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A FRAMEWORK OF ANALYSIS FOR AGRICULTURAL TECHNOLOGY DEVELOPMENT AND UTILIZATION IN SEMI-ARID AFRICA:

A Short-run Solution to Sub-saharan Africa's Food Security Crisis

By

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Chapter I

Introduction: The Induced Innovation Model Applied to Sub-Saharan Africa

The rapid growth rate in yields and production of rice in Southeast Asia, and rice and wheat in Central Asia followed a period of intensive public sector research on high-yielding fertilizer responsive varieties at IRRI*/ and CIMMYT **/ and, to a lesser extent, at several national research centers within the respective countries of that area. This public investment was initiated and sustained because of a relatively unique set of conditions, which Y. Hayami and V. Ruttan have modeled in their theory of induced technological and institutional development.

However, the success of the "Green Revolution", as the seed-fertilizer approach to technology generation has become known, has been limited to those aforementioned parts of Asia and has not been witnessed in rainfed sectors of Latin America, or among the producers of secondary crops in Asia, nor anywhere in Africa. Does this mean that the model which emerged is not applicable, or does it simply mean that given different values for each of its parameters, the model leads to an alternative solution? If one returns to the introductory notes of the several Hayami/Ruttan articles,1/ they state "there are multiple paths towards change in agricultural

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*/ The International Rice Research Institute in Los Banos, Philippines.

**/ The International Center for Wheat and Corn Improvement in Mexico City.

1/ Yujiro Hayami and Vernon Ruttan, 1984, "The Green Revolution: Inducement and Distribution", in The Pakistan Development Review, Vol. 23, No. 1, p. 37.

technology" generation and adoption, and that each society or region must choose that path most appropriate to their own resource and cultural endowments, and their own particular societal dynamics, such as income levels, income distribution patterns, and rates of population growth. How does one interpret this model, then, in view of the existing set of natural and human resource endowments and the current status of agriculture in Africa? Let us first briefly review the Induced Innovation Model.

The Hayami/Ruttan Model

The model shows, with empirical evidence drawn from the U.S., Japan, Europe, India and Southeast Asia,[1/] that changes which lower prices for factor endowments and increase product demand induce investments in research to develop higher yielding technologies. The research strategy which emerges is one which capitalizes on the use of a cheap input which can be substituted for that input facing inelastic supply, or, in other words, substituting an alternative cheap input when demand for a specific input with limited supply drives its price up to unacceptable levels.

The degree of effort directed towards capitalizing on these conditions is determined by the rate and magnitude of decline of the ratio of prices of the new relatively cheap input and the rate and magnitude of increase in the price of the final product in urban markets. As this ratio declines research is initiated to take advantage of the economic

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1/ Vernon Ruttan, 1985, Technical and Institutional Change in Agricultural Development: Two lectures, Bulletin No. 85-1, Economic Development Center, Minneapolis, University of Minnesota.

benefits which can be derived from "a technology compatible with market prices that reflect product demand and factor endowments of the economy".[2/]

The direction of technological change which emerges depends on the nature of the underlying factor endowments. In the U.S. during the late 19th Century and early 20th Century, research was devoted to developing innovations in mechanization for maize, wheat, and cotton, to replace labor use at a time when land was relatively extensive in supply. The mechanization technologies which emerged were labor-saving and capital-intensive. This bias arose when labor was in great demand for industrialization and was becoming extremely scarce for agricultural pursuits, given the bidding up of wage rates in urban areas.

In Japan in the early 1900's, rice varieties extremely sensitive to fertilizer were being developed because the supply of land was becoming limited, labor was relatively abundant, and fertilizer costs were low due to advances in fertilizer processing techniques. This led to the emergence of a labor-using, capital-saving technology, just the opposite of the case of the United States. Nevertheless, in the 1930s and 1940s, the U.S. also embarked on a research strategy to develop high-yielding fertilizer-responsive corn varieties to overcome land limitations which arose during that period, even though technologies were already biased towards cropping patterns using mechanized tillage practices.

2/ Yujiro Hayami and Vernon Ruttan, Op. Cit., p.-44

Although the relative price and availability of the input determines the type of bias in the direction of technology generation, this is only half of the explanation supporting these induced effects. Product demand must push the price of the commodity up significantly relative to input prices. This occurred in both the U.S. and Japan during their respective periods of technology development referred to above. Urbanization grew rapidly and the percentage of the population remaining in agriculture declined drastically as the economic transformation took place. The demand for food rose dramatically, and increases in production were required to fuel this growth. 1/.

The results of these two phenomena occurring simultaneously give rise to the process of induced technological change. Publicly funded research on new technologies is carried out according to the degree of compatibility which exists with market prices. In the U.S. a labor-saving, capital-intensive technology first arose to increase production of wheat and maize, followed in Japan by the development of a land-saving, labor-using technology for rice. This latter approach later took place for maize in the U.S.. This pattern of land-saving technology development was subsequently extended to India and Southeast Asia, as will be described in a later section, but neither of these two approaches to technology development took hold in Africa. Why not? What has been tried and what has gone awry in Africa?

1/ Explanation of the dynamics of the economic transformation can be found in John Mellor, 1966, The Economics of Agricultural Development, Ithaca, New York: Cornell University Press.

Agricultural Failure in Africa

In contrast to the heralded and noteworthy success of the "Green Revolution" in Asia, agricultural performance in Africa in the last few decades has been a relative failure. Production and productivity of export crops since independence has declined due to a degeneration of genetic material, a decrease in basic research devoted to these crops, increased frequency of droughts, inappropriate pricing and taxation policies, and institutional mismanagement. A case can be made for each and not one alone is the sole reason for agriculture's general decline and demise.

Nevertheless, the question arises as to what happened to the resources originally supporting these pursuits when those resources were withdrawn; and, to what activities have they been reallocated. Apparently, they were not assigned to the creation of a support structure for research and development of staple food crops nor for non-traditional export crops. In fact, it appears that these resources evaporated in the non-agricultural sector and were soon lost completely on account of the reduction in earnings.[1/]

While this decline evolved, some interest in food crop development remained, either lingering remnants of colonial activities or initiatives fueled by international donor projects coupled with the expanded mandates of the International Agricultural Research Centers (IARCs)[2/].

1/ Carl Eicher, 1985, "Agricultural Research for African Development: Problems and Priorities for 1985-2000", paper presented for World Bank Conference, Bellagio.

2/ Ibid. p. 17.

On the other hand, most export commodity research, the mainstay of the colonial agricultural systems, was carried out by specialized institutions, often supported by the private sector. Several of these institutions continued after independence but slowly lost support as the new governments concentrated their efforts on industrialization and the care and feeding of their urban support base. Negative pricing policies for producers of food crops and heavy taxation on exports served to reduce to insignificant levels whatever production incentives remained after the transition period. Even the well-documented and highly successful Kenya Tea Development Authority has experienced severe financial stress in recent years such that its future is questionable.[1/]

In the case of the IARCs there was an attempt to transfer technologies (seeds) from other regions of the world. Because CIMMYT (Mexican) wheat seed worked well in India, it was felt that sorghums from India could rapidly adapt to West Africa and significantly increase yields there. This decision was made for several reasons. First, the French had invested heavily in sorghum research since the thirties with litttle success.[2/] Second, wheat and rice were transferable in Asia, so there was no reason to doubt that sorghum could be transferred to Africa. Third, the scientific community directing the Consultative Group on International Agricultural Research (CGIAR) and the IARCs, felt that dramatic breakthroughs with yield increases of over 100% would be required to achieve success

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1/ Personal conversation with Dr. Carlos Zulberti, Harvard Institute for International Development, Ministry of Agriculture, Nairobi, Kenya, August 1984.

2/ Carl Eicher, Op. cit. p.

and overcome the socio-economic constraints to adoption. However, after more than a decade few if any of the imported cultivars have been able to out perform local varieties and reach acceptable productivity levels compared with their homelands in India. There is some indication that success may be on the horizon though, since a new hybrid has emerged in Sudan which is 52% higher in average yield compared with local varieties. With regard to maize, Kenya and Zimbabwe have internally developed hybrid maize seeds which perform well under varying conditions and have, as a result, generated widespread adoption, but farmer yields have failed to approximate the higher yield levels attained at the research stations.

Perhaps the one key point which is often overlooked when comparing technology generation strategies among regions is the relative fragility and heterogeneity of the African environment compared with the homogeneity of the Asian region where the "Green Revolution" took place during the last two decades. In Asia, rice and wheat grow under irrigation, where moisture regimes are regulated, and soil fertility is controlled with heavy fertilization. Access to herbicides, pesticides, seeds, and mechanization is relatively unlimited. Stable, high, market demand allows for input purchases and crop mortgaging. In contrast, the amount of irrigation in sub-Saharan Africa is negligible. Rainfall levels and frequencies are low. Rainfall in rice regimes are generally over 1000 mm per season; for sorghum and millets in Africa they can dip below 300 mm. The frequencies of droughts and the variability of rainfall patterns, both seasonally and

year to year are increasing and becoming more unpredictable as desertification advances. Soil fertility is low with old depleted soils rather than the young, rich soils of Asia. Pest and disease incidence runs much higher in Africa than it does in Asia. This increased fragility must be included in the model in terms of the base levels of factor endowments or as a conditioning variable.

In spite of the fact that improved technologies have not emerged which can be labeled "miracles", that is, ones which yield significantly more than local varieties under the stressful production conditions found in Africa, improved technologies do exist throughout Africa, which are capable of increasing local productivities and overall production rates if the right combination of inputs are applied. The question remains as to how to improve the utilization of existing technologies and how to make significant improvements on them in ways that permit their use by the African farmers.

Chapter II

Historical Perspectives on Development Strategies and Agriculture

The remarkable productivity increases in South and Southeast Asia during the last two decades grew out of a unique set of conditions, ones which fostered technological and institutional changes that led to widespread agricultural growth. The conditions which allowed for this to take place were rooted in developments of earlier periods, decades when different approaches to technology development and economic growth held reign. Each earlier period generated their own set of theories about development strategies and agricultural growth. Both social and economic circumstances influenced these models, and technological "breakthroughs" guided the direction and bias of each succeeding generation of development theorists in their quest for speeding up the development process. Agriculture has played a critical role in this economic and social growth process but the degree to which agriculture contributes to growth and in fact leads the way has often been disputed by development experts throughout the ages. This section will review the basic development models of the last century and thereby try to place the design of an appropriate model for semi-arid sub-Saharan Africa in its proper context.

Agricultural Strategies

Perhaps Ruttan[1/] has been the most focused and consistent reviewer of the history of agricultural development models in the last decade. He identifies five different approaches. In the Resource Exploitation model, the expansion of cultivated or grazed area provided the means for production increases. North and South America and Australia, in temperate ecological zones, experienced dramatic success in this endeavor during the eighteenth and nineteenth centuries.

Paraphrasing Ruttan, we find that this process has occurred throughout the world for many centuries, in Europe, Asia and Africa. Colonization of Europe north of the Alps, the Chinese push south of the Yangtze, and the Bantu spread in Africa, all were based on the exploitation of the land. Yields were low, but sustained by long fallow periods for fertility regeneration. As populations increased, annual cropping systems emerged that could transfer the agricultural surplus to feed the urban areas, extracted by landlords or the church as rents or tithes. However, this strategy does not generate a large surplus beyond local needs, and conditions in Africa today, where pest and disease infested infertile soils cannot sustain this growth model.

1/ This section draws heavily from and attempts to paraphrase Vernon Ruttan, 1982, Agricultural Research Policy, Minneapolis: University of Minnesota Press, Chap.2.

The Conservation Model recognized that resource exploitation led to degeneration of the natural resources and yields decline. Hence, a considerable amount of effort was directed towards land and soil conservation. The English introduced this approach based on the German concept of "soil exhaustion" or chemical depletion. The concept of diminishing returns to labor and capital, emerging from economics, supported this startegy. Well into the twentieth century, European agriculturalists developed intensive crop and grazing rotation systems using "new forage and green manure crops and increasing the use of animal manures". By recycling plant nutrients,
soil fertility levels were maintained and agricultural growth rates were sustained for several decades. Only when the agricultural demand reaches upwards of 3% does the conservation model fail to provide sufficient growth in supply to meet its needs. What appears strange in this context is why European colonialists reverted to the resource exploitation model in Africa when the conservation model would have been much more appropriate during the early twentieth century. Very often mixed cropping systems with grains and legumes were replaced by export oriented crops or sole stands, thereby ignoring the notion of resource fragility.

The Location model, originally formulated in Germany, tried to explain regional differences in the intensity of farming systems based on the level of labor productivity in industry and the demand for farm

output. Ruttan states that "empirical tests have repeatedly confirmed that a strong nonfarm labor market is a pre-requisite for raising labor productivity in agriculture and improved incomes for rural people". Much of the literature on the dynamics of the economic transformation and its pathological stepsister, the theory of the core and periphery, emmanate from the concepts developed by the application of this model to the U.S. in the 1950s. At that time, the Location model was used to explain the failure of the resource development and price policies of the thirties to eliminate regional disparities in rural incomes and agricultural factor productivities.

Probably the most well-known agricultural development model is the Diffusion model. Corn from South America was transferred to Europe and Africa after Columbus' Voyage and rubber in Malaysia came from Brazil via Europe. The Diffusion model served as the basis for technical assistance after World War II, when agriculturalists observed the differences between "land and labor productivities among farmers and regions". It was felt at that time, especially in the U.S., that significant improvements could be made by simply disseminating technical knowledge, and transferring improved seeds and inputs.

The Diffusion model has been the "intellectual foundation" for farm management and production economics in the early twentieth century. Rural sociology enhanced the reknown of the Diffusion model when adoption rates were correlated to educational and wealth levels and other socio-economic characteristics of farmers. In the 1950s,

better explanation for what is known as the High-Yielding, High-Input model is needed. The Hayami/Ruttan model provides this necessary framework, and will be described in detail in Chapter III.

Economic Development Strategies

When Nobel Laureate Simon Kuznets, through the analysis of national accounts, showed that the percentage contribution of agriculture to national product declines and almost vanishes as incomes increase with industrialization, many new theories of economic development favored investments in industry at the expense of agriculture. The Mahalanobis and the Harrod-Domar models argued for the development of heavy industry as the engine of growth for India during her first five-year plan. The reconstruction of Europe after World War II under the Marshall Plan focused attention on the ability of the U.S. to rebuild Europe's industrial capacity through massive injections of capital and infrastructure. The World Bank followed this path, under the guidance of Hollis Chenery, by using donor capital to finance investments. The early models of economic development were biased towards long-term growth which required heavy industry as opposed to the development of more light industries of consumer goods such as textiles, even though it was recognized that equity objectives could not be satisfied in the short-run. Only recently have hypotheses emerged which suggest that a mixture of light and heavy industry can generate growth with equity, such as can be found in Taiwan, Korea, and to a lesser extent in Hong Kong and Singapore. Nevertheless, the

majority of these models look on agriculture in an exploitative way, rather than admitting that improvements in agriculture itself can assist in and are necessary for increasing the economic growth rate.

