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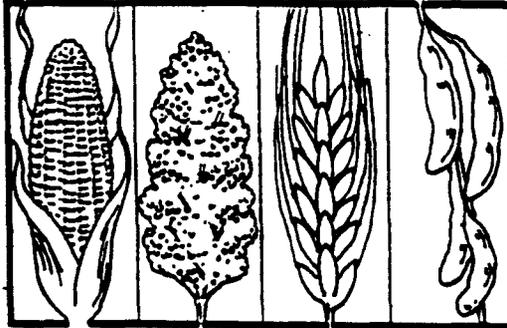
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RESEARCH AND DEVELOPMENT STRATEGIES
FOR A SUSTAINABLE AGRICULTURE

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"Food production and rural income are two prime concerns of Third World governments. Increased food production and greater food security are goals which countries strive to achieve through agricultural development. The technologies generated by research, commonly known as green revolution methods, have provided an impetus to food production in some favored zones where resources are available to take advantage of this production package. New varieties, productive and responsive to fertilizer, have bought time while countries work to control population growth and develop agriculture and industry" (Francis and Harwood, 1985).

The pioneering work of the International Agricultural Research Centers has been successful in developing varieties and packages and in training national program scientists and extension specialists to validate and move them to the field. The process and progress have been summarized by Wortman and Cummings (1978). We now know that the substantial inputs of chemical fertilizers, pesticides, and fossil fuels needed to adopt many of these new technologies has made them unavailable or unaffordable to most limited resource farmers. In addition, experience shows that indiscriminate use of fertilizers and pesticides can add unnecessary production costs and even create dangers to farmers and their families.

The greatest immediate challenges facing national research and extension programs and the international centers are the development of appropriate and productive alternative technologies and how to move these practices and systems to those farmers who are as yet beyond the reach of current programs. There is growing consensus about the focus of future research and development priorities, including:

- concentration on low-input strategies which depend on internal resources on the farm;
- exploitation of biological efficiencies inherent in diversified cropping systems;
- development of more productive multiple cropping and crop/livestock integrated systems;
- examination of how components fit together in systems and how complex interactions can be understood and used to advantage;
- analysis of risk inherent in adoption of new and possibly more expensive technologies; and
- application of some farming systems methodology in identification of key constraints and participatory approaches to development of solutions.

These ideas are not new -- many have emerged through experiences of scientists in the international centers and in key national programs. Each of the topics is explored in some detail, with key references given for further reading and study.

Focus on Internal Resources

Traditional agriculture has depended for centuries on internal resources -- those which are present on the farm or in the immediate environment. In general, these are renewable resources, and become newly available each cropping season -- rainfall, solar energy, mineralized nitrogen, nutrients cycled from organic matter and

from lower soil strata. Although rainfall and solar energy cannot be changed, we can influence the availability of these resources through manipulation of the cropping system.

A useful comparison of these internal resources with production inputs brought in from outside the system was presented by Rodale in a USAID seminar in 1985 (Francis and Harwood, 1985) and refined by Francis and King (1987). Summarized in Table 1, these contrasting internal and external resources make up the prime list of crop plant needs for growth, development, and useful production. All cropping systems make use of a mixture of these two types of resources. It is the balance of use of internal and external resources which may determine both the profitability and sustainability of a production system.

Most new technology developed over the past four decades has built on the foundation of successful experience in temperate regions where chemical fertilizers, pesticides, mechanization, and irrigation have produced remarkable advancement in crop yields per unit land area and per unit labor. These external resources presuppose abundant and inexpensive sources of fossil fuels. Sophisticated cropping practices based on extensive use of outside resources also presuppose an ability by the farmer to purchase the inputs, an educational level to understand and use them wisely, and a physical infrastructure which permits easy access to both inputs and to the market. Many of these elements are missing in developing countries for the majority of farmers.

Research has concentrated on maximum production based on availability of external resources. Data abound on the response of crops to different levels of nitrogen, the yield levels under different herbicide regimes to control weeds, and the economical levels of irrigation for crop production. Less well known are the effects of crop rotations in the tropics, the value of green manure crops and alternative sources of fertility, and the trade offs between herbicide and cultivation and other management options to control weeds. Likewise, we have often focused on whole system modifications -- the "package of practices" approach -- rather than analyzing existing production systems to see what components could be modified and improved. In some favored areas, these packages have found acceptance -- in many others they have not.

