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Chapter 15

Future Perspectives of Multiple Cropping

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There is an increasing recognition by scientists and agricultural administrators of the current and potential future importance of multiple cropping systems. This importance was discussed in the introductory chapter. In a conference inauguration, the Minister of Agriculture of Tanzania, Hon. John S. Malacela (1982) observed that,

> The fact that mixed cropping is the way of life for the subsistence farmer in the tropics underscores the reasons for studying it in some detail. Theoretically, there are a variety of reasons why farmers have adopted this practice. Insurance against the vagaries of weather, diseases, and pests is a major reason. By planting more than one crop in the same field, the farmer is also maximizing moisture, maintaining soil fertility, and minimizing soil erosion, which are some of the serious drawbacks of monocultural farming. . . . Intercropping . . . offers unlimited opportunity to increase the productivity of arable land, and research efforts should be mounted to tackle problems that limit the efficiency of the practice.

Even though multiple cropping systems have been considered important by farmers in many parts of the world for centuries, the interest of the research community has accelerated only in the past two decades. In the literature search cited in Table 1.1, there were only 187 published articles up to 1960, but 359

papers were published from 1961 to 1970. In the decade of the 1970s there were 1440 published reports in the survey, and this trend continues. The majority of these research reports describe agronomic systems, interactions among crop species, crop interactions with the environment, and the effects of cultural practices on multiple crop performance. It is this wealth of recent information and its interpretation that causes many in the agricultural research and development community to seriously examine the future of multiple cropping systems.

The future global importance of multiple cropping is difficult to predict. Current trends indicate an expansion in double cropping and other sequential systems in many areas, both in the developing world and in developed countries. The potentials of short-cycle rice (*Oryza sativa*) and other cereal varieties have made possible two or three crops per year in areas with ample resources, such as the intensive, high-input rice and catch crop patterns practiced in the Central Visayas of the Philippines. Yet the rapid expansion of mechanization and increase in farm size has resulted in a reduction of intercropping or other intensive multispecies practices in the more climatically and edaphically favored parts of developing countries. It is unlikely that intensive cereal/grain legume intercrops will expand in the near future except where there is a clear complementarity between component species.

There is ample evidence that some forms of intensive sequential or relay cropping systems will continue to expand:

- Winter wheat (*Triticum sativum*)/soybean (*Glycine max*) double cropping in southeast United States
- Overseeding legume cover into growing maize (*Zea mays*), wheat, and soybeans
- Strip cropping of maize/soybeans or sorghum (*Sorghum bicolor*)/soybeans
- Double and triple cropping of high-value vegetable crops
- Intensive use of relay and sequential systems in China and Southeast Asia
- Use of multistoried perennial and perennial/annual crop mixtures in Southeast Asia
- Alley cropping in West Africa and other intensive terrace systems, such as those in Burundi

Thus, a number of intensive cropping systems are being practiced by both low-resource and high-technology farmers, both in the developed world and in developing countries.

This importance warrants continued study of multiple cropping potentials. The evidence is that intensive cropping systems are not merely a vestige of the historical roots of crop culture, as eloquently described by Plucknett and Smith in Chap. 2, but would appear to be increasing in importance in much of the world in specific situations where there is an economic, biological, environmental, or social advantage to this type of crop culture.

In each of these production situations, it is important to examine current

and potential future cropping systems. Some methods for setting specific research priorities are outlined in Chap. 13, but in the broader picture a look at the total system is essential. The research emphasis placed on either intensive intercropping or relay cropping, as well as that focused on intensive sequential systems, depends on learning (1) why farmers practice these systems today, (2) how likely is the practice or expanded use of these systems in the future, (3) what constraints are faced by the farmer in improving food production and increasing profits in these systems, and (4) how likely can research and development efforts solve these constraints (J. Sanders, Purdue University, personal communication). There is a need to examine these questions from the points of view of several disciplines.

The future potential of multiple cropping to help meet burgeoning world food demand needs to be put into perspective by looking at the biological potentials of these systems and the ecological and environmental consequences of their use, as described in Chaps. 3, 4, and 5. Of equal importance are the economic and social impacts of multiple cropping systems, discussed in Chaps. 11 and 12. Multiple cropping systems represent a response by farmers to production resource scarcity, as well as an attempt to maintain the lowest possible costs of production and most stable, least-risk strategies to produce food and income. To some degree, the expansion of multiple cropping systems or intensification of their use will depend on how research drives the technology or information base in this area and how national political decisions encourage or discourage the small-farm sector.

The farther one projects into the future, the less confidence can be placed on the analysis. The previous chapters describe in detail the advantages of multiple cropping: more efficient and complete use of resources such as solar energy, nutrients, and water; reduced risk with increased diversity in crops and income sources; and greater biological stability in the cropping systems and the environment. Finite supplies of fossil fuels obligate us to carefully consider alternatives, and these intensive systems appear to provide such biological efficiencies as reliance on nitrogen fixation, reduced pesticide use through genetic resistance and integrated pest management and potential biological production compensation by multiple species in a system. Thus, there are clear indications that in some areas these intensive systems offer promise as innovative approaches to crop resource use that can be sustained and are appropriate for adequate long-term food production. Multiple cropping systems provide a potential for the majority of farmers who operate in a low-resource situation. Research in multiple cropping systems and the analysis of their applications are both timely and important in the overall strategy to meet world food needs.

