has not been even from one region to another. (Figure 2). Per capita food production in Asia and Latin America increased slightly in the 1960s and 1970s. But this was not the case for Africa south of the Sahara. Per-capita food production there actually decreased some 20 percent from 1960 to 1983.

While the widespread drought of the past 2 years have intensified the problem and called it to the attention of the world, the underlying causes, including soil deterioration, are yet to be fully addressed. In ascertaining these causes, we must determine what steps the countries in Asia and Latin America took to increase their food production. Certainly, their creation and adoption of high yielding agricultural technologies (e.g., new cereal varieties) was one step. They made available production inputs such as water, fertilizers, credit,etc. And they developed and trained human resources at all levels in the production system. Non-technical factors were

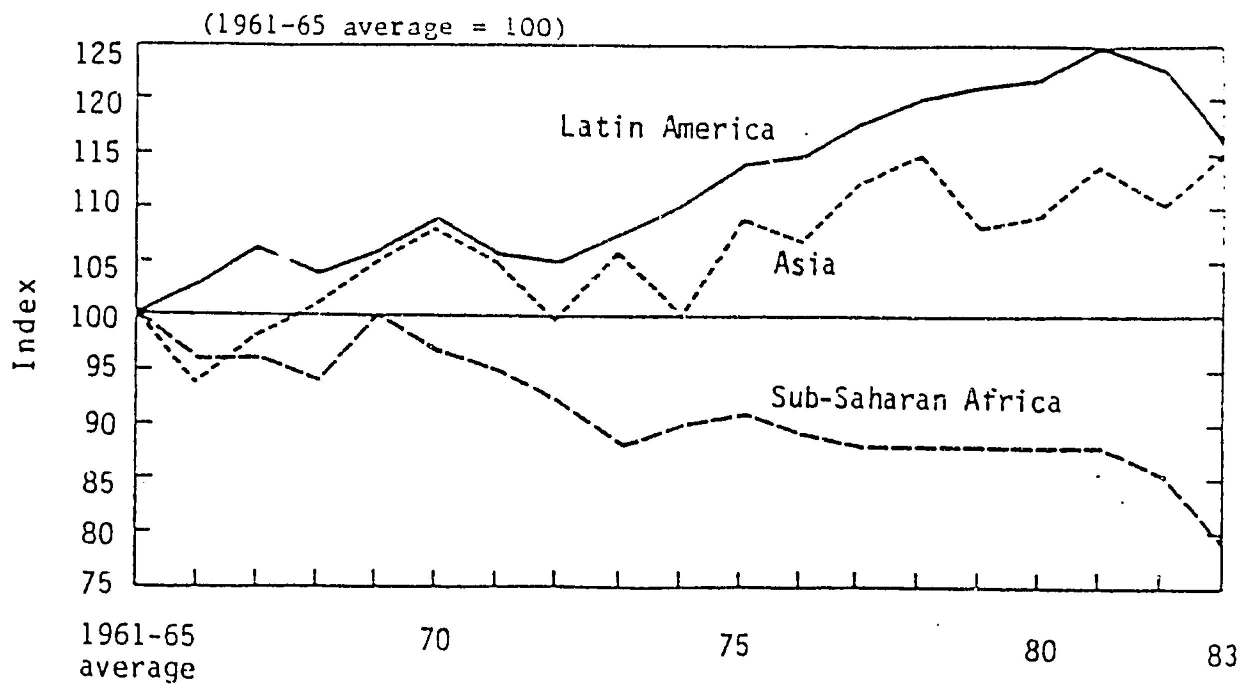

Figure 2. Per capita food production in Latin America, Asia, and Sub-Saharan Africa, 1961-65 to 1983. (U.S. Department of Agriculture data from World Bank, 1984a).

also critical. For example, they implemented prudent government price policies which made it profitable for the farmer to accept the new technologies and to use the appropriate inputs. All of these factors must be examined by the Africans if they are to increase their food production.

As impressive as have been the developing country performances in increasing their food production, it is obvious that even more impressive performances must be made in the years ahead. The additional food needed in the next 25 years will come from three primary sources:

- Expansion of land under cultivation;
- Increased yields per hectare on land now being farmed; and
- Increased cropping intensities on land now being farmed.