In fact, it took Sir Arthur Lewis's article in 1954 to show how economic development could be enhanced by using "unlimited" supplies of labor which could be extracted from the agricultural sector without a fall in production because labor's marginal productivity was at or close to zero. However, Fei and Ranis (1961), Jorgenson (1961), and the early writings of Mellor and Johnston (1964), expanded this concept. In doing so, they recognized that agricultural technology and labor productivity would have to increase in order for labor's transfer to be possible without a decline in production, and that production would actually have to increase to feed the new urban masses.[1/] At this point, Jorgenson, Mellor, and Johnson go on to claim that surplus earnings in Japanese agriculture went even further and played a major role in providing investment capital for the modern sector through the mechanism of dual landlords. Excess earnings from rice and silkworms were reinvested in industry because the landholders were also the industrialists. If this be the case, agricultural growth could supply the capital as well as the labor necessary for rapid growth in the modern sector and provide additional food for the workers who migrate. Mellor has developed this concept more fully in his analysis of India, but at the

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[1/] John Mellor, 1982, address to the International Association of Agricultural Economists, Jakarta, Indonesia..

International Association of Agricultural Economics (IAAE) meetings in Jakarta in 1982, he added the notion that more investment in infrastructure and utilities may be necessary as preconditions for initiating this process in Africa..

Several other developments during the 1950s kept agriculture out of the limelight in development economics. Prebisch ( ) and Singer ( ) independently came up with the idea that since the terms of trade turn against agricultural exporting countries who import manufactured goods, their growth was limited.[1/] The conclusion they advocated was the need for developing import substitution industries through trade protection, a strategy which completely ignored agriculture. Another approach was introduced by Hirschman ( ) based on the concept of the multiplier effect of forward and backward linkages, in terms of the "investment-generating forces that are set in motion" by these linkages. He goes on to say that "agriculture certainly stands convicted on the count of its lack of direct stimulus to the setting up of new activities through linkage effects--the superiority of manufacturing in this respect is crushing".

Although the early heavy industry models, the import substitution theories, the linkage and labor surplus strategies all led to the neglect of agriculture, they were also criticized by the political economy theorists. Since low-income countries were less successful in generating broad-based capitalist societies and peasant farmers were

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1/ Carl Eicher and John Staatz, ed. 1984, Agricultural Development in The Third World, Baltimore: Johns Hopkins University Press.

individually unable to generate surpluses to earn capital for investments (because marginal productivities of labor were close to zero), concepts of collectivization arose. At the same time, the theory of the center (the modern world) and the periphery (the developing countries), a political economy theory, was espoused by Prebisch ( ). DeJanvry[1/] carried this last notion even further within a country to criticize the agricultural development projects in Latin America, maintaining that agricultural technology without redistribution of resources would only continue the bimodal structure of the economy rather than drive it towards a unimodal solution, as advocated by Johnston[2/] in his recent plea for asssistance to small farmers in Africa.

Integrated Development Strategies

Throughout the fifties and sixties, attempts were made to integrate the development process, and to provide assistance to all sectors simultaneously. The Community Development concept arose out of political concerns to foster democratic societies. However, as the food crisis widened in the late 1960s, community development gave way to Rural Development with a concentration on agricultural production.[3/]

1/ Carl Eicher and John Staatz, op. cit. p.___

2/ Bruce Johnston and Thomas Tomich, 1984, "Rural Development Research — Farmer Productivity and Feasibility of Small Farm Development Strategies", USAID, Washington, D.C.

3/ A survey of community development projects is presented by Lane Holdcroft, "The Rise and Fall of Community Development, 1950-65: A Critical Assessment" in Carl Eicher and John Staatz, op.cit., Chapter 3.

The methodologies employed in these approaches, however, were simple applications of the Diffusion model with stress on Communication. No research on environmental adaptations were included, and as a result little impact was generated in food production. However, in the late sixties and early seventies, the green revolution took hold and led to great optimism among development experts that the food crisis in the third world could be overcome. When food no longer required everyone's attention, the development community looked for a means for distributing the wealth being generated by food surpluses. The Basic Needs approach then arrived on the scene with projects and policies designed to provide a complete social welfare package. However, since the "Green Revolution" took hold in only limited areas of Asia, the luxury of the basic needs approach was short lived.

It is in the context of this historical panorama of development models which evolved both sequentially and simultaneously during the last several decades, that we now turn our attentions towards the application of the Induced Innovation model to semi-arid, sub-Saharan Africa. The several agricultural models, the economic and political economy models, and to some extent the integrated development models have all been tried in Africa at one time or another and in one place or another with less than resounding success. Perhaps they were inappropriate given the resource base and the social and economic dynamics of the time. Maybe with the approprate application of the Induced Innovation model we can turn the tide of history and find a catalytic mechanism which may bring true development to Africa in our time.

Chapter III

The Induced Innovation Model of Hayami and Ruttan

The Hayami/Ruttan induced innovation model is based on a view of dynamic factor substitutions driven by market forces. When certain conditions are reached, innovation rapidly takes place. When these conditions are not present, innovation lags, stagnates, or declines. The dynamics of current production systems in developing countries are subject to the norms of this model as will become evident when it is applied to several African situations with several commodities. The basic premise of this model is drawn from Hayami and Ruttan's one hundred year analysis of agricultural growth in the United States and Japan, and corroborated by a similar study by Binswanger on several European countries. The model states the following:[1/]

Technological change comes about through research on factors of production which lower per unit costs, or conversely, increase yields per unit of input. The key to the particular research strategy chosen in terms of the input selected, and the size and nature of the research effort, are determined by one input's ability to substitute for another input whose availability appears to be reaching its limit. If an input experiences an inelastic supply curve, that is, where access to more of those resources does not increase when prices rise, then a search is made for a substitute through the research

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1/ Yujiro Hayami and Vernon Ruttan, 1984, op. cit.; Vernon Ruttan, 1985, op. cit.; and Vernon Ruttan and Yujiro Hayami, 1984, "Toward a Theory of Induced Institutional Innovation", The Journal of Development Studies, Vol. 20, No. 4.

(experimentation and trial and error) process. The degree of effort and the organizational structure pursued in this process is determined by the nature of product demand facing the farmers. If there is broad-based demand with increasing prices, i.e., rising urban incomes, this research will be directed towards staple food crops managed by public sector institutions. If the demand is for specialized export crops, research will be financed and carried out by private or semi-private organizations. Whichever is the case, the value of the ratio of the price of the input being substituted for the scarce resource and the product's price in the market, will determine the size of the research effort and its longevity or sustainability. If the perceived benefits to be garnered from these efforts are viewed to be short-lived due to expectations of extreme fluctuations in the environment or from negative price policies in national or international markets, or if relative economic decline actually sets in to keep the price ratio from falling, then investments in technology generation, public or private, will never materialize or be terminated prematurely if attempts are made at all. Since it is recognized that biological research and adaptation takes time, measured in decades rather than years, many research efforts are bypassed for activities with expectations of immediate benefits, such as price supports or subsidies, exchange rate controls, or new taxation schedules. These activities generally attract most donor attention and host country receptivity; long term research is usually foregone because of the lack of perceived short-term benefits.

Given the Hayami/Ruttan model, two conclusions can be drawn. The first is that there are alternative paths towards technological change, depending upon the factors which are chosen for substitution, and second, demand schedules guide the selection of the commodities which are subjected to the intensive research process.

The Hayami/Ruttan model clearly defines the relationships between the biological and economic inputs and the level of product demand which led to the impressive technological changes which occurred in the United States and Japan during the early 1900's. But the model does not define the process of institutional change, how and why institutions respond, which institutions require change, or more importantly, whether exogenous institutional changes trigger or constrain the evolution of the technology generation process. Certainly, if institutional changes serve to increase factor prices or decrease product prices, the induced technological change process cannot procede. If institutions fail to reduce variations or cover risks, the same stagnation will evolve.

The path of technological change chosen by the United States initially differed from that of Japan. In the late nineteenth Century, land in the Midwest and South was relatively abundant. Production increases were achieved by simply placing more land under production. But as industrialization progressed, labor was shifted out of agriculture into manufacturing. In order to continue to provide food for the urban populations a new factor of production was needed to replace the lost labor, since agricultural products did not face elastic demand schedules, especially for staple grains such as

corn and wheat. As a result, research in mechanization began in earnest, and allowed the land to labor ratio to expand considerably. When land finally became limiting, research work shifted to factors substituting for labor During that later period, investments were made that led to the development of less costly ways of producing fertilizers (the work of the Tennessee Valley Authority) and the breeding of fertilizer-responsive seed varieties. Although the high-yielding seed-fertilizer technique proved to be successful in the U.S., it occurred after Japan had already initiated substantial efforts to produce high-yielding rice varieties.

Japan, unlike the United States, felt the pinch on land resources in the late nineteenth century and early twentieth century. In order to substitute for land which was not an unlimited resource like it was in the United States, Japan began a research program on high-yielding rice varieties and enhanced the response pattern with high levels of fertilizer application. This can be seen by the high rates of fertilizer utilization per hectare. With high fertilizer doses, the maximum benefit to plant breeding was attained.

Increased crop sequencing was possible because the soil fertility was rejuvenated artifically with each application thoughout each growing season. This was made possible, once again, not only by relatively low fertilizer costs but also because the ratio of fertilizer price to the price of rice was relatively low. When the price of rice increased dramatically from 1965 to 1977, rice yields rose even further.[1/]

[1/] Yujiro Hayami and Vernon Ruttan, 1984, op cit.

In the United States, demand for grains was always quite high throughout this development period. When prices began to level off, the farm lobby gained sufficient political support to institute a myriad of price supports and market controls. In effect, these policies guaranteed sales at cost plus profit price levels. Even though much of this research was initiated and maintained in the public sector and supported by the USDA and the land grant University research system, private seed companies continued to flourish because market price support policies kept the input price-market price-ratio very low.

Although this model explains quite well the process of technological change in the United States and Japan, it is not at all certain that it applied to the late developing countries. This we will investigate in the next chapter, but first let us look at where the "Green Revolution" took root, to see if it followed the same pattern outlined by the model's application to the U.S. and Japan.

CIMMYT and IRRI's Work with Wheat and Rice

In the 1950's, as was pointed out in Chapter II, there was great concern over developing the Third World. This meant increasing food production. The Rockefeller Foundation was the recognized leader in pursuing a research program for increasing food production in Latin America and Southeast Asia.[1/] Work began in Mexico with Norman

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1/ This section is drawn from William Paddock and Elizabeth Paddock, 1972, We Don't Know How,

Borlaug and the formation of CIMMYT, the wheat and maize improvement center, and was succeeded in the Philippines when Frosty Hill established the Rice Research Institute. Both of these centers followed the same strategy, adapting high-yielding, fertilizer responsive, seed-types to local conditions. Both were enormously successful, but not in the same way. The invisible hand of our model was at work. The original process described above for the two industrialized countries led to the perfection of the technique of plant breeding for precisely high-yielding fertilizer responsive varieties. The process used by these two Centers was to borrow promising seed materials and, through local environmental testing and adaptation, generate new hybrids or composites which could out-yield local varieties and still withstand local stress. For both rice and wheat, this meant developing short-stemmed varieties to prevent lodging. In addition, this breeding technique was best suited to irrigated lands, which was common in Asia for rice and happened to be present in parts of Mexico where Borlaug began his work on wheat.

It is curious to note, however, that success in wheat was not achieved in Mexico, where the work was initiated in the late 1940s, but was most dramatic in Asia. Several reasons account for this phenomena.

The process which led to the development of the Mexican dwarf-wheat varieties with genetic characteristics suitable to Asia reads as follows. During World War II, an aide to General McArthur noticed some "ankle-high" wheat varieties in Japan, which he collected and sent to the USDA plant quarantine nursery in Arizona.

Orville Vogel, a plant breeder from Washington State, using these seeds, developed several crosses which showed that plant height did not correlate directly with yields. From this finding and seeds from Vogel's new stock, Borlaug and others continued experimenting with dwarf wheats. Since Borlaug was testing at two locations, twice a year, due to latitude and altitude differences, he was able to produce results more quickly than the other researchers. Also, he was breeding for gross yield and not taste or quality and hence, was not as constrained as were other reserachers in the U.S.

Another characteristic emerged from this research that was perhaps even more unique. Since the Mexican research stations were further South, the wheat varieties which emerged were tolerant to the short days of the more tropical latitudes, although this chacteristic did affect the quality and taste standards. In spite of the favorable conditions for Borlaug's experimentation, he still followed the premise that adequate moisture and high levels of fertilization, comparable to the norm in the U.S., were imperative if high-yielding, tropically tolerant varieties were to solve food problems. The result was that these varieties <u>could not</u> produce their high yields <u>without</u> these inputs. When India and Pakistan in the late 1960s were looking for wheat to recover after a severe drought, and Borlaug had already demonstrated his stock there, they sent buyers to Mexico, and the rest is history. The Mexican dwarfs were perfectly suited to the irrigated and fertilized fields of India and Pakistan, were rust-resistant dwarfs grew well with short days.

However, in Mexico, the story is less convincing. Borlaug and the Rockefeller Foundation claim that their research increased wheat production, made Mexico self-sufficient in wheat and led them to export wheat, all dubious conclusions in light of the economic conditions surrounding this case. First, wheat is a minor crop in Mexico, in terms of number of farmers (1/40 compared to corn farmers), acres (1/8 of corn), and total grain output (about 1/4 of corn). Second, the costs of irrigation in the north of Mexico where wheat is grown, has been heavily subsidized, as was the price of wheat. Moreover, these dwarf wheats "must be fertilized", and Hertford's 1967 study shows that fertilizers were subsidized throughout the sixties. Most chemical inputs were subsidized during the seventies as well. Also, Mexico's petrochemical industry developed fertilizer and provided access to them at the time Borlaug was doing his research. Hertford's study also shows that from "1953 onward, over half the change in Mexican crop yields was due to increased use of chemical fertilizers". The Green Revolution in wheat which won Borlaug the Nobel Prize occurred in Asia.[1/]. On the contrary, Rockefeller's similar effort in corn breeding in Mexico led to a seemingly stark failure. However, in later years, as the program was modified and adapted to Mexican conditions, it became a resounding success. But what happened with corn?

[1/] This is not to detract from Borlaug's accomplishments, but to identify what were the conditions and characteristics of this success in order to determine what can be applied to Africa.

Vice-President Henry Wallace, founder of the Pioneer Seed Company, suggested a corn-breeding program for Mexico in the early 1940s. Given the success in the corn belt with hybrids, this was the route chosen by Rockefeller, led by Wellhausen—a renowned corn-breeder. In order to generate a rapid impact, the Foundation concentrated its efforts on the large, prosperous farmer—the ones who had the best land plus access to seeds, fertilizers, and pesticides. Unfortunately, corn was grown by smallholders and ejiditarios, [2/] under varying environmental conditions. As a result, no single hybrid was adapted on a broad scale throughout Mexico, and the breeding work done to generate seeds responsive to fertilizer and water often fell on infertile soils and environments. If small holders grow corn for subsistence, and the environments do not guarantee moisture and fertility, the farmer will naturally shy away from the introduced hybrid. Hertford's study once again indicated only moderate adoption of hybrids up to the 1970's, no higher than 15% in acreage.