To give serious attention to the potentials of agricultural productivity of limited resource farmers requires careful attention to the internal resource base. By shifting attention to internal resources, we can design a logical exploitation of production potentials of the local environment and seek ways to make efficient use of renewable resources on the farm. Although there are certain inputs which may be needed from outside, the most appropriate system will recommend only those which are not available from any internal source, and will seek a balance between both purchased and renewable resources. Some outside inputs such as seed of a bean variety or information on an efficient crop rotation become internal resources as soon as they are adopted and incorporated into the farmer's system. Such production systems can be designed to be compatible with the local resource environment and need to be sustainable over time.

Biological Efficiencies in Cropping Systems

Complex interactions among crops, weeds, insects, microorganisms, and the natural environment are not well understood. Yet these are the vital processes which influence crop growth and productivity. In high-input agricultural systems --

dependent on fertilizers, pesticides, perhaps irrigation -- some of the dynamic interactions in systems are masked or reduced in importance due to the dominance of the external inputs. For example, nitrogen fixation is suppressed by high rates of N application; competitive ability with weeds by an intercrop mixture is not expressed when a broadcast herbicide is applied; and differences in drought tolerance among sorghum or millet lines cannot be evaluated when the nurseries are irrigated. Much of our early work with intercropping of maize and beans was conducted in the level Cauca Valley with needed fertilizer, pesticides for weed and insect control, and irrigation at the first sign of drought. Although this gave valuable information about the ultimate potential of intensive systems, we no doubt missed some of the most important information about crop/crop and crop/pest interactions by controlling the production environment.

Examination of specific components of a production system -- density of each crop in a mixture, varieties, planting dates, physical organization -- as they interact and influence each other gives us some appreciation of biological structuring of complex cropping systems. There are biological efficiencies which build on these complex interactions (Harwood, 1984). The potato/maize/bean intercrop pattern of Eastern Antioquia in Colombia illustrates efficient use of sunlight and rainfall through the twelve months of the year. Differences in rooting pattern, aerial growth, and temporal use of resources make this relay pattern more efficient than any imaginable monoculture in the same environment.

The potential biological efficiencies possible in a complex intercrop pattern far exceed those of monocultures -- in light and water use, nutrient cycling, and promotion of greater microorganism activity. Some systems include as many as fifteen or more species planted at different times during the year, as illustrated by the food crop mixtures in the tropical forest zone of southwest Nigeria. Resource use in these complex systems is somewhat analogous to that of a diverse natural ecosystem. If chemicals are not used as part of the production package, the potential biological advantages may be even greater. More detail on specific aspects of biological efficiency can be found in recent references (Edens and Haynes, 1982; Heichel and Barnes, 1984; Jain, 1985; Patten, 1982).

Multiple Crop and Crop/Livestock Systems

The emerging appreciation of the importance of multiple cropping systems in supplying food for developing countries is illustrated by an increase in research attention over the past four decades. Table 2 shows the publications from an ICRISAT literature search in 1984 (from Francis, 1986). For the fourteen crops listed, there were only 42 publications during the years 1951-55, but this increased to 1000 publications during the years 1976-80. In the recent reference book "Multiple Cropping Systems", thirteen of the twenty authors were specialists who had conducted research either as staff or as graduate students in one of the IARC's.

Early experience in the centers with productivity of new varieties of crops in monoculture gave way to a more balanced concern about evaluation of germplasm in a range of systems. This included screening under different stress conditions such as the pressure of sequential and intercropping. Examples of this work include the rice--rice--mungbean patterns in IRRI, maize/bean work in CIAT, the pigeon-pea/sorghum research in ICRISAT, and cowpea/maize studies in IITA. The ILCA concern with alley cropping in outreach programs in the Sahelian region is another expression of the perceived importance of complex interactions and crop/animal

systems in Africa. This type of research and development emphasis is most likely to continue and even accelerate as we direct attention to limited resource farms and their dependence on complex cropping and crop/livestock systems. Other recent and useful references on intercropping and other intense systems include the review articles by Willey (1979a, 1979b) and books by Harwood (1979), Beets (1982), Steiner (1982), and Gomez and Gomez (1983).

Focus on Systems Research

The IARC's were not envisioned as centers for systems research and training. Given the mandate to study a small number of high priority food crops and animal species, each of the original centers was organized into classical departments by discipline. Most of the centers quickly changed this to crop-focused teams and emerged as a dominant force in the development of germplasm worldwide. Major advances were realized through plant breeding and the development of "complete package" systems for single commodities. In some locations, the variety was a single component with sufficient advantage to cause a marked change in cropping systems -- short cycle rice for example.

An independent but growing awareness of the importance of total cropping and crop/animal systems in several centers led to organization and funding of multiple cropping, small farm systems, or practical farm-based training activities which focused on more than one species. The centers, especially CIMMYT and IRRI, gave major impetus to the early development of theory and methodology of farming systems research and extension. This built on the experience of a number of development projects with national programs (see Gilbert et al., 1980; Byerlee and Colinson, 1980; Hildebrand, 1979).