Each of these sources have contributed to past successes and each will likewise contribute in the future. Soil scientists have critical roles to play in enhancing the output from each resource.

WORLDWIDE LAND AND SOIL RESOURCES

There is a total of more than 13 billion hectares of land on the major continents, but most is not suited for crop cultivation (PSAC, 1967). In fact, about half is completely nonarable because it is mountainous, too cold or too steep for tillage; it may be swampland or it is desert and too dry for food and fiber producing plants. Some 25 percent of the land area supports sufficient vegetation to provide grazing for animals, but cannot be cultivated. This leaves only about one-fourth of the land with the physical potential for crop production (FAO, 1981). And only about 40 percent (1.4 billion hectares) of this potentially arable land is actually under cultivation (World Bank, 1984a).

In Asia and Europe, where population pressures have been strong for years, most of the arable land is already being used to produce crops. In the other continents, however, there are large areas of potentially arable land. In fact, in tropical and subtropical Africa and Latin America only a fraction of the potentially arable land is cultivated. This has led some to suggest that the alleviation of food deficits on these continents can be achieved easily merely by clearing more land for agriculture. This had not already been done, however, and for some very good reasons.

Factors Influencing Expansion of Cultivated Land

Several factors are known to limit future expansion of agricultural land in Africa and Latin America. First, these untilled lands are generally not located where population pressures are greatest. The Amazon basin in South America is such an example. Likewise, in Africa much of the potentially arable land not now being tilled is in 11 countries in Central Africa where population densities are not very high, and where rainfall is plentiful (FAO, 1980). In 14 other African countries, however, the land area is insufficient to fully sustain the existing population, and as a consequence, the land is being overused or abused. Most other African countries have barely enough land to support their populations (OTA, 1984).

Some have argued for migration from areas with land scarcity to underused areas, such as occurred when Europeans moved to the Western Hemisphere in the 19th Century. However, such a solution would almost certainly lead to serious civil strife.

Secondly, expansion of arable land requires major investments of scarce capital to clear forests, provide the necessary infrastructure (roads,etc.) and to purchase and distribute fertilizers and lime needed to produce food crops on virgin farmland. Unfortunately, these high costs would make such land clearing economically unsound.

Third, there are serious non-monetary costs associated with the conversion of forested areas to cropland. Ecological and other problems can arise with the destruction of the primary forest cover including renewable fuelwood resources. We are reminded that land clearing for agriculture can place serious constraints on the one-third of humanity for whom trees are the primary source of cooking fuel. Also, clearing tropical forests can have adverse effects on biological diversity. The debilitating effects of land expansion and development on natural resources cannot be overlooked. Soil scientists are keenly aware that uncultivated lands are indeed not idle, but are playing an active role in the long-term development of a country.

Fourth, soil erosion is a decided hazard to agricultural lands worldwide and especially to overgrazed dryland areas and to humid tropical areas subject to torrential rainfall during at least part of each year. If the land is being cropped and has little surface cover, severe erosion can result. Western style large-scale land clearing, especially in areas with significant slopes, can be disastrous. Even in subhumid and semi-arid areas sporadic heavy rainfall striking unprotected soil surfaces causes serious erosion problems.

Fifth, the prevalence of human and animal diseases contrains agricultural practices in some areas (World Bank, 1984a). For example, the prevalence of river blindness (onchocerciasis) had made some fertile river valleys in West Africa almost uninhabitable. Likewise, sleeping sickness (trypanosomiasis) which affects both humans and animals has rendered nearly half of the land in Sub-Saharan Africa essentially unsuitable for cattle production. This limits available proteins for human consumption and also restricts animal power for land cultivation.

A sixth factor is that the soil fertility of much of the cleared land in the tropics is not high. In Africa and Latin America the largest uncleared areas are in the humid tropics. Under this climatic setting the soils are commonly highly leached. The existing natural vegetation often grows well. But when the land is cleared, the natural nutrient recycling system of the permanent forest cover is broken and the fertility of the soils rapidly declines. Thus, soil areas that may be quite productive under natural vegetation are quickly converted into relatively infertile fields of little use to struggling low-income farmers.