But the story on corn changes in Mexico. In 1967, CIMMYT spawned a new initiative. In collaboration with the State of Puebla, researchers began adaptive work on corn in farmer's fields. Mixed cropping techniques with beans were evaluated and local varieties were compared with the hybrids. Seeding densities, time of planting,

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[2/] Farmer's holdings called ejido were communal lands broken into small parcels, and farmed individually.

fertilization rates and techniques of application, and pest controls were all tested in field plots. Breeding work was not included. From 1967 to 1980, yields increased, on the average for the Puebla Region, from one ton per hectare to 3.0 tons per hectare. Many have felt that the success of the Puebla project depended upon the doubling of corn yields in seven years, and one of the CIMMYT directors, Haldore Hansen, figured that corn breeding needed to produce seeds capable of generating three to five times more than traditional varities in order to justify the effort. Neither of these accomplishments materialized, but with steady and vigorous research, adaptation, field-testing, retesting and adoption monitoring, coupled with evaluation of the linkages between technology generation and institutional and policy supports for adoption, the farmers of Puebla have reached considerable milestones in fifteen years. Technology generation in the eighties now concentrates on 70,000 seed per hectare maize for fodder and concentrates, plus trellised beans which have yielded up to eight tons per hectare in on-farm experimental plots. [1/]

In Southeast Asia the process was more straightforward. The Rockefeller Foundation, led by "Frosty" Hill, identified Los Banos in the Philippines for the location of the International Rice Research Institute (IRRI). IRRI's mission was to adapt the

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[1/] Personal sight visit with local farmers, extension agent and Mauro Gomex, ex-Puebla Project Director and current District Chief, Rainfed Agricultural Districts Program.

Japanese dwarf rice varieties to Southeast Asian environments. Since almost all rice in the area was grown under one form or another of irrigation and more importantly, was already fertilized, the breeding work considered these input variables as givens. When the high-yielding varieties reached sustainability, they were readily adopted because the new input package was relatively risk free. 1/ The only input which was different from existing inputs was seed-type, a small cost in the total package of inputs.

In both cases of wheat and rice, we saw a research program devoted to substituting an abundant resource (fertilizer) for a scarce resource (land). In Mexico, it was irrigated land which was scarce. 2/

Because fertilizer prices remained low, and output prices rose, the research program throughout Asia was sustained, and spread through Malaysia, the Philippines, India, Sri Lanka, Thailand and Indonesia.

1/ James Roumasset,

2/ Surprisingly enough, the wheat program in Mexico was concentrated on irrigated lands, a phenomena which was not characteristic of wheat research in the U.S. because it would not pay.

3/ Vernon Ruttan, op. cit., p.

In Mexico, the program continues at CIMMYT, but Mexican National support is extremely weak, perhaps even non-existent.[1/] In Mexico, price supports, crop insurance, input subsidies and irrigation districts take credit for Mexico's agricultural successes, not plant-breeding research. In Mexico, the pressure on the land was not great enough, the cost of fertilizer was not cheap enough, and the demand for wheat was not sufficient to sustain the high-yielding fertilizer responsive research program in wheat. For corn, the additional complication arose which was the hybrid's inability to adapt to varying stress under different soil and climatic environments. What happened with corn in Mexico and Colombia, and presumably for wheat and rice in rainfed parts of Asia was that without proper moisture regimes and adequate fertilizers, and with competition for nutrients and moisture from weeds, the hybrids failed to perform as well as local varieties.

Crossing Production Functions

If the hybrids fail to outperform traditional varieties under low input levels, their production functions will cross, a phenomena which many plant breeders refuse to recognize. Perhaps under single-variate relationships they rarely do, but under farm conditions, crossing production functions are commonly observed. The production function describes this situation in Figure 1 below. Figure 2 compares these production functions with the one presented by Hayami and Ruttan in their article on "The Green Revolution: Inducement and Distribution".

1/ Personal interview with Alvarez-Luna, General Director of the National Agricultural Research Institute, Mexico City, Mexico, July, 1981.

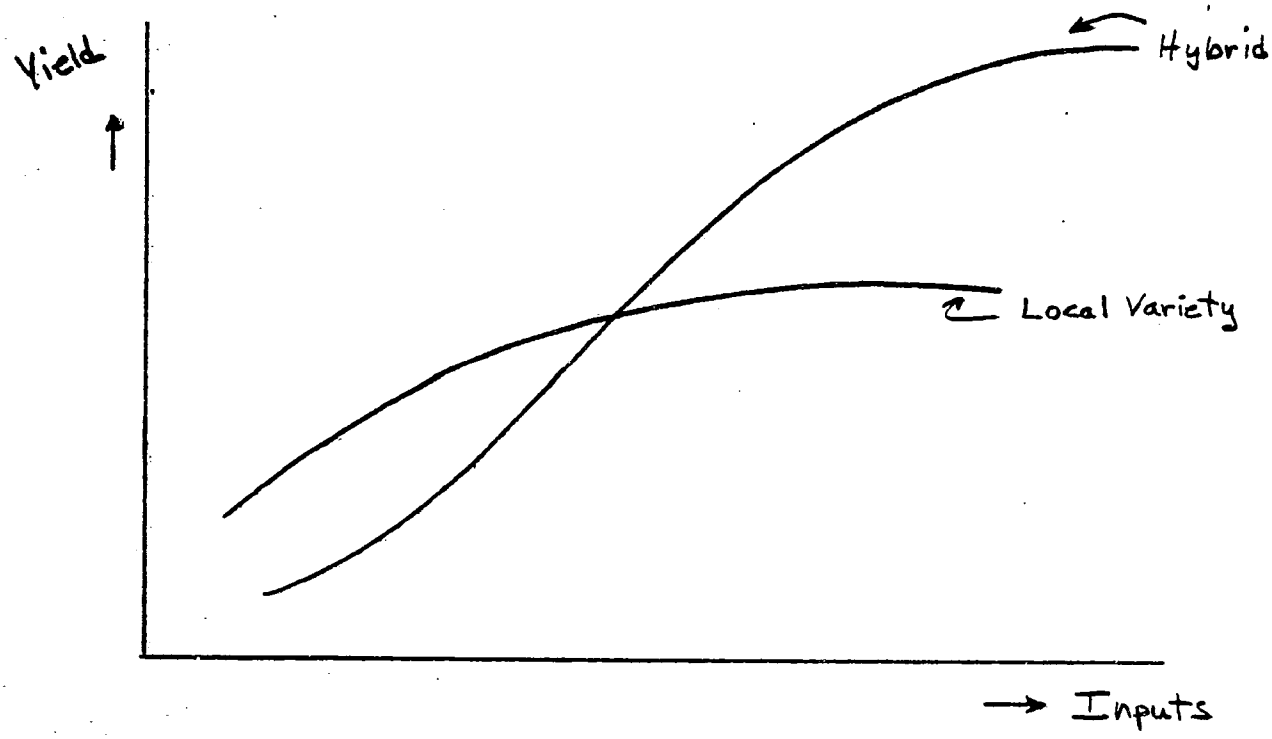

Figure I. Crossing Production Functions

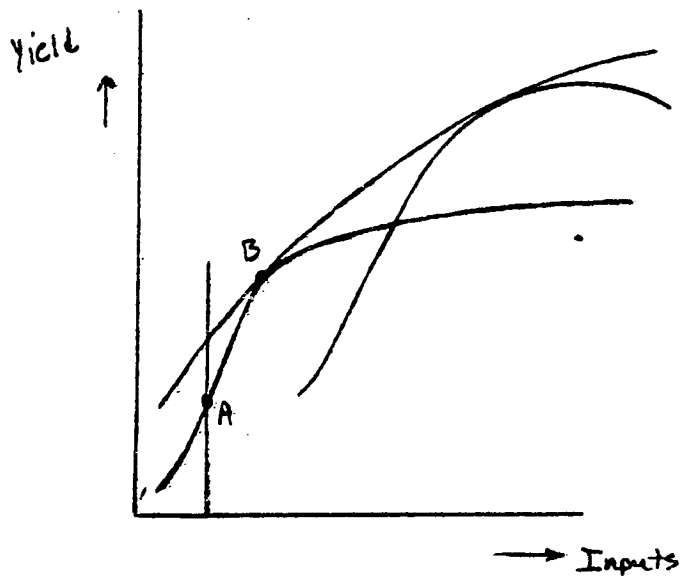

Figure 2.A. Farmer's Optimizing with Limited Resources

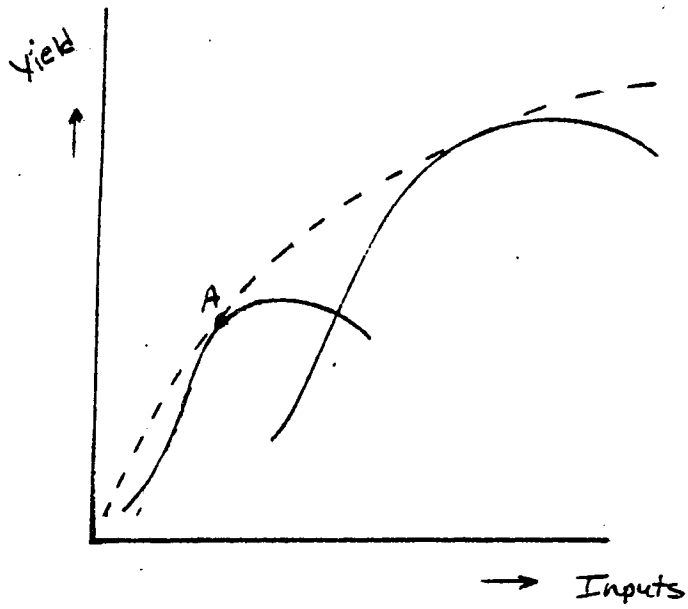

Figure 2.B. Hayami/Ruttan Model for Asia. [1]

[1] Yujiro Hayami and Vernon Ruttan, op.cit., p. 40.

First, the farmer operates at one of two positions, either at an optimum at A, in Figure 2.B, which assumes unlimited resources, or at point A in Figure 2.A, where resources are limited for some reason. Movement to the right can be motivated by (a) access to more resources, or (b) change in the price ratio of inputs to output. In the Asian case, a jump from A to B was feasible and the new technologies justified this move. But in the Latin American case, first a move to C was elicited by reducing resource constraints, that is, by reducing risks, providing access to inputs and manipulating price policies (the Puebla Project model) and then an iterative approach, stepwise from A to B along the meta-production function, seemed to evolve. Each step along this path carried demands for different combinations of supports and mixtures of crop enterprises. This same kind of work evolved in Asia during the mid-seventies as well, but attracted little attention save for the multiple crops program at IRRI. Even so, perhaps one of the interventions most responsible for increasing rice production in the Philippines was the Masagana 99 Project, which provided subsidized inputs, marketing, credit with guarantees, and price supports, all promoted through a comprehensive mass-media campaign. The question remains as to which approach is appropriate and feasible for semi-arid Africa, and how can one shape the research and extension effort to conform to these conclusions?

Chaptver IV

Application and Adaptation to Semi-Arid Sub-Saharan Africa

The Hayami-Ruttan model calls for the substitution of a "cheap" resource for one facing scarcity, coupled with high product demand in order to justify prolonged research for and achieve broad-scale adoption of high-yielding agricultural technologies. The bias of this technology emerges from the identification of that resource factor doing the substituting and the unique mix of resource and cultural endowments currently present in each country or region. The path of expansion along the hypothesized meta-production function remains constrained by the degree to which rising product prices generate returns to factor inputs. These constaints are acute in semi-arid, sub-Saharan Africa. Demand prices remain low, due to chronic stagnation of the economic transformation process[1/], (i.e., rural, subsistence populations linger above 70% of total population) and the fact that urban consumer price ceilings always loom oppressively on the horizon. Hence, a jump from traditional production technologies with low input levels to ones with high input levels which the high-yielding seed varieties generally require, appears to be exceedingly difficult to engineer. That is not to say that if some "miracle" technology were to be discovered, it could not be introduced, such as a drought-tolerant, nitrogen-fixing maize variety, but the conditions that create its likelihood are absent.

1/ John Mellor, 1966, op.cit.

Instead, the route to technological advance for this part of Africa must be one which flows out the existing production function to the production frontier, and then expands iteratively along that path. In order to make progress in this two-staged approach, a diagnostic profile must be made of each farming system to determine the nature of the traditional or existing production function. The diagnostic process must determine which resources are abundant and identify those which are in relatively scarce supply. The degree of variation in supply is also to be included, especially for water. When one looks at semi-arid Africa, one finds land in abundance, though of poor quality and extremely dry. On the other hand, capital for cash inputs is extremely scarce. Within the capital supply function, distinctions must be made among moisture control—an infrastructure variable; fertilizer—a cash or credit outlay; seeds— an access problem for hybrids, composites, or improved varieties; and dust and sprays—an insurance principle at work. The other major input variable, labor, on the surface looks to be in excess, but often is exhausted at peak labor demand periods and, in fact, acts as the determinant of the size of cropped area. The area planted is determined by the amount of labor available for peak demand periods. However, moisture variation alters the level of use of all inputs and especially influences the frequency of full employment, underemployment, or overemployment by its control over weeds, pests and diseases, and yields. Moreover, the more complex the inter-cropping system, the less likely fixed expectations exist

regarding the amount of labor required for any given season for each crop pattern and cycle. Hence, labor supply becomes an extremely tricky variable, complicated even further by task appropriateness for males and females, and age groupings.

Once the factor endowments and production relationships are determined, a process can be set in motion for designing interventions to reduce the constraints identified. When optimal production points are reached, research must be initiated to shift the function out the meta-production expansion path. This process requires a somewhat different approach to agricultural research than what has traditionally been espoused by the international agricultural research community. Given the apparent success of the "Green Revolution" in Asia, it was expected that the investments made in the International Institute for Tropical Agriculture (IITA), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and other international centers for tropical agriculture would in a few short years reap miracle-level breakthroughs. Since this has not materialized to any significant extent, these centers have been severly criticized. But one may submit that perhaps the strategies they pursued fit neatly into the Hayami/Ruttan model as applied to semi-arid Africa.

A recent review of the research and output of these research centers highlights this point. IITA has carried out impressive research on "alternative approaches to land clearing and tillage methods aimed at finding [techniques] for maintaining the fragile fertility and structure of the lateritic soils typical of the sub-humid tropics[1/]. However, as Eriksson also points out,

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1/ John Eriksson, 1985, memorandum to AID staff, Washington, D.C.

the heavy reliance on chemical pesticides and herbicides in their no-tillage work may be counter-productive. Because of the constraints on chemical supply, breeding research on disease and pest resistance needs to be the focus. Alley-cropping work also should be singled out as being particularly well suited to the tenets of the Hayami/Ruttan application to sub-Saharan Africa, either sub-humid or semi-arid. Alley-cropping involves maize and cowpeas or any other grain-legume mixture, grown in alleys between leucaena or gliricidia trees. "Nitrogen-fixation, woody mass, shade, [nitrogen rich] mulch and weed-suppresant characteristics" of these systems are being tested [1].