The current dissatisfaction with farming systems research/extension methods is a result of exceedingly high initial expectations by researchers and administrators about the potential results of this methodology and the early promotion of this approach as the solution to all development challenges. This is not the fault of the method -- it has been shown to be successful in many areas as a logical and practical application of farmer participation in the research process. Whether known by the same names or not, this approach will likely be central to much of our development work with limited resource farmers. Practical linkages of FSR/E methods with commodity-specific programs are illustrated by the CIMMYT training manual (Perrin et al., 1979).

Recent work on conceptualizing the biological changes in a given farm field centers on the linear and the cyclical changes which result from choice of a given crop and cropping pattern (Francis et al., 1986). Choice of crop rotation, biological sources of nitrogen, diversity in crops, and low- or non-chemical control methods for weeds and insects can cause a number of favorable changes in the field environment; this is a reliance on internal resources for production. Continued monoculture cropping with heavy outside resource inputs may successfully dominate the field environment and produce high yields for a time, but there are negative consequences of this strategy -- even if the input level can be maintained. Careful study of cyclical changes in weed and insect populations, organic matter and nutrient cycling, and trapping and conservation of rainfall can lead to a favorable "progressive biological sequencing" in that field.

Individual fields are not managed in isolation, one from another, on the farm. Interactions with other enterprises and fields influence decisions on which crops

to plant, what the sources of fertility will be, and how limited resources will be distributed across the several activities in the farming system. This could be called the "integrative farm structuring" of the operation (Francis et al., 1986). Careful consideration of available resources and potentials of efficient use of internal production factors can result in a viable and sustainable production system for the farm.

Analysis of Risk

Early emphasis on production economics in the IARC's was given priority over other types of analysis including potential increased risk from adoption of new technology. Given the complexity of small farm diversified agriculture, existing production economics models were difficult to adjust to the reality of limited resource farms. Goals other than maximizing profits were found to be important -- these included nutritional, social, political, and environmental concerns of families and communities (Francis, 1985). This complicated the economic evaluation of success of the new varieties and other technologies.

Some studies in the centers evaluated yield stability of intercrop patterns as compared to monocrops. The CIAT data on maize/bean systems (Francis and Sanders, 1978) and the ICRISAT data on sorghum/pigeon pea systems (Rao and Willey, 1980) both showed the intercrops to be more stable than either component crop monoculture. This substantiates one of the reasons why farmers with limited capability to absorb risk insist on preserving multiple species systems. The maize/bean mixture was shown to be more stable in yield and income over a wide range of relative prices between the two crops, and under a wide range of assumptions about level of technology and input costs.

To date, we have operated under the assumption that levels of inputs and accessibility to technology will continually improve. "The principal advantage of intercropping appears to be risk reduction. This risk reduction is made possible by diversification and, in some cases, by the complementarity or interaction effects from growing the crops together. As input levels are increased and more environmental control is obtained, gradual shifts to more specialized production activities are anticipated and have been observed in developing and developed countries" (Lynam et al., 1986). Based on the tenacity with which farmers maintain multiple cropping patterns, we can question whether "shifts to more specialized production" are the only possible alternatives to success in development.

Conclusions -- Focus on a Participatory Approach

What is the direction research and training should take in the future? There is no doubt about the value of improving germplasm of principal food crops. This work needs to move ahead vigorously and efficiently, with greater concern given to the systems in which new varieties and hybrids will be used. In some instances, this may require merely an expansion and/or broadening of the range of testing environments for late-cycle germplasm evaluation. Testing under a range of stress conditions, including the interspecific competition of multiple cropping systems, will better enable the plant breeder and agronomist to select for increase those lines or combinations which will do well in less favorable environments.

Greater concern with the total cropping and farming system will lead to an appreciation of the complexity of developing and introducing new technology to farmers -- especially those with limited resources. Participatory approaches such as

farming systems research/extension methods can be used to advantage in recognizing critical production constraints and developing component technology which will readily be accepted by producers. New methods and designs are needed to make this on-farm research efficient and repeatable, and even subject to rigorous statistical analysis. Much of this methodology is under development in a number of centers.

The small farmer who operates primarily with internal resources on the farm may need different varieties or hybrids and a new approach to improved technology. This producer must make rational decisions about how to invest the scarce capital and labor resources available, including consideration of the opportunity cost of labor outside the farm. Given what we are learning about biological efficiencies of cropping systems, there are new areas to explore in research for increased productivity. Better appreciation of the complex interactions and diverse cropping combinations available can broaden our search for biological and economic efficiency -- within the context of the low-resource farm family.

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