These six constraints, as well as others, will likely drastically limit the expansion of land under cultivation. In fact, they would suggest that in Asia and in specific areas in Africa and Latin America, some lands currently used for agriculture should best be allowed to revert to forests and grasslands.

The limited role for expanding arable land in the future is illustrated in the study made the by Food and Agriculture Organization of the United Nations (FAO, 1981). This study indicates that only about one-fourth of the worldwide increase in food production in the next 25 years will come from an increase in arable areas. (Table 1). The remainder will come from higher yields per hectare and increased cropping intensities. Only in Latin Amer-

Table 1. Expected contribution of three major sources of increased food production to meeting food needs by the year 2000 in four regions of the world.

Region	Contributions to output growth			
	Arable land area	Changes cropping intensity	Yields per hectare	Total
Africa	27	22	51	100
Far East	10	14	76	100
Latin America	55	14	31	100
Near East	6	25	69	100

ica and, to a lesser extent, in Africa will increased arable lands likely provide a major share of increased food production in the future.

Each of these six constraints present challenges to soil scientists. In specific situations we can help remove them, thereby assuring the orderly transfer of land from forests and natural grassland to agriculture. In other cases, we can greatly stimulate increased crop production on the more fertile, gently sloping farmlands, thereby permitting the release from agriculture of some fragile lands which should more appropriately be used for forestry or grassland.

INCREASED CROP YIELDS PER HECTARE

Food production increases in the developing countries during the last 25 years, especially in Asia, have been due primarily to increased yields per hectare. The creation and widespread adaption of new high-yielding cereal varieties, coupled with comparable expansion in irrigation and fertilizer use, was largely responsible for these yield increases. Increasing food production in Asia was accomplished almost entirely by increasing yields per unit area. The data in Table 1 suggest that most future food production increases will also likely come from this source.

There is great potential for increasing crop yields per hectare in most developing countries. Their current yields of most staple food crops are only a fraction of the average yields obtained in the more developed countries, and an even smaller fraction of the yields which are biologically possible. For example, national average rice yields in the tropics are commonly only 2 to 3 tons per hectare. This is about half the average yields being obtained in Italy, Japan, and the United States, and about one-seventh the yields known to be biologically possible. Obviously, there is great potential for increasing food crop yields in the developing countries.

Increases in the yields of food crops during the past two decades have been made mostly in areas with favored environments. Lack of water has not been a serious limiting factor either because of adequate rainfall or of irigation water. Increased rates of fertilizer application have provided the chemical elements needed for increased yields. Although remarkable yield increases have been made in these so-called favorable environments, it is likely that much of the additional food needed in the next 25 years will come from even further yield increases in these areas.

But all people in the developing countries do not live in areas with favorable environments. Many live in rainfed areas, some of which are semi-arid or arid. Others live in areas with soils deficient in nutrients or high in toxic substances such as aluminum. Such water and nutrient deficient areas are present throughout the world, but are most characteristic of large areas in Africa. These areas will need to produce an increasing portion of food requirements in the future. A green revolution must be attained for these less favored areas of the world. An increasingly significant role must be played by soil scientists in developing improved technologies for these areas.

INCREASED CROPPING INTENSITIES

The new high-yielding cereal varieties and scarce land resources have also stimulated attempts to increase cropping intensities. Varieties with short growth duration which respond to fertilizers, irrigation, and good management have made possible the production of two or even three crops per year where only one has been grown in the past. China has been especially aggressive in promoting intensive cropping systems (Guo and Lin, 1986). From 1952 to 1979 the grain cropping intensity in the thirteen southern provinces of China was increased from 1.53 crops per year to 2.03. (This was in addition to green manures). The shortage of arable land stimulated this intensification. Other countries of Asia have also made considerable progress in increasing the area of double and triple cropping and will likely continue to make such progress (See Table 2).

Further increases in cropping intensities will be determined by a number of factors. For example, the availability of short-seasoned varieties will leave time for the production of additional crops during the year. Likewise, the timely availability of animal or mechanical power will speed up harvesting and land preparation, making possible the introduction

Table 2. Cropping intensities in 90 developing countries in four regions in 1974-76 and as projected in the year 2000. (Expressed as ratio of harvested to arable land times 100). (FAO, 1981).