Commodity-based research continues on breeding and distribution of streak-resistant varieties of maize as well as work on striga and stem borer resistance. IITA has also recently developed a high-yielding, disease-resistant hybrid maize. Farmer demand for these hybrids currently exceeds supply, and support has been stepped up with two private firms in Nigeria to supply this seed.

Here is a case where a support institution to provide seed production, distribution and financing for cash purchases needs to be developed simultaneously with, or prior to, the spread of the innovation. Without it, the new seed will not be utilized and its inbred qualities will dissipate.

With cassava, considerable progress has been made to control biologically the cassava mealy bug, while at the same time increasing the carotene content and reducing cyanide. Nevertheless, controversy

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[1] Ibid.

has arisen with regard to who and how they should develop (rear), promote, and disseminate the predators. An institutional problem once again gets in the way.

The short-growing cowpea (60 days), like the mung bean in Asia, seems to be taking off rapidly. Cowpeas are extremely drought-resistant. In fact, farmers in Kenya earn $100 shillings a bag (1978 prices) for leaves even in years when the moisture is too sparse to produce bean pods[1/].

IITA manages a seed unit to train and provide technical assistance in seed multiplication technology. IITA has limited the expansion of this activity, an action judged to be overly conservative in view of this paper's interpretation of the Hayami/Ruttan model.

The research of the International Livestock Center for Africa (ILCA) has taken a similar approach. Studies are underway on nutrient value of forages, crop residues, and feeds. Other studies are being carried out on energy outputs related to nutrient intake and water consumption by breed. Eriksson notes an impressive piece of work on "identifying, collecting, and evaluating indigenous and introduced legume species" and the development of legume-based networks. Available evidence indicates that the native forage legumes respond miraculously to "modest additions" of phosphate, increasing yields "5-to-6 fold". Notice how all of these research activities are following the iterative path identified in Chapter III, moving out the meta-production function expansion path in stepwise fashion. Concurrent institutional supports are obviously needed, and the bias the technology takes if it is to be assured of full scale utilization depends on the environmental resource endowments as well as the

1/ Recent work supported by the National Academy of Sciences in Kenya has produced well-adapted Amaranth which rivals cowpeas as perhaps the most drought-resistant grain or legume food crop in Africa, yielding 1,300 kg/ha with 100mm moisture in field trials, when sorghum and millet failed to generate grains. Lecture by Gupta, National Academy of Sciences, October 14, 1985,

existing, functioning institutional structure. But let us look more closely at the process of developing technologies under stress conditions before we draw our conclusions.

Several research studies have suggested that varieties which perform well under modified and controlled environments with high input levels, fail to match local variety output levels when submittted to more natural environments with high stress levels[1/]. However, plant breeders know that before a new seed can be released for diffusion, it must perform well under all likely conditions in the areas in which it will be distributed. If a seed requires certain levels of moisture at specific times, it cannot be released in drought prone environments without the assurances of supplementary irrigation. Similarly, if a seed only performs in superior fashion with high nitrogen levels, it cannot be released where credit or cash for purchased inputs are absent or fertilizer supply is erratic or negligible.

The modified stability index concept of Heildebrand can be expanded to demonstrate how research must be tailored to fit the environment or research domain as it is called in farming systems research[2/]. Using the same production function concept as in Figure I, visualize two crossing functions, with yield on the vertical, or

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1/ Hubert Zandstra, Kenneth Swanberg, 1979, et. al, Caqueza-Living Rural Development, Ottawa: IDRC.

2/ Kenneth Swanberg, "Economic Justification for the Farmiing Systems Approach", A.I.D. Economist Conference, Annapolis, Maryland, November, 1984.

Y-axis, and inputs, resources or endowments on the horizontal, or X-axis. When the amount of X present in the environment (applied or naturally existent) increases to the right, curve A in Figure 3 shows that the improved seed variety is superior. When X falls towards zero, the traditional seed is better, curve B in the figure.

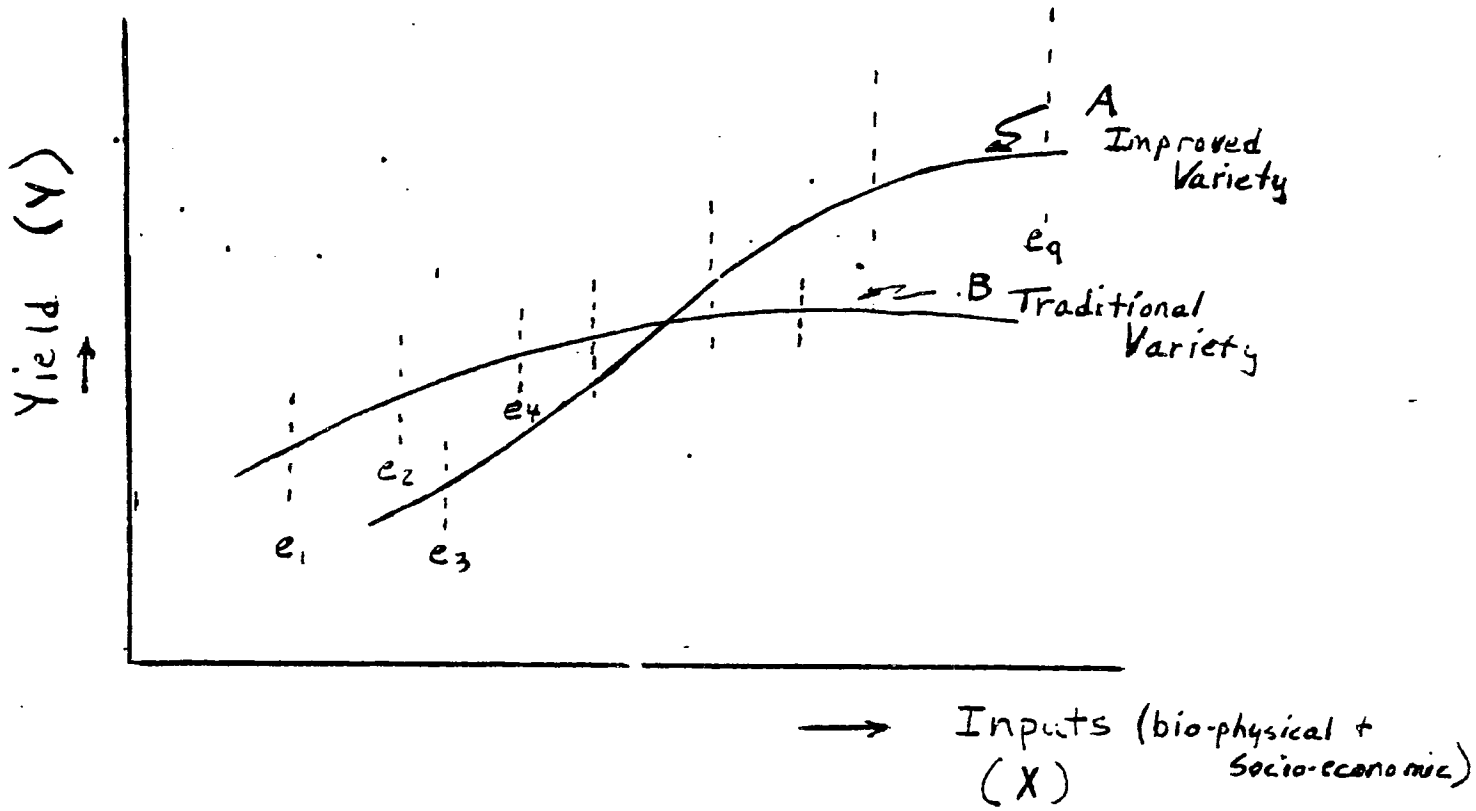

Figure 3. Crossing Production Functions

Hildebrand uses environments at each farm level test location for these input levels and uses a surrogate of treatment yields at each location to represent all the inputs. Then individual yields per treatment (the verticle points in Figure 1 at each X-value) are correlated to average yield per site, which is the environmental index. But since the environmental index is the average yield of all treatments per site, where yield is a function of all inputs, we really have yield as a function of inputs, the traditional production function. If all input variables could be measured, we would not need the environmental index. However, management techniques, input timing, and micro-climatic variations are difficult to detect in farm budget surveys or production function testing methods, and moreover, defining the structural form of the appropriate equations to catch all of these interactions is virtually impossible.

Economists often revert to Cobb-Douglas, CES, or Spillman functions, which are complete, interactive, multiplicative functions, to avoid this definitional dilemna, in effect simply looking for the best "fit". As a result, we end up glumping variables and interactions together, considerably complicating the recommendation process. Perhaps the concept of the environmental index as a stepwise process can be quite useful in this context. First, divide the test results into several environments—in effect what is done with group enterprise analysis, often referred to as "Head and Tail" budget analysis[1/]. Then run separate budgets or regressions on each group. The separation of groups could also be done with dummy

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1/ Kenneth Swanberg, 1975, The Small Farmer Series (Spanish), Colombian Agricultural Institute, Bogota, Colombia.

variables if degrees of freedom become problematic given the number of observations available for study.

One specification of this process looks like this:

Let	Y_{ij}	$= f(e_j)$
where	Y_{ij}	= Yield per treatment i;
	e_j	= Average yield for all treatments at site j;
and	j	= 1, 2 . . . n, for each trial site.

Then,	e_j	$= f(Z^t)$
where	Z^t	= inputs $X^1, X^2, \ldots X^n$
and	X^1	= fertilizer
	X^2	= seed quantity, type or spacing
	X^3	= soil fertility
	X^4	= climate
	X^5	= moisture
	X^6	= cash used
	X^7	= labor used
	X^8	= cultivation practices
	X^9	= management techniques
	X^{10}	= risk level
	X^{11}	= wealth level

etc.

1/ NOTE: Some of these variables might have to be entered in dummy variable structures, and act as slope-intercept shifters.

Usually, when fertilizer and seed are identified for investigation and some form of research design is employed, there is an implied assumption that within the research domain, all "other" (non-treated) variables are constant and similar. Although this may be relatively true for major variables such as soil type, hill slope, and cultivation practices, this is often not true for climate or rainfall (rainfall can vary considerrably on either side of a road in semi-arid Africa), labor availability or wealth levels. As a result, the research design is misspecified. The environmental index, two-step process can correct for this problem.

Let $Yij = f(X_1, X_2, [e_j - (X_1, X_2)]$

where $[e_j - (X_1, X_2)]$ = farmer practices at each site; or

$$Y_{ij} = A + \beta^1 X^1 + \beta^2 X^2 + \beta^3 X^3 (\text{Farmer}).$$

Once the grouping of performance levels by site is made the additional regression or budget analyses of the most highly visible and most important variables for each farmer group can be identified. This process produces the following results.

The group identified with low levels of X can be studied to find out how efficiently available resources are utilized. If efficiency is high, but resources constrained, interventions can be designed to reduce these constraints. If resources are not constrained, then the best technology with the greatest stress tolerance has been identified. Field research on these technologies can shift them upwards and to the right moving out the meta-production function. This can be done by (1) doing mass selection of those seeds performing

well (top percentiles) at any given input level, (2) doing research on production/farmer responses to constraint reductions, new combinations of inputs, cultivation practices, or cropping patterns, or to input price reductions, or (3) doing on farm incremental tests on new inputs, practices or combinations of each.

One way to reduce input prices is to reduce risks of access. If the supply of an input is erratic, assurances of timely supply in appropriate amounts at fixed prices or insurance against input response failures could go a long way to increasing their use, in effect reducing the cost of the risk premium attached to each[1].

One of the dominate concepts in Farming Systems work involves expanding the use of inputs with the highest marginal returns or conversely, generating greater returns to those factors experiencing low marginal productivity rates. In order to pursue this task, good diagnostic data is needed as well as the ability to determine which factors fall to the right of optimality in the production function analysis and which fall to the left. This author's research in Kenya and Colombia has determined that labor in food crops demonstrates underemployment. This means that it generates marginal returns below wage rates in agriculture. Purchased inputs, on the other hand, tend to be overemployed and in short supply, given their place in the production functions. In these analyses the third factor, land, appears to be more optimally employed. A more detailed look at this phenomena will be presented in the next chapter.

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1 Hubert Zandstra, Kenneth Swanberg, et. al., op. cit., p. _____, and C. Ford Runge,

In conclusion, we can see that conditions in semi-arid, sub-Saharan Africa do not permit a jump from low input, tradition-bound agricultural technologies to high-input, environmentally-controlled agricultural techniques and systems. A more incremental or iterative approach is needed. However, the strategy chosen must seek higher use or productivity of those cheaper inputs which can substitute for the more costly or scarce resources, which in general appear to be cash or credit for high-cost chemicals. Figure 4, graphically depicts this process.

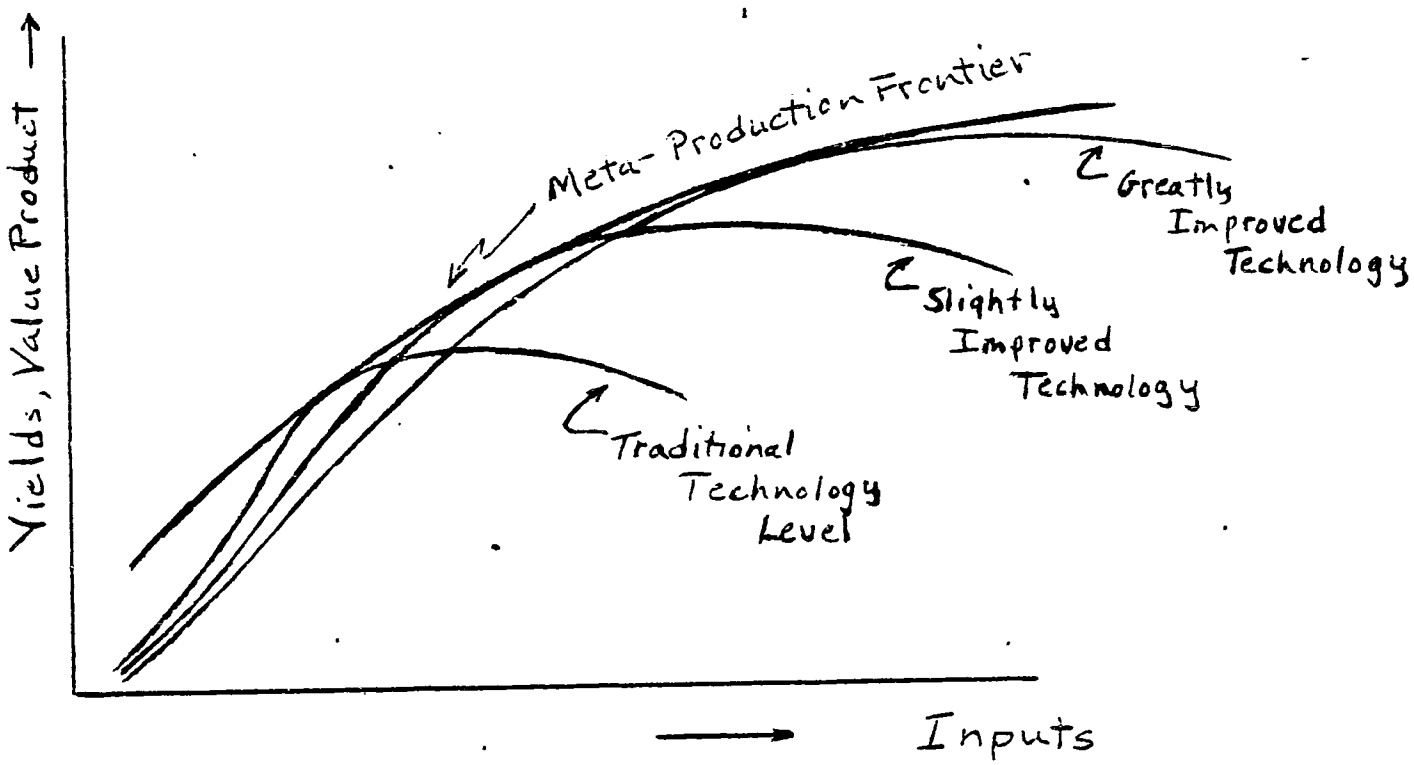


Figure 4. Technology Iteration Process

This diagram shows that each improvement is achieved without losing the stress tolerance of the farmer at each technology level. Hence, any occurrence of a less than appropriate environment will not lower the output expectations. If over time, environments improve across the board, less stress tolerant characteristics can be incorporated into the new packages, but should always be done with extreme caution. Variance and stress are still endemic to sub-Saharan Africa.

Notice the difference between the set of production functions of Figure 4, and those in Figure 2(B), page 31. In Figure 4, the greatly improved technology performs equally as well as the Traditional Technology at lower levels of inputs and supports, and then outperforms the traditional at higher levels of inputs. The improved technology, in this case, would be preferred by the farmers, over the traditional based on average performance values and assuming all key inputs and environmental conditions measured are included in the Input variable. In general, the improved technology outperforms the traditional technology when standard risk measurements are applied to these functions. But the Expected Value of the Loss Function as a risk measurement technique usually shows that potential losses from costly high input level technologies may be so severe as to limit such input use. In such cases, artificial risk absorption mechanisms would have to be introduced. This concept will be discussed in section (C) of the next chapter.

Chapter V

Using the Adapted Model to Analyze Constraints to Agricultural Technology Development and Utilization

Since the demand for non-export food crops in sub-Saharan Africa remains weak due to low income and less than 30% urbanization, we know the basic strategy which must be followed for technology generation is a stepwise, iterative approach. High output prices must be present in order to generate expectations for significant returns to investments in any specific high-yielding miracle-type technology to justify its development. In the absence of high output prices, according to the model, more diverse technologies must be developed. Nevertheless, these technologies must be designed to be consistent with the numerator of the model's key indicator, which means maximizing the productivity of those resources which can be substituted for any scarce resources. Of the three basic inputs, capital, land and labor, we concluded that capital, in terms of cash for purchased inputs, is scarce. Land, on the other hand, has been deemed abundant. Labor varies from abundance to scarcity, depending upon the season, and as a result, overall productivity rates remain low. How, then, do we procede with the model?

Capital, Land and Labor—What's Limiting? Where's the Substitute?

Land is not limiting. There is no need to "save" land but the productivity of the land needs to be increased. How can this be done? If purchased inputs are limited, is there an alternative? In most situations there is, but the new cropping pattern becomes very complex.

Farmers in sub-Saharan Africa raise a variety of crops, for consumption, for livestock, for market sale. They raise these crops in patterns which attempt to provide subsistence needs throughout the year for their families and animals. As the frequency of droughts changes over time, traditional drought bridging techniques lose their reliability. Traditional knowledge loses its value and Government salvage-type reactions (famine relief) simply increase the risks the farmer faces because the reliability of such support services fades. Let's take an example from a semi-arid portion of Kenya in Machakos District.

In the areas where the Kamba Tribe originated, rainfall was reliable—plentiful enough for most crops including coffee, and relatively high in altitude, around 1,500 meters. But as population grew, their two "mountains" could not sustain this growth, and expansion into dryer areas was necessary. In the new areas at first the Kamba tried to grow temperate, moderate altitude crops. Since the climate of the new areas had lower temperatures due to low altitudes and rainfall was much less, it did not work. Slowly, the farmers introduced more hardy crops—sorghums, millets, cassava, cowpeas, pigeonpeas, sisal and sunflower.

Unfortunately, the existing support system was designed to service maize, beans, coffee and fruits and vegetables from the highlands. It was difficult to adapt these institutions to new cropping patterns with different timing requirements for inputs and market services. Moreover, the timing and pattern of crop mixtures became much more complicated. Rainfall profiles included much greater variations than

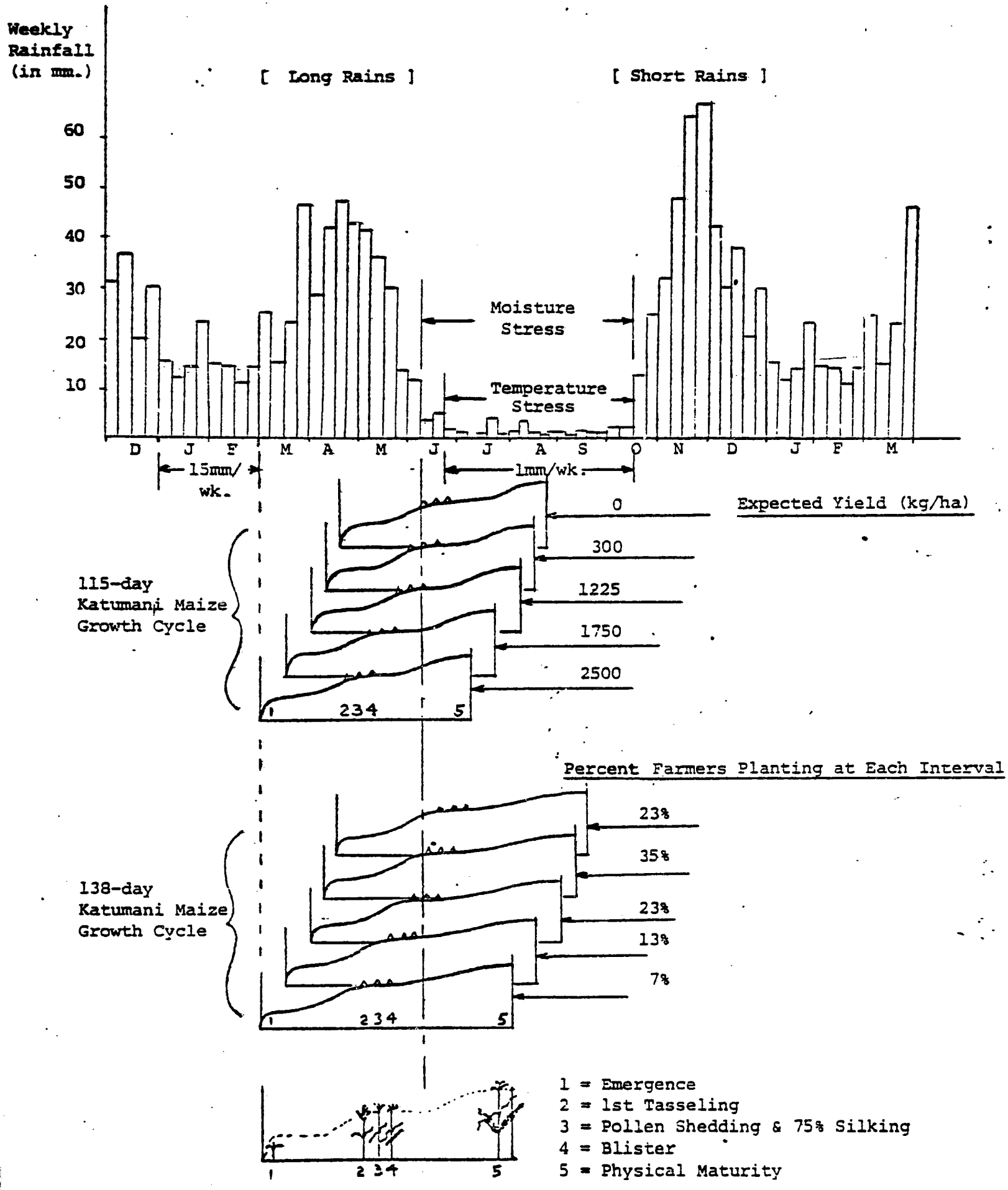
before. Overtime, new, adapted cropping patterns arose, but they arose amidst the lack of support services and research knowledge about how to grow mixed stands of cotton, pigeon peas, sorghum and sunflower. Only the most highly stress tolerant patterns survived.

The overriding constraint in Machakos is rainfall and its timing. Yields are only minimally correlated to fertilization rates, but highly sensitive to planting dates. Figure 5 superimposes the maize growth cycle with average rainfall patterns. It can be seen from the figure that each rainfall season is distinct, yet the extension recommendation allowed seeding to occur up through April during the long rains. No wonder farmers seed sorghum, a much hardier crop, along with the maize if they actually plant that late. Moreover, there should be no surprise if farmers do not fertilize after March 15.

A second observation can be made with regard to spanning or bridging the dry season. The farmers in the region only bridge during the January-February dry season, quite correctly, because of the high incidence of intermittant rains. It was also detected that if the intermittant rains in February did not occur, the long rains would be shorter and dryer, suggesting the need for sorghum rather than maize.[1/] Cotton and pigeon peas were often seeded in October and harvested in June or July. These crops were dry-planted in October in the same fields with maize because, as may be seen in Figure 5, there rarely were false starts for the rains during that season. If dry planting were done in February, more than likely a false start would occur, that is, germination could take place and then it could go dry before the sustained rains would set in.

[1/] Stewart, using data from Machakos, has shown that total rainfall can be predicted with the measurement of the date of onset of the rains and the first thirty days of rainfall, hence, giving an accurate technique for deciding whether to fertilize with side-dressing, plant sorghum as an alternative, and/or thin the crop down to one stalk. Ian Stewart, 1983, Rainfall Criteria to Enable Response

Figure 5. Rainfall and the Katumani Maize Growth Cycle in Machakos



These cropping systems are presented to illustrate the complexity of the pattern, how crops are planted to fit within the rain cycles, how several crops are produced within the same field, sharing soil fertility, moisture and labor, and how the pattern attempts to spread the risks over time and with crops with different levels of susceptibility to disease, fungus and pests.

The area of Machakos is famous for its development of the Katumani maize seed. The composite, short-season variety of only 115 days fits in perfectly to the short-rains season in October. Curiously enough, rainfall accumulated density functions show that the probability of the amount of rain for both the long and short rains are equal; it is the timing and duration of these which distinguishes them. In fact, it is questionable whether the correct translation of the Kamba words for the rains is actually long and short. These words were probably assigned by colonial researchers at the Katumani Research Station Their words more than likely referred to the "secure" versus the "insecure" rains..

Research in the Machakos area revealed yet another curious phenomena. The colonialists and donors, up to the mid-70's, were overly concerned with sheet erosion in the lower altitude regions, which appeared to increase as cropping intensified. To combat the erosion, they introduced bench terracing. The traditional system of women's work groups was easily encouraged (or coerced) into digging the terraces. One survey found that only eight farmers out of 100 did not terrace (and some of them were on tops of knolls or in valley bottoms where it was not needed)

and they indicated that the reason for terracing was not to save the soil but to retain moisture. Indeed, well into the dry season some beans and sunflowers were still ripe for harvest. If yield is correlated to rainfall, as shown in Figure 6, bench terracing can serve to shift the function to the left in its lower reaches, as described by the dotted line. Similarly, any of a number of supplementary irrigation techniques can perform the same function, even including watering the plants with buckets or watering cans, which is done for seed germination of carrots in Jamaica.

All of this crop mixing and water management is done to increase total output from the land per year, and to avoid inhibiting constraints. Risks are spread among crops and overtime and labor utilization is distributed more evenly throughout the year. However, distributing labor throughout the year is quite complicated because labor profiles differ for each crop. Rice requires relatively equal amounts of labor for each cultivation practice in the Philippines. In contrast, unmechanized rainfed maize uses the most labor at seeding and weeding time. Potatoes and vegetables require more labor at harvest to avoid rotting when maturity is reached. Figures 7a and 7b present two labor profiles, one for rice in Southeast Asia, and one for maize and beans in Kenya.