Year	Africa	Asia and Far East	Latin America	Near East	Total
1974-76	52	106	61	62	75
2000	65	121	71	77	85

of an additional crop into the cropping system. The development and implementation of viable minimum tillage practices coupled with the availability and use of selected herbicides will reduce the labor requirements at critical times of the year, thereby encouraging the inclusion of more crops in the farming systems.

Soil scientists have made and will continue to make significant contributions to increases in cropping intensities in the developing countries. They have developed efficient water and fertilizer management systems on which improved cropping systems depend. Also they have helped develop practical minimum tillage systems which encourage double and triple cropping, while simultaneously saving water and reducing soil erosion.

FUTURE ROLE OF SOIL SCIENTISTS IN ENHANCING FOOD PRODUCTION

Experiences of the past 25 years provide guidelines for the future. At the same time they warn us of the critical problems ahead. They support the interdisciplinary creation and adoption of improved crop cultivars, and matching soil and crop management practices. Generally they suggest that the steps taken in Asia and Latin America can now be followed vigorously in Africa. Such progress is now under way.

In the next quarter century, soil scientists must make significant contributions in many components of agricultural production. I will discuss briefly four major areas where their contributions are needed (1) soil characterization and classification, (2) soil fertility and fertilizers, (3) soil and water management, and (4) farming systems.

Soil Characterization and Classification

Most of the developing countries are located in the tropics or subtropics. All too little is known about the soils in these areas and about their management. Research on tropical soils is distressingly lacking as compared with that on temperate region soils. However, in recent years we have begun to gain more knowledge. We have learned that the variability of soils in the humid and sub-humid regions of the tropics is greater than in the arid and cooler zones. (Moorman and Greenland, 1980). Also we know that soils classified as Oxisols or Ultisols are dominant in the humid tropics. Their relative importance is thought to be greater in Latin America (82 percent) than in Africa (56 percent) or Asia (38 percent) (NAS, 1982).

We know that the chemical characteristics of soils of the tropics differ markedly from those of soils of temperate regions. The high hydrous oxide content of Oxisols is responsible for enormous phosphate-fixing capacities. As compared with temperate-region soils, they contain less organic matter and nitrogen, are more acidic, and frequently exhibit aluminum toxicity. Their low cation-exchange capacities coupled in some areas with heavy rainfall permit the loss through leaching of both macro- and micronutrients. These soils are commonly deficient in nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, copper, and other micronutrients (Sanchez and Cochrane. 1980).

Soil scientists need to obtain further information on the characteristics of these soils, and on their classification and response to management, and they need training to do so. Fifteen international fora or training workshops on soil classification and on the use and management of soils have been held (SMSS, 1985). These fora have helped identify some of the research needed to better understand soils in the tropics, and their classification and proper use. (For example see ACSAD. 1981). Such international cooperation should be encouraged.

Likewise, research is being done to make it easier to transfer agroproduction technology on the bases of soil taxonomy units (Beinroth, 1980, and Tropsoils, 1985). Such research must be pursued to ascertain the degree to which results obtained at one location are applicable at other locations around the world with similar soils. These results can be used to determine specific soil management needs in relation to the broad agro-ecological zone studies make by FAO to ascertain the crop-specific land potential of different regions (For example see FAO, 1980).

Detailed soil surveys have demonstrated significant differences between soils of the tropics and their temperate zone counterparts. For example, the soil survey of the ICRISAT Sahelian center showed the soils to be more acid and higher in aluminum than the soils in the semi-arid areas of the U.S. (West et al., 1985). Apparently these soils in the Sahel were developed under a higher rainfall regime than exists in this area at present.

Soil Fertility and Fertilizers

Observations of high biomass production by the native vegetation in the humid tropics have led some to assume that the soils are naturally fertile and would produce bumper crops. Numerous trials have proven this assumption to be incorrect. While the nutrient content of the entire tropical forest production system is high, most of the nutrients are in the above-ground biomass and not in the soil (Woodmansee, 1985). The nutrients are recycled as the forest litter is decomposed and biomass production remains high. But when the land is cleared and the forests are removed or burned, the primary "reservoir" for the nutrients (the trees) is lost. Temporary enrichment of the soil may occur and stimulate the first agricultural crops. But dry matter production by the food crops is only 25 to 50 percent of that of the natural vegetation (Ruthenberg, 1980). Consequently the nutrient "reservoir" of the system is depleted. When heavy rains come, the nutrients are quickly leached from the soil and productivity goes down.