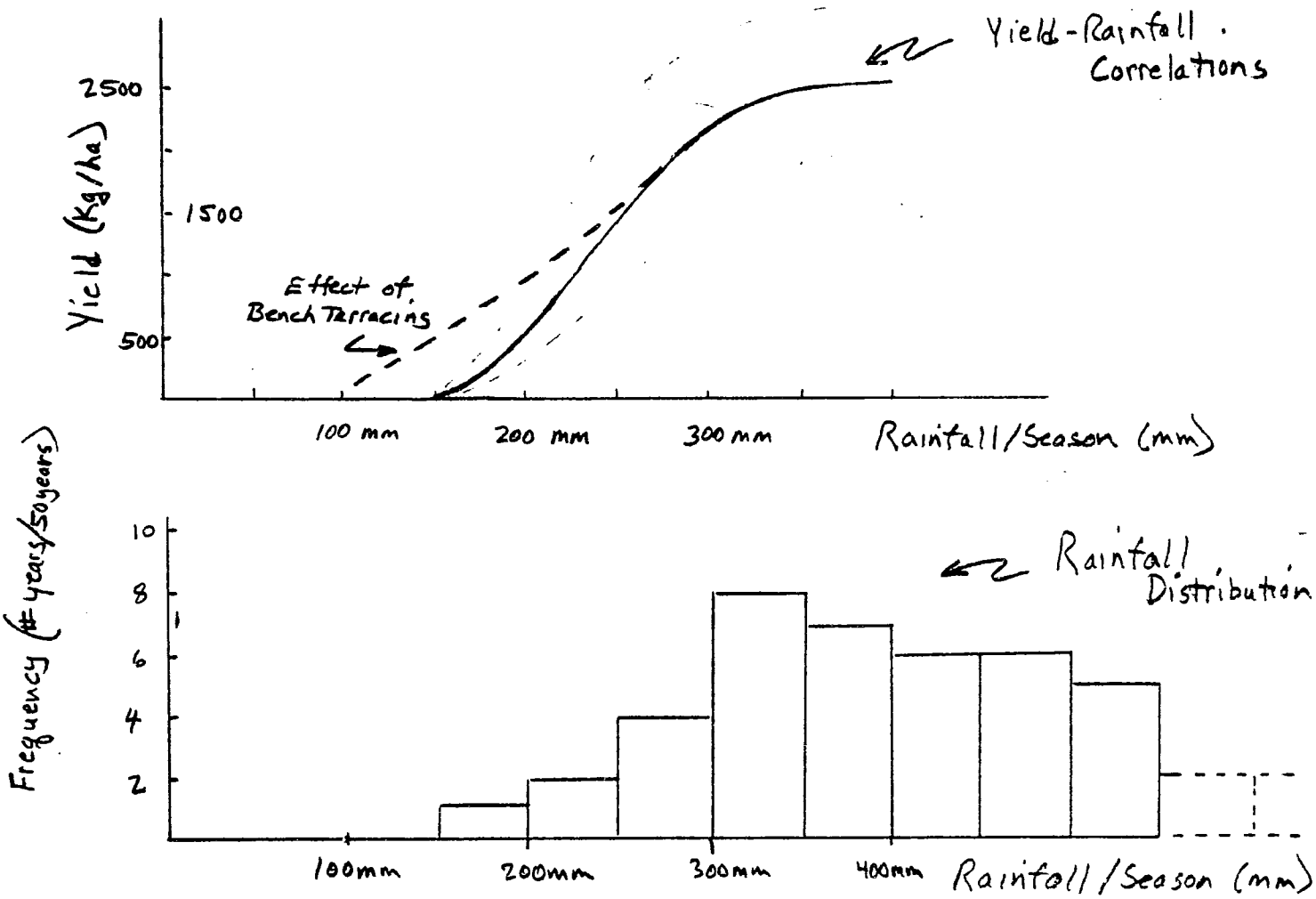
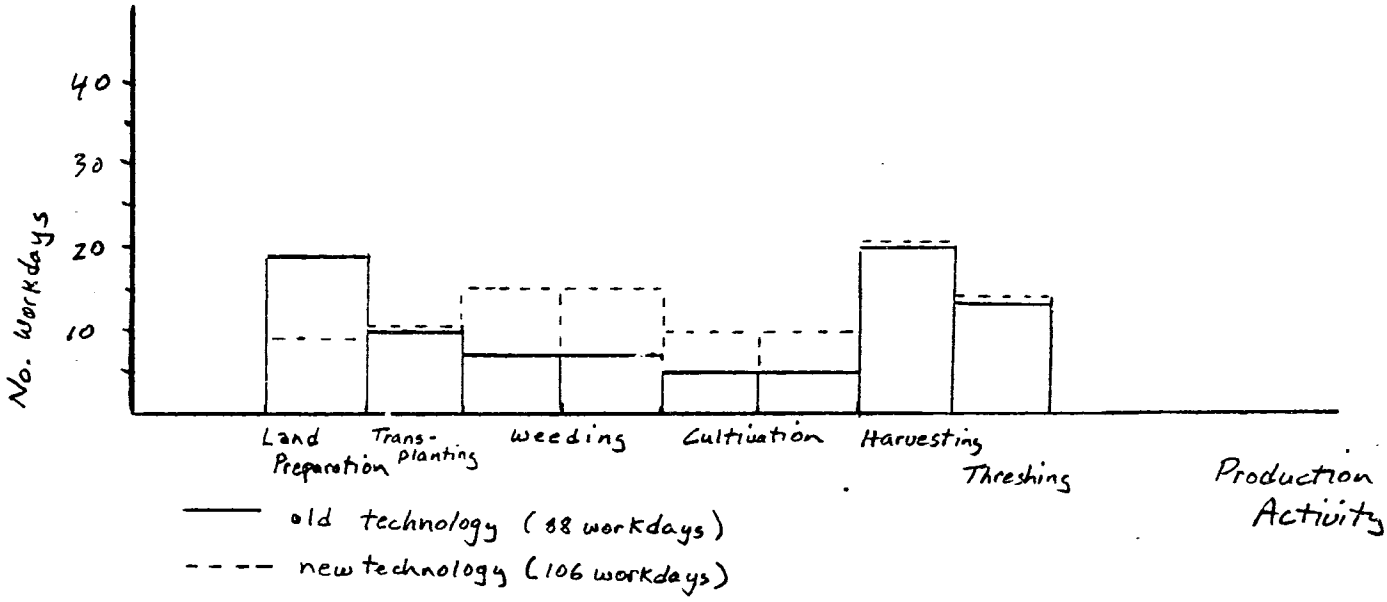


Figure 6. Yield-Rainfall Relationships in Machakos

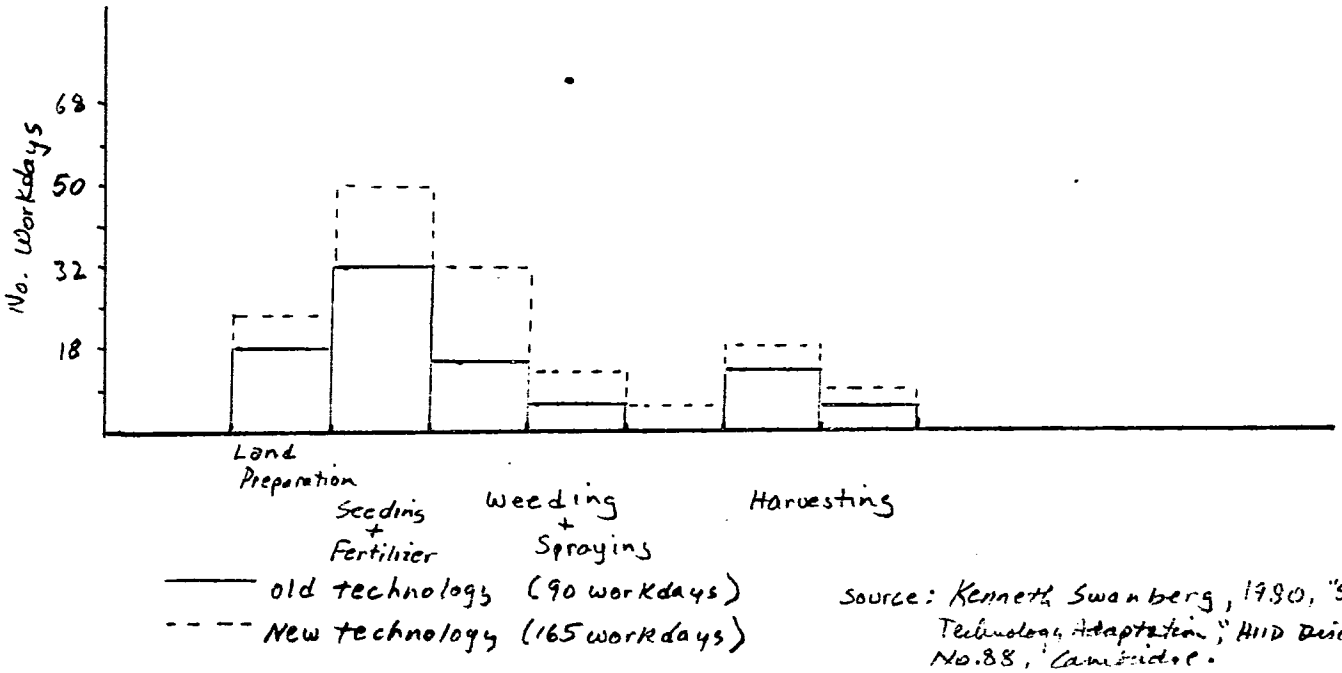
Source: Kenneth G. Swanberg, 1980, "Small Farmer Technology Adaptation—Reducing the Constraints caused by the Requirements-Limitations Gap", HIID Discussion Paper No. 88, Cambridge, Mass.

Figure 7a. Labor Profiles for Rice in the Philippines



Source: Yujiro Hayami, and Vernon Ruttan, 1984, op.cit., p. 53

Figure 7b. Labor Profiles for Mixed Maize + Beans, Machakos, Kenya.



Source: Kenneth Swanberg, 1980, "Small farme Technology Adaptation," HIID Discussion Paper No.88, Cambridge.

In general, production function analysis of rainfed subsistence crops in Kenya and Colombia have shown that the marginal products for labor were below local agricultural wage rates (see Figure 8). Labor marginal productivities for cash crops were higher than for subsistence crops but still below the wage rate. However, when mixed food crops were analyzed, productivities were higher than for the sole stand subsistence crops, but still below cash crops. Wage rate analysis, though not conclusive, lends support to the notion that labor productivities increase when family supply is limited or when families must hire or borrow non-family members. Hiring or borrowing labor occurs most frequently when family labor is not sufficient to perform the task, or the task is somewhat specialized. Further, hired or borrowed labor is used more for cash crops than for food or subsistance crops. Family labor seems to be "dumped" into subsistance crops especially for weeding.[1/]

The whole question of male-female differences so far has not been addressed. In Kenya, each province or ethnic and linguistic grouping shows a different pattern. Some share tasks equally, others are more male dominated for cash crops and/or for chemical applications or other types of mechanization. Wage rates seem to follow the degree to which one sex dominates the other. Where task sharing is equal, wage rates are quite similar. Where more sex differentiation occurs, women receive lower wages.[2/]

1/ Kenneth Swanberg and German Escobar.

2/ Vera T. Joffee

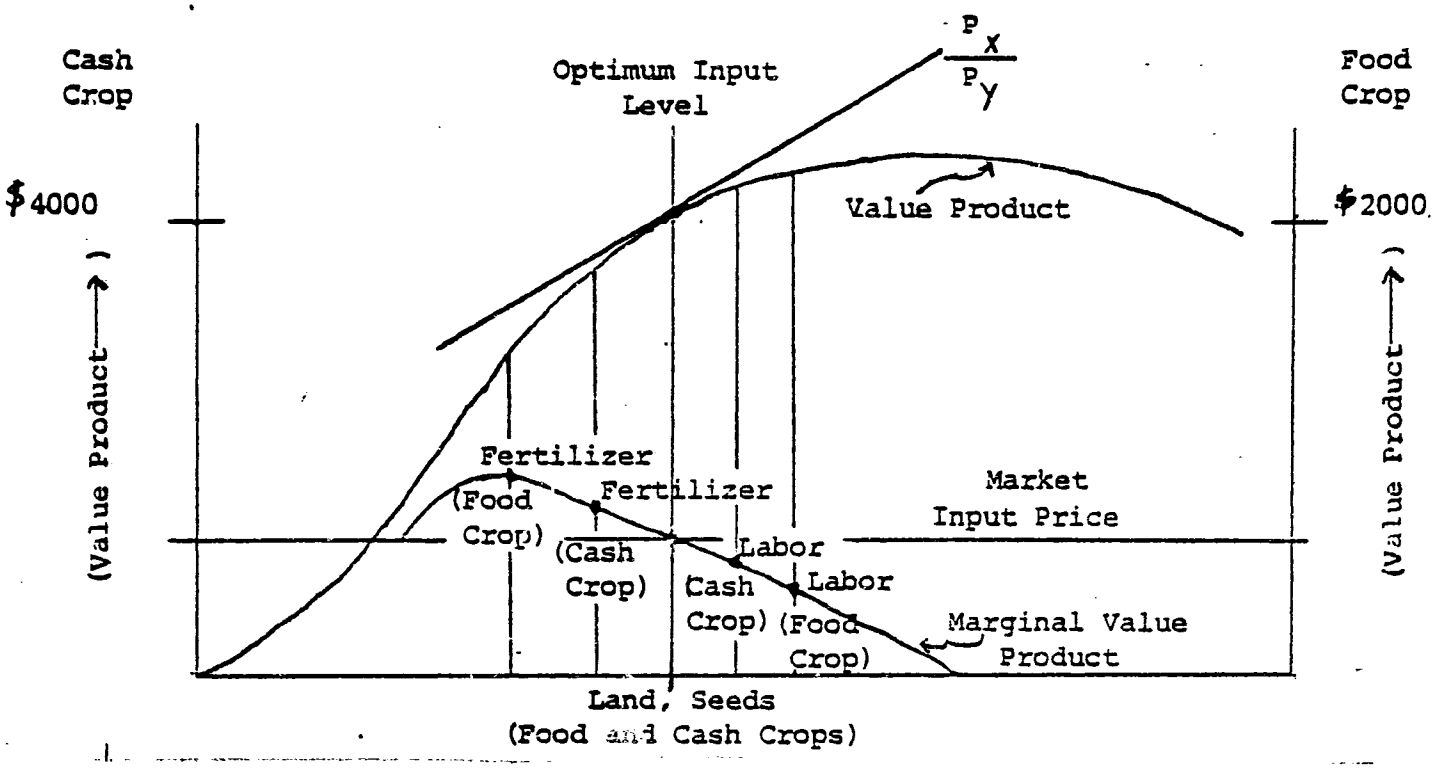


Figure 8. Productivity Variations by Crop and Inputs

This presentation clearly demonstrates how complex labor production profiles can be. Although macro-analyses of the African labor force suggests extremely low productivity rates,[1/] one suspects that much of the output used in calculating income per unit of labor at the margin is lost because only marketed or stored product is measured. Nevertheless, labor appears to be the one input whose producitivity could be increased and whose current cost is relatively low. How could this be done?

Two points need to be considered. The first is that although fertilization rate correlations with yield fail to produce significant positive results, it would be misleading to suggest that soil fertility and plant nutrients are sufficient. When fertilizer applications are tested under field and farmers conditions, other constraints may be binding which prohibit the plants from responding to the fertilization. Gerhart[2/] showed that time of planting was the overwhelming determinant variable in yield analyses in Western Kenya, but he carried out his study in a highland area where soil fertility was not deficient. Hence, our conclusion is that semi-arid, sub-Saharan cropping systems need nutrients, but at no or low-cost to the farmers. Most systems which can provide low cost nutrients involve preparation of legume mulches or developing live mulches or alley cropping with leguminous trees. Rodale Press developed a complete regenerative organic system for Tanzania reported on by Harwood last year.[3/] Another way to improve fertility depends on manipulating crop-sequencing to take advantage of crop, fertilizer and moisture

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1/ John Mellor, 1985, "Food Situation - A CGIAR Perspective" in International Food Policy Research Institute, Annual Review, Washington, D.C.

2/ John Gerhart, 1975, "The Diffusion of Hybrid Maize in Western Kenya", CIMMYT, Mexico, DF

3/ Richard Harwood, 1984, "Resource-Efficient Farming Systems for Tanzania",

residues, or yet another involves sharing inputs with mixed cropping techniques. Figure 9 graphically compares sole stand crops with mixed crops in Kenya.

Analyzing the data derived from Figure 9, Table I shows that returns to labor can be raised significantly by using mixed cropping systems. Moreover, low-cost inputs can also be incorporated into this system, which can lead to significant increases in returns to capital. Total labor use and total value output per hectare also increases, almost doubling for each. One question which arises is how can labor returns be increased even further?

Even though the mixed cropping system spreads labor throughout the year and does not increase labor demand for the peak period, improved hand tools, two-wheel or rotary ploughs, and "bush whackers" could extend even further the labor to land ratio during these time periods. The latter machine could be used for land clearing after the dry season as well. A key factor in Bradfield's multiple cropping work in the Philippines was the notion that labor demand peaks limited the number of crops which could be grown in one field in a year. By introducing the small, gas-powered, two-wheel tractor, he was able to reduce the labor requirements for land preparation, cultivation, and weeding, so that more rapid change over from one crop to another could take place, significantly increasing per hectare output. If labor becomes a constraint in mixed farming in sub-Saharan Africa, uniquely tailored mechanizaton and hand tools could be a first step to relieve these constraints.

With this kind of cropping system in mind, productivities could be increased. Many combinations of crops can be tried; there is no limit to what can be tested. The goal is to employ a constant supply of labor uniformly over the year to match the labor profile of rice in the Philippines. This kind of cropping pattern also deals admirably

with the risk function and environmental stress because Katumani maize does well in the short season and can be dry-planted. Pigeon peas and cotton can go dormant during the January-February wet-dry season. All three crops are sensitive to different temperatures, diseases, and pests. Pigeon peas cost little in inputs and are very drought-tolerant. While cotton requires costly pest controls, this crop can withstand quite a bit of moisture stress. In fact, it does well in dry climates. Maize is more delicate with respect to rainfall, especially during tasseling, and for this reason is concentrated in areas with more "secure" rains, the short-rains. By covering the ground for ten months, wind and sheet erosion is also reduced. All in all, this system appears to be extremely well suited to Zone IV ecological zones and quite drought-tolerant in general.[1/].

Risk and Environmental Stress-

Production risk increases when input costs rise unless output variance falls dramatically. The factors which determine risk levels include mean yields, their variance, price variance and input costs. Although many econometric models have been developed to measure production risks, applications of different models rarely lead to different conclusions[2/]. And

[1/] Innis has done a similar job explaining the adaptability of traditional intercropping systems in West Africa, drawing heavily from Norman and Okigbo's work. Donald Innis, 1980, "Measuring the Superiority of Traditional Agricultural Methodologies in Northern Nigeria", State University College, Geneseo, N.Y.

[2/] A recent study of rice farmers in the Philippines tries to show that rain-fed rice farmers are no less risk-neutral than irrigated rice farmers, a premise held by Roumasset [1975]. When stress is tolerable (potatoes in Caqueza), farmers respond in risk-neutral fashion. When risks are excessive, they react much more conservatively. In Caqueza, it was shown that farmers accept risks according to their wealth levels, a surrogate for risk absorption. The greater the risk and the lower the wealth levels, leads to the observance of higher risk avoidance responses. Unfortunately, the referenced article deals with Asia, not Africa.

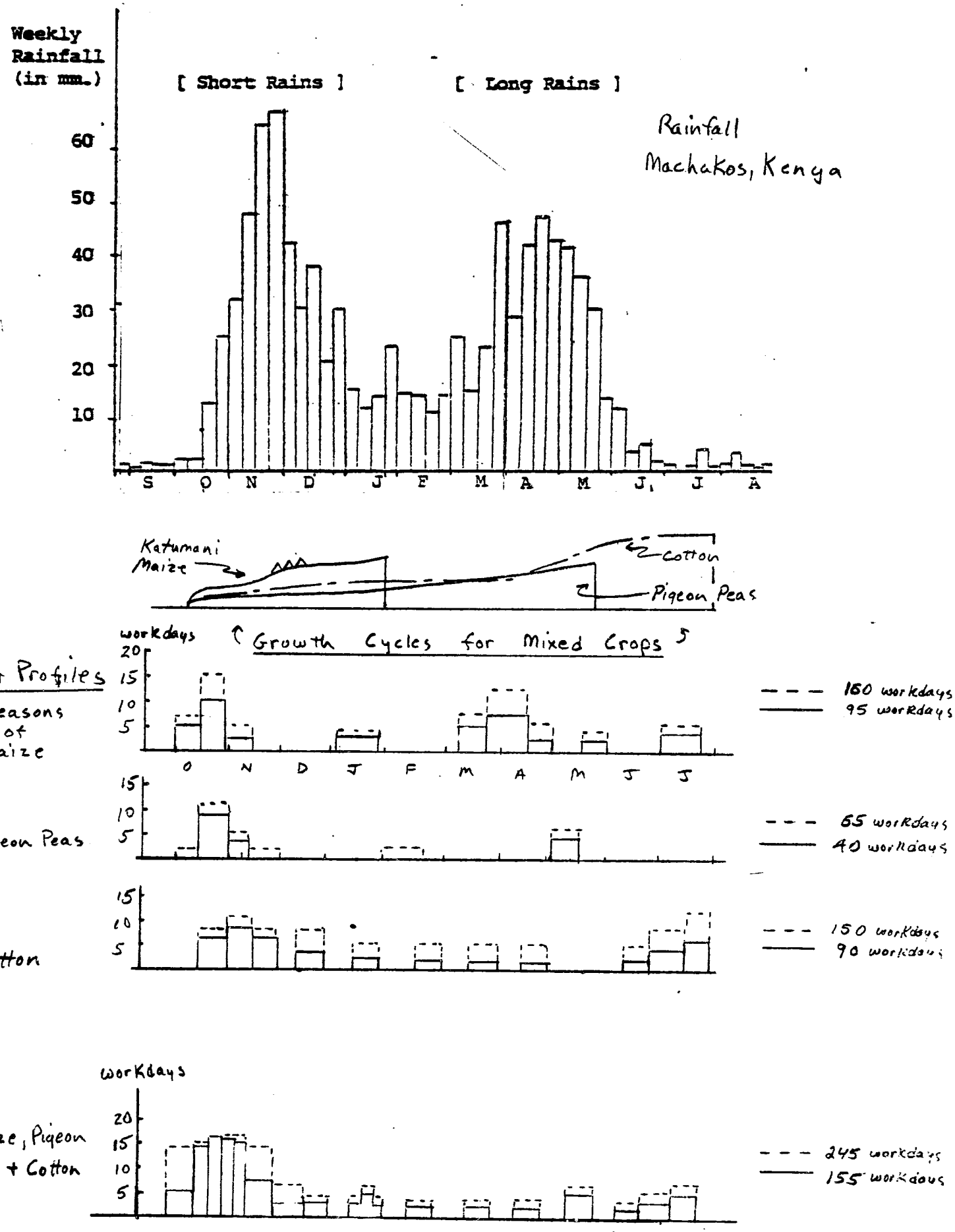

Figure 9. Relationship between sole stand and mixed crop labor profiles with rainfall, Machakos, Kenya.

when risks, however measured, are high for new technologies, their adoption and utilization will only occur when additional interventions are introduced to absorb or "buffer"[1/] their impact. This can be done in many ways. Application or retention of moisture reduces output variance and increases mean yield. Price controls stabilize market prices. Input subsidies reduce production costs. The most common risk analyses consider a safety-first type mean-variance model. This involves looking at the probability of assuring some minimum output level or accepting a minimum loss rate and comparing mean-variance tradeoffs. Generally speaking, once subsistence is assured, adoption will occur on crops with yields higher than traditional crops as long as variance remains constant, or adoption will be greater for technologies with low variance. However, when both yields and variance change radically, response functions are hard to predict. Nevertheless, it can be said that interventions or technologies which reduce variance or guarantee output or incomes normally generate high utilization rates. Cost reducing programs such as subsidized credit are less successful because crop losses may be of such magnitude that no earnings are available for even partial paybacks. Price subsidies meet the same fate.

When climate changes dramatically from season to season environmental stress becomes a major factor inhibiting technology generation and utilization. Rainfall, temperature, and pest and disease incidence are closely correlated, but manifest themselves and affect production output in different ways.

2/ Hubert Zandstra, Kenneth Swanberg, et. al., Op. Cit., p. ____

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Excessive rain in a short time period can cause gulleying or rotting, and drought can starve the plants. Any intervention which can control water management can dramatically reduce production variance. Terracing, tie-ridges and catchments can retain moisture; water furrows, small earth dams, sub-surface dams, and water harvesting techniques can provide water for trickle irrigation. Windmills can pump water from lakes, wells and streams. However, full scale irrigation schemes have become costly, often silting up too rapidly, and creating health hazards. Without high output prices, irrigation schemes can rarely support investment costs in spite of their mean-variance reducing advantages. One exception may be Ruthenberg's suggestion of valley bottom development with sub-surface, earthen dams.

But just as variation in the physical environment requires control, the variation in service delivery systems needs to be managed.. If the mean output of a service is the delivery of an input or knowledge imparted by an extension agent on a farm visit, the timeliness or the lack of regularity of such services can affect farmers in the same way as the reliability of rainfall. In the technology utilization formula the assurance of the delivery schemes' schedules may be much more important than the quantity of inputs delivered, their price or the basic knowledge transmitted. When a pest, disease or weed outbreak occurs, immediate care is required. The absence of extension agents at such times can critically affect the viability of new technology introductions regardless of how high potential yield expectations may be. Environmental stress includes institutional variance, as well as physical variance. Institutional stress refers to the manipulation of prices and price information and the timing and quantity of services delivered. The greater the variance of expectations the greater the stress. Technology development itself, then, must build in minimal tolerance levels, or design buffer institutions to reduce such stress.

The Pattern of Institutional Innovation

In the two previous sections we talked mainly about bio-physical constraints--land, climate, inputs and environmental stress. Labor and capital were also mentioned, but more in terms of their quantity rather than the organizational structure which provides for their access. But just as bio-physical constraints can prohibit technological utilization so can socio-economic constraints, in the form of institutional structure and performance, limit the use of existing, potentially high-yielding technologies. In the book Caqueza-Living Rural Development [1/], the concept of "buffer institutions" was introduced, which is "an expression which attempts to catch the essence of the dynamic absorptive nature of the new transitional [adaptive] institutions being created." Although the term "buffer insititution" has been severely criticized since the book was published, the description of the need for adapting institutions just as technologies require adaptatation is perhaps even more appropriate now for introducing new technologies in semi-arid sub-Saharan Africa then it was for Colombia and Latin America a decade ago.

> "The concept of buffer institutions may be illustrated by referring to the generation of agricultural technology. Researchers seldom can identify techniques leading to substantial production improvements while operating entirely within the limitations of the small farmer. Generally, the rate of production increase is related to the extent to which the researcher moves beyond these limitations. This

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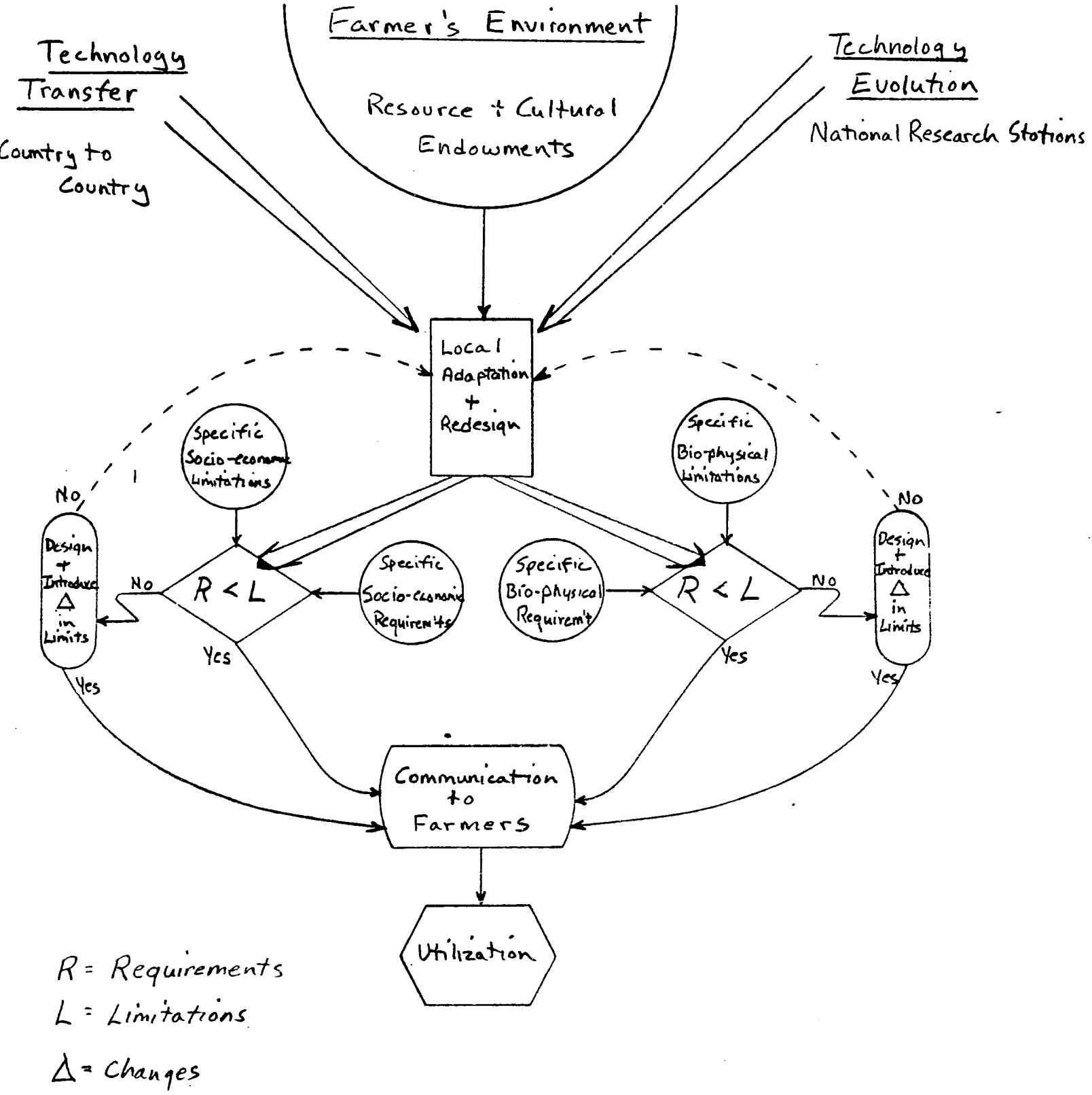
1/ Herbert Zandstra, Kenneth Swanberg, et. al., op. cit.

> process] forces agricultural researchers to decide for which level of institutional support their technologies are to be formulated If the researcher introduces a technology which demands changes in the institutuional support system, the approach is "interventionist". If the technology design falls completely within existing resource endowments and institutional supports, the process is labeled "submissive".".

The book goes on to analyze the adoption of a new technology and suggests that any new technology will require more of some input. If the existing institutional support system does not currently provide access for the increase required, either adoption and utilization will stagnate, or changes will have to be introduced. This process can be simulated as shown in the diagram on the next page.

1/ Hubert Zandstra, Kenneth Swanberg, op. cit. p.

Figure 10. Technology Transfer and Feedback Mechanisms



The diagram shows that when the requirements of the technology are greater than the environmental limitations or endowments, a constraint arises. Either an expansion of the limitations (interventionist approach) or a reduction in the requirements (submissive approach) is necessary for communication and adoption to procede. The top of the diagram shows that technologies can either be transferred internationally (such as seed stock, fertilizers, pesticides or equipment) or developed nationally (typically cropping patterns, disease resistence, fertilization rates, or equipment). In the same way, institutional designs can be imported or developed locally.

In Figure 3, we showed that technologies must be introduced in an iterative process, so that each "new" technological component or characteristic fits within the context of market prices for inputs and outputs given technical and cultural response rates. Perhaps institutional reform and evolution must follow the same alternataive path. Unfortunately, development schemes supported by the donor community, especially the World Bank and USAID, have followed the "transfer" process rather than the evolutionary or iterative, adaptive strategy. Esman refers to this process as the activities of expatriate specialists exporting their own familiar organizational models.