Thus, it is easy to see why agricultural soils of the tropics are commonly less fertile than are those in the temperate region (Table 3). Furthermore, fertilizer consumption is decidely lower in the Third World than in the industrial countries. In 1982, for example, the lowest income countries (exclusive of India and China) applied an average of less than 40 kilograms of plant nutrients per hectare (World Bank, 1985). This compares to more than 110 kg/ha in the industrialized countries. In the low-income countries of Sub-Saharan Africa, an average of only 4.2 kilograms of plant nutrients per hectare was applied.

Table 3. Approximate areas of soil-related chemical constraints in acid infertile soils of tropical America (Sanchez and Cochrane, 1980).

Constraint	Millions of hectares				Totals
	Oxisols (512)	Ultisols (320)	Inceptisols (119)	Entisols (88)	(1043)
P deficiency	512	320	83	83	993
N deficiency	504	306	71	88	969
K deficiency	512	160	0	40	775
Al toxicity	409	256	18	73	756
S deficiency	512	160	0	73	745
Mg deficiency	496	224	0	7	727
Ca deficiency	504	224	0	0	728
P fixation	512	160	0	0	672
Zn deficiency	468	100	0	77	645

We need to assess the fertility requirements for high food production on soils of the tropics, especially in Africa. Fortunately a number of trials have demonstrated the general value of chemical fertilizers on these soils. A recent report of the International Fertilizer Development Center clearly demonstrates the profitability of modest applications of chemical fertilizers on African farms (IFDC, 1985). An example of the results of one test is shown in Figure 3. A network of cooperating researchers is needed to follow up on these results to clearly focus on soil areas with greatest payoff for fertilizer use.