The transfer of institutional forms began during the early colonial period, and continued throughout the post-World War II period in Japan, the Philippines, Latin America and in Africa by the formulation of imported institutions dealing with public administration, parent-teacher organizations, highway departments, 4-H

clubs, and agricultural extension[1/]. Prior to the U.S. influence, the European powers introduced the single crop research institutes and marketing boards, usually for high-valued export-oriented crops. Many of these organizations remain today. However, the U.S. tried to export a different model based on what was successful at home and spurred on by the post-World War II euphoria of Truman's Administration, attempting to transfer "Yankee know-how". The principal characteristics of the extension system were training and demonstration of better agricultural techniques. The key was education and communication. Also, prior to World War II, supervised credit was added to the organizational mix in the U.S.. Low-interest loans were part of the New Deal efforts to save the family farm. When the Food Security Administration was eventually subsumed by the USDA, low-interest loans to marginal farmers lost support. Nevertheless, this same program surfaced as a major element in donor projects during the 60's.

In the early 60's, the value of straight extension came under question. In the U.S., the land grant system of research, training and extension, all housed in one organization, was viewed as the more viable approach. Several land-grant type institutions emerged in developing countries as a result. Although the land grant model originally did well in terms of providing a framework for local research, testing and adaptation of new technologies rather than a simple "short-term transfer of known practices and methods," it failed in its assumption about the farming environment. In the U.S.,

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1/ Milton Esman, 1983, "Research and Development Organizations: A Reevaluation", in W.F. Whyte and D. Boynton, eds., Higher-Yielding Human Systems for Agriculture, Ithaca, New York: Cornell University Press. Esman

client-farmers of the land grant system had access to market information, easy credit, price supports, crop insurance, market orders, transportation, futures, mortgages for equipment (based on a functioning land market) and much more. All of these conditions were absent in the developing countries. Unless these elements were included in the package, their absence served to prohibit rapid agricultural change.

What emerges from this analysis is that institutional forms, just like agricultural technologies, must be adapted to local conditions. "Cheap" human resources can be created by means of reorganization and changes in the rules of the game which can then be substituted for institutional inputs facing inelastic supply. Credit based on land titles provides nothing when cadastral surveys have not been processed or lands are communally owned. Mortgages must shift to annual crops or livestock instead of value-less land. The concept of "buffer institutions" comes back into the picture.

As technologies are designed, considerations must be made for their institutional requirements, and institutions responsive to those requirements must be designed and adapted to local conditions based on a thorough understanding of local laws, customs, cultural heritage and

human resource endowments. Also, as the production mix shifts from subsistence to market orientation, the array of demand for support services changes accordingly. Figure 11 captures the essence of this process as it follows the shape of a typical adoption curve[1/].

When farmers raise subsistence crops for home consumption, little information is demanded on prices and sources of credit or any other support activities. Although few farmers produce exclusively for home consumption, the degree to which the matrix of support activities has developed depends, to a large extent, on how much of their output hits the market. Darlymple has claimed that if less than 50% of farm output is sold, the farmers are considered subsistence farmers. This classification may be totally arbitrary, but nevertheless, minor market participation of the "subsistence" farmer does not draw as heavily on the varied support activities that a dynamic totally commercial agriculture requires. What is not known, though, is what comes first—the provision or delivery of the whole set of support services, or the increased output. Certainly the lack of services constrains output and it can be shown that services cannot be offered if output is minimal because the value added for small volumes could not justify the costs for the services. But there must be a way to order the kind of services needed along an evolutionary path which coincides with the emerging technologies so as to create just enough

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1/ Kenneth Swanberg, 1982, "Institutional Evolution: From Pilot Project to National Development Program—Puebla and Caqueza", HIID Development Discussion Paper No. 132, Harvard University, Cambridge.

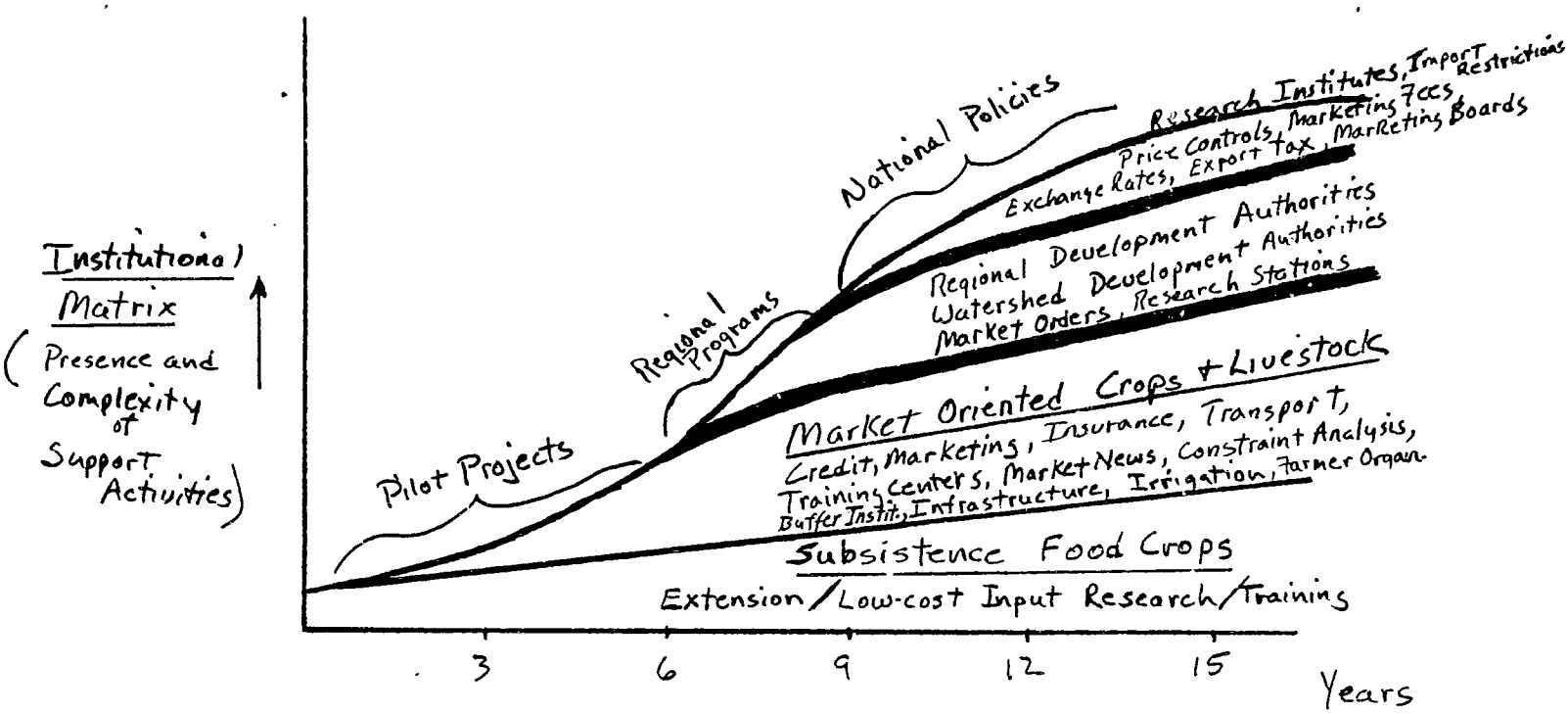

Figure 11. Phases of Development Projects

incentive to spur on the adoption process. The problem which needs to be addressed by research is that of how to identify this set of institutional supports and the time schedule they require for development. Research in semi-arid sub-Saharan Africa using this framework must be carried out on the correlations between technology change and institutional supports.

Imagine, if you will, an economy with land surplus held in common by ethnic groups, with complex rules and regulations regarding rights to use and transfer. Technologies which change the values of those lands but fail to touch on the land transfer or payment issues for those improvements will never achieve high adoption, unless the impact of the technologies are so great as to induce the required institutional changes.

Expenditures for bench terracing to control erosion and reduce moisture loss will be less forthcoming if hereditary rules pass the land on automatically to other family or clan members whenever the family head dies. Until some kind of land market or land trade system evolves, the farmers efforts to improve the basic stock of land will be limited. Resistance to technological innovations will occur in situations which deal with water control techniques such as access to water from small earth dams or subsurface dams by trenching, water harvesting in the stream basins, or valley bottom water table manipulation, if compensations in land rights are not included. Without these institutional changes to create the assurance of constant moisture at critical growing periods, the adoption of expensive seeds, chemicals, and fertilizers will be avoided.

The key institutional issues for semi-arid sub-Saharan Africa as they affect technological change and utilization have not, as yet, been identified. But let us look at the relationships between technological and institutional changes. Just as inelastic supply of land induces technological innovations which maximize labor use, constraints on land acreage also induce institutional changes with regard to property rights. Similarly, if labor is expensive relative to land, technologies will concentrate on mechanization or capital substitutions for labor, and institutional changes will be ones which give greater definition to labor obligations and the workers' control over work conditions, i.e., less servitude or slavery, and more equality among sex and age groups.[1/] When the technological change is less dramatic as we have suggested for semi-arid sub-Saharan Africa compared to Asia, perhaps the institutional changes will need to be more spread out over a whole range of institutional support functions and mechanisms. Moreover, with capital and purchased inputs facing inelastic supply schedules, new institutional forms will be required which reduce the cost of marketing or distributing inputs to farmers, or spread input supply over the multiple cropping season, or finance more varied sets of inputs including hired labor throughout the year rather than for any particular rainy season. Of course, without the appropriate institutional changes, farmers will shy away from the technological innovations. So if the technological changes

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[1/] Vernon Ruttan, 1985, op.cit.

move iteratively along the meta-production expansion path, it could be that institutional changes also need to be iterative and simultaneous, corresponding to the specific technological needs along that same path. Experience has shown that, as new technologies become available and increase production potential, existing institutional arrangements can become contraints to their use. But as soon as appropriate institutional modification occurs, new technological adjustments and adaptation will be required in order to keep the flow going. The use of this model will perhaps give guidance to researchers in Africa who are currently groping with the design of the proper matrix of technologies and institutions which are needed to increase technology utilization and leverage more rapid agricultural growth rates. It is certain that no one set of institutional reforms will be appropriate across the continent. Each set of institutional reforms must be tailored to local factor and cultural endowments, but it is postulated that a given set of institutional functions must be designed for each environmental strata. If any particular function required by the newly iterated technology is not provided or delivered, its absence could be the cause for the lack of technology adoption and the advance of agricultural growth. A list of these critical functions could, presumably, be developed from field surveys. The design of institutional reforms and experimental field trials would then have to be carried out. Past research would indicate that the principal

functions could include one or more of the following: control over labor exchange and payment, the generation and supply of technical information, the supply of low-cost inputs, the control and financing of water conservation systems, production and market risk alleviation devices, and the financing of enterprise mixture. with debt roll-over schemes to handle potential droughts. Since not much has been researched in this area, trial and error approaches under field conditions may have to be implemented and tested. The challenge, though enormous, also becomes intriguing.

Chapter VI

Conclusion: A Statregy for Improving Agricultural Output in the Short-Run: Food for Africa

The Hayami/Ruttan induced technological change model of development shows how the "Green Revolution" evolved in Asia. It identifies the conditions that were required for stimulating investments in the agricultural research institutions which developed the "miracle" varieties. Historical analysis of the U.S., Japan, and Europe, highlighted the fact that those countries developed technologies which substituted readily available cheap resources for inaccessible expensive inputs, for use on commodities with high demand. When these conditions existed, resources were devoted to improving these technologies, and institutional responses were also induced to reinforce the research and the resulting production patterns. Their insight went on to demonstrate that because

conditions similar to those found in the U.S., Japan, and Europe also appeared in Asia, an identical strategy was successful, and in fact, occurred quite rapidly due to the efforts resulting from heavy investments made in research institutions devoted to developing precisely this type of technology, namely, high-yielding fertilizer responsive rice and wheat varieties. Where the conditions were not similar, such as in Mexico and Latin American, these kind of results failed to materialize even though the same kind of research investments were made. One can deduce, then, that resource and cultural endowments coupled with the level of demand for outputs determines the strategic path that technology development and institutional supports need to take. When the ratio of the price of the input substitute and the product price is not dramatically small, as it was in Japan and Asia, harboring expectations of "miracle breakthroughs" are ill-advised and perhaps counterproductive. Economies without the conditions specified above cannot justify nor sustain such research. Instead, an alternataive approach is needed for moving out the hypothetical production function expansion path of all possible technological combinations. The jump from a strategy of low input levels with low output expectations and low variances to the opposite extreme, especially in the absence of clear cut opportunities for cheap resource substitutions, becomes virtually impossible. Such situations, instead, dictate an iterative, staccato approach of technology generation and adoption.

In Chapter IV, the situation in Africa was described as one with (1) low product demand at current prices or with existing price policies, (2) capital and cash for chemical fertilizers as the expensive input facing inelastic supply, (3) labor as the relataively cheap input but only at certain seasonally determined periods, and (4) an entire system permeated by intensive risk patterns, both in biophysical as well as socioeconomic terms. The strategic path which needs to be followed given these conditions is one which induces institutional changes in order to expand use of required inputs in existing production relationships and then to initiate research to move out the expansion path by changing seeding dates, developing better mixed cropping techniques, and designing low-cost nutrient supply systems along with pest management and control techniques.

All of these input manipulations would lead to increases in labor use during non-peak demand periods, thereby generating higher labor productivity rates. Secondly, institutional forms (infrastructure, policies or support organizations) need to be modified towards a greater ability to manage risk, to get a handle on the bio-physical variance through the study and introduction of cropping patterns and crop combinations which are drought-tolerant or drought-avoiding. Risk also appears in the institutional realm in terms of a whole set of policies which affect a) price variation or stability, b) input controls, and their prices and delivery schedules, and c) explicit or implicit taxation on outputs. Experimentation with different organizational forms and adaptation to local environments and communities are needed for induced institutional changes in Africa just as this process is required for on-farm adaptation of

technological packages. There is an urgent need to apply this model of Hayami and Ruttan to several African countries. A process must be initiated to identify existing production relationships and productivity rates, to record local demand schedules, and to describe current institutional support structures. Subsequently, promising new technologies and corresponding institutional adjustments must be tested and evaluated. Once new possibilities emerge, communication to farmers and policymakers must take place in order for implementation to occur. It is felt that with the use of this model great inroads can be made towards the design of new development programs which will improve technology utilization rates in semi-arid, sub-Saharan Africa in the immediate future.

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Table I. Budget Analyses of Sole Stand, Mixed Crops and Relay Crops

(x 2 seasons)

Sole Stand, Maize	Traditional System	Improved System
Yield (kg/ha.)	(875 x.7*/)2 = 1225	(2500x.6*/) = 3000
Price (U.S. $)	$.94 1/	$.94
Value (U.S. $)	(823 x.7)2 = 1152	(2350 x.6)2 = 2820
Labor (workdays)	(50)2 = 100	(80)2 = 160
Returns to Labor	= 777	= 5.13

*/ adjusted for rainfall variation, drawn from interpolation of figure 6.

1/ all prices are Kenyan prices, 1980.

Mixed Crops */	Maize	Pigeon Peas	Cotton	Total Values
Traditional				
Yield (kg/ha.)	575	250	270	
Price (U.S. $)	.94	1.89	3.20	
Value (U.S. $)	575	472	864	1911
Labor (workdays)	50	30	80	160
Returns to Labor	7.77			8.58
Improved				
Yield	1500	625	800	
Price	.94	1.89	3.20	
Value	1410	1181	2560	5151
Labor	70	55	120	245
Return to Labor				980

Data Source: Kenneth Swanberg, op. cit., p.20