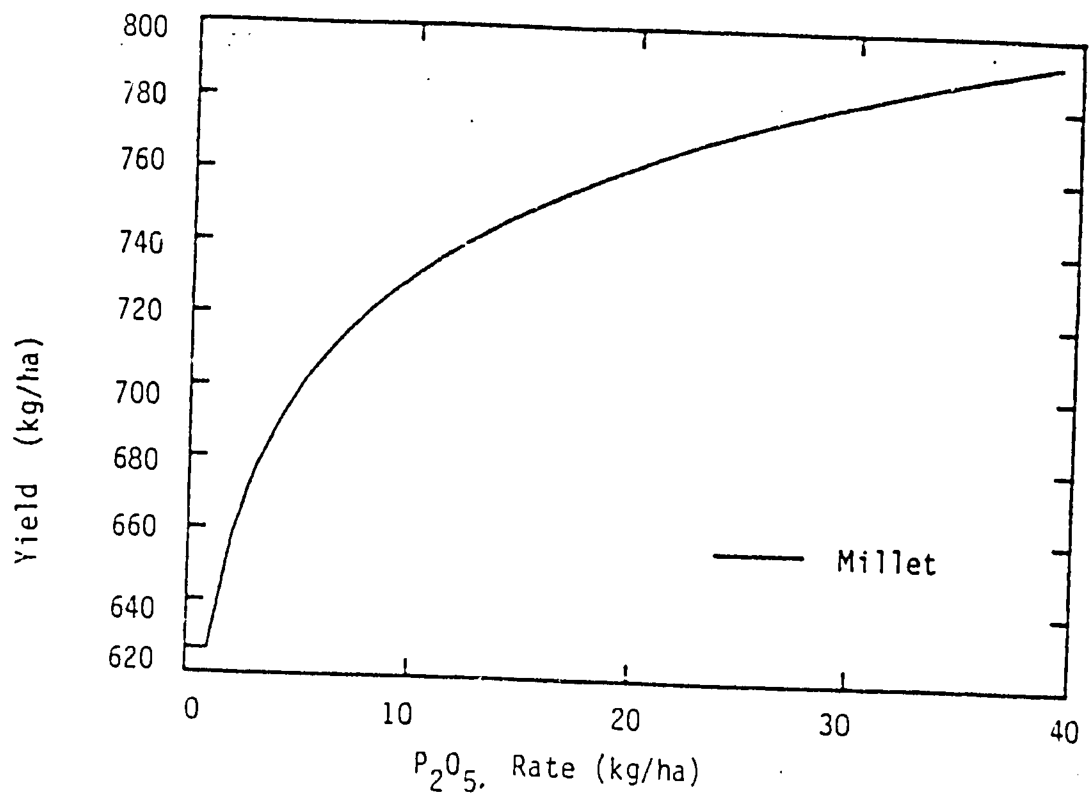

Figure 3. Response function of millet to phosphorus in semi-arid Sub-Saharan Africa. (From IFDC, 1985).

Research in Peru has also clearly shown the viability of modest fertilizer inputs in sustaining crop production (Trop. Soils, 1985, and Sanchez and Salinas, 1981). From 1972 to 1982, 21 consecutive crops (a rotation of rice, maize, soybeans) produced annually an average of 7.8 tons of grain per hectare. The unfertilized areas produced essentially no grain after the third crop. Clearly there is a role for modest lime and fertilizer applications. Soil scientists must clearly identify the conditions under which such applications are economically viable.

Initially, major attention must be given to the macronutrients: nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. As yield levels increase, however, it is expected that micronutrients will become of considerable significance. Already widespread zinc deficiencies are found in countries of Asia, Latin America, and Africa (Lopez, 1980) and less extensive areas of deficiency of other micronutrients. Soil scientists must take steps to identify the soil conditions under which micronutrient deficiencies will likely occur.

Soil fertility maintenance must also be encouraged through the judidious growth of legumes. These include food legumes such as cowpeas, beans, and the lentils as well as associated forages and cover crops. Also, intercropping with woody legumes must be encouraged. While some chemical fertilizers would be needed to ensure acceptable yields of these leguminous crops, the nitrogen they can add to the system is of considerable consequence.

Soil microbiologists must also focus on the role of mycorrhizae in food production in the tropics. These fungal organisms can help the host plant absorb essential nutrients and especially phosphorus from soils with low native supplies of these elements. (Barea and Azcon-Aguilar, 1983). Clearing the native vegetation can reduce the number of specific mycorrhizae strains (Harley and Smith, 1983) as can the use of fungicides (Menge, 1981). Consequently, innoculation may be necessary, especially for crop and wood cultivars not native to the area.

Soil and Water Management

Compared with much of Asia and Latin America, Africa is mostly a water-deficit continent. Consequently, the management of the soil, the crops and the farming system must all focus on the effective utilization of the precious rainfall. Furthermore, prudent efforts should be made to keep the water on the land, thereby reducing runoff and soil erosion. Similar concerns must prevail in the semi-arid areas of Asia and Latin America.

The water-holding capacities of the root zones of tropical soils high in Kaolinite and hydrous oxides are known to be low (Lal et al., 1983). But many of the other characteristics which would determine how these soils should be managed are not so well known. For example, the erodibility of different tropical soils is uncertain (Lal, 1984). In most areas the erodibility of the soils is inferred from research findings in the temperate areas, but little data are available on tropical soils. Likewise, all too little is known about the erosivity of climates in tropical areas.

Research has shown that attention must be given to soil and crop management practices as a primary means of both controlling soil erosion and increasing the efficiency of water use (Greenland and Lal, 1977). These practices must enhance the vegetative cover of the soil, thereby decreasing evaporation losses. Simultaneously they will increase the infiltration of the rainwater, thereby decreasing water runoff and soil erosion.

The effect of specific soil and crop management practices such as mulching, the use of cover crops and minimum tillage should be acertained. Also we need more quantitative information on the soil erosion-productivity relationships (Langdale and Lowrance, 1984). In a recent report, the World Bank identified soil moisture conservation and utilization as a priority research area (World Bank, 1984a). Such research would need to be tied into the development of new varieties, improved land use and agro-forestry systems.

Soil scientists must cooperate with plant breeders in developing and testing crop varieties which tolerate low moisture conditions. This approach has shown some promise in the development of drought tolerant varieties of food crops such as sorghum (ICRISAT, 1984) and must be pursued vigorously. Likewise, the development and testing of appropriate farming systems must also focus on means of conserving water.

Farming Systems

Soil scientists have helped develop improved farming systems for all agricultural areas in the tropics. But perhaps their greatest challenge is to develop a viable replacement for the shifting cultivation or "slash-and-burn" farming systems so common in the uplands of Africa, Latin America, and Asia. These systems involve the slashing and burning of forested or bushland areas, planting food crops for 1 to 3 years and then fallowing the land for 5 to 20 years. The farmer moves to another site where the "slash-and-burn" procedure is repeated. Some 720 million hectares of forested areas are subject to the "slash-and-burn" systems (Sanchez and Cochrane, 1980). At least 300 million poor people subsist on these systems worldwide. About 45 percent of Africans are said to be dependent on these systems.

Shifting cultivation was reasonably sound when the fallow intervals between cropping seasons were sufficiently long (5 to 20 years) to let the system recharge itself. But population pressures have made it necessary to drastically shorten this period of fallow to 3 to 8 years. The result has been lower soil productivity and increased soil erosion. Appropriate modest fertilizer use can arrest the decline in food-crop yields (NAS, 1982), but economic factors have not made it widely profitable to use chemical fertilizers in Africa.

Several research programs are under way to develop viable alternatives to the "slash-and-burn" systems. A notable example is the development of the so-called "alley cropping" system which involves the continuous cropping of food crops between rows of perennial fast-growing leguminous woody species (IITA, 1985). The latter provide ground cover to reduce soil erosion hazards. Leaf and stem prunings from the woody species are placed between the crop rows as a mulch to reduce evaporation from the soil. When these residues decay, they also provide chemical nutrients for the food crops. Tests have shown that crop yields are stabilized for a period of at least 5 years and soil erosion is markedly reduced. (Table 4).

Table 4. Effects of alley cropping and fertilizer application on the yield of maize and cowpea grown on Egbeda sandy loam (Oxic Paleustalf) (G. F. Wilson, unpublished data).

Species	Maize yield			Cowpea yield		
	No F	+F[1]	Mean (tons/ha)	No F	Res. F	Mean
Natural regrowth (control)	2.8	4.4	3.6	0.84	0.81	0.83
Acioa barterii	3.2	4.5	3.9	0.63	0.62	0.63
Gliridica sepium	4.4	5.2	4.8	0.63	0.78	0.71
Mean	3.5	4.7		0.70	0.74	

[1](+F), fertilizer applied to maize only: 60N - 60 P_2O_5 - 60 K_2O in kg/ha.

Source: IITA, 1985.

The "alley cropping" system is merely one attempt to provide an acceptable alternative to shifting cultivation. Others must be developed and evaluated on farmers' fields to be certain they are socially, as well as economically, acceptable. Soil scientists must play a key role in developing such systems.

Special attention also must be given to range management systems, especially as they adversely affect the quality of the soils. The systems now in use, coupled with drought conditions in Africa, have led to serious problems of desertification. While one may be critical of the traditional systems being used, we have yet to develop new ones that would provide sustained productivity, while at the same time preventing soil deterioration. While interdisciplinary approaches must be used, soil scientists must play a critical role.

SUMMARY AND CONCLUSIONS

Unprecedented increases in human population, particularly in the developing countries are placing a significant strain on the ability of the world to feed itself. Concomitantly, strains are being placed on the soil and the other natural resources essential to produce this additional needed food. Soil scientists have a dual role to play. They must help provide the technological systems needed to produce the additional food and they must find means of maintaining and improving soil quality while doing so.

Most of the world's future food production will come from increased yields on land now being cultivated. Furthermore, the increases will come primarily from the tropics and subtropics where most of the increases in population will occur. Unfortunately, too little is known about soils of these areas and how they might best be managed. Soil scientists have the obligation to obtain that information, and to work with scientists from other disciplines in developing sustainable food production systems.

Four major areas of current and future contributions of soil scientists are emphasized particularly as they relate to the tropics (1) enhanced characterization and classification of soils of the tropics, (2) improved means of removing nutrient deficiencies and chemical toxicities, (3) improved and sustainable soil and water management systems, and (4) improved farming systems which provide stable crop yields and minimize environmental deterioration.

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