BIOLOGICAL POTENTIALS OF MULTIPLE CROPPING

Research has shown that multiple cropping has several advantages over monoculture under a range of circumstances. According to Swindale (1981), intercropping

> Appears to make better use of the natural resources of sunlight, land and water. It may have some beneficial effects on pest and disease problems, . . . and there is an advantage of mixing a legume with a nonlegume to save on the use of nitrogenous fertilizers.

Results from current research on crop rotations (Chap. 8), publications on pest incidence (Chap. 9), and detailed physiology studies (Chap. 4) are beginning to unravel some of the intricacies of these sytsems and explain how they function. Yet many of the biological efficiencies of the systems have evolved over centuries as farmers, through a directed trial-and-error process, brought together new combinations of plant species and cultural practices to meet their needs (Fig. 15.1).

Plucknett and Smith (Chap. 2) have outlined some of the known and probable origins of multiple species systems. It is unlikely that most farmers understood why, in a biological sense, their systems produced more food at a lower risk. Yet they undoubtedly did understand the benefits of diversity and intensive culture of several crops together. This led to the development of a diversity of species combinations and practices for producing them. By combining and integrating the qualitative indigenous knowledge about cropping systems and the quantitative analytic techniques used in scientific research, a clearer picture of the biology of multiple cropping systems is possible. An understanding of the soil/plant/water environment, the potentials of newer crop genotypes, and improved management (Rao, Chap. 6) makes possible the development of systems

Figure 15.1 Intercropped mixture of *Xanthosoma* sp., cassava (*Manihot esculenta*), pineapple (*Anana* sp.), and *Bixa orellana*, near Lázaro Cárdenas, Teapa, Tabasco, Mexico. (Photo by Dr. Stephen Gliessman.)

with increased resource use efficiency, agronomic sustainability, and thus greater food production security and its concomitant rewards (Greenland, 1975). Long-term viability also depends on taking into account the environmental consequences of the intensive resource use that comes from an exploitation of these biological potentials. What are some of these biological potentials?

The intensification of use of land and growth resources in the time dimension is one obvious potential for multiple cropping. Although extended maturity of individual crops can take advantage of certain entire temperature-favorable or moisture-favorable growing seasons, especially in the temperate regions, there are many more options with shorter-cycle component crops in multiple cropping systems. The soybean/winter wheat double cropping or relay cropping in the temperate United States is a successful combination of a summer annual with a winter annual, which makes efficient use of both potential growing seasons while maintaining vegetative cover on the land for most of the year (Langdale et al., 1984; Lewis and Phillips, 1976). Two- and three-crop rice patterns in the Philippines and China, as well as rice/grain legume and rice/rice/grain legume systems are examples of the same type of intensification in the tropics and subtropics where moisture rather than temperature may be most limiting (Gomez and Gomez, 1983). A combination of summer grain crop (maize or soybean) with an overseeded relay legume species which grows in fall and again in spring for nitrogen production is another example of the concentrated use of time in agronomic systems (Hofstetter, 1984). Intensive cropping patterns use the growth resources and land area through the maximum possible period of the year, and thus result in as much dry matter and food as potentially can be produced by the farmer. Intercropping and relay cropping are examples of systems that make the most efficient use of potential total growing season.

The intensification of land and resource use in the space dimension is another important aspect of multiple cropping, especially with intercropping and relay systems. Enhanced efficiency of incident light use is possible with two or more species that occupy the same land area during a significant part of the growing season and have a different pattern of foliage display (see references and discussion in Trenbath, Chap. 4). Different rooting patterns can explore a greater total soil volume with roots of different depths. These combinations of crops can result in tapping of deeper strata and bringing nutrients to the surface for succeeding crop cycles (Harwood, 1984). When there are differences in the timing or intensity of uptake of critical growth elements (both nutrients and water) from the soil, then some combination of species could make greater total use of available growth factors than would be possible with a single species in monoculture (Barker and Francis, Chap. 8). The several chapters on agronomic practices (Chaps. 6 through 8) give examples of these potentials in cereal grains, legumes, and root crops. These biological potentials can be realized when interspecific competition for growth resources is less than intraspecific competition in the same environment, and the result is greater resource use and overyielding by the multiple cropping system (Andrews, 1972).

The intensification of resource use in both time and space is one of the

ultimate biological potentials of multiple cropping systems. Different maturities and rooting patterns of grossly different species provide an agronomic mix of plants which is far different from a monoculture in the same place, and the potential yields may be far greater. A relay or intercropping system of maize and sorghum in Central America or of sorghum and pigeon pea (*Cajanus cajan*) in northern Nigeria illustrate the potentials of crops which have different temporal and spatial exploitation of growth factors (Rao, Chap. 6). These systems can make use of an entire rainy season in a manner more efficient than any known monoculture. Their potentials could be compared to a double crop of one species or of two short-cycle species that could be grown in this type of rainfall regime to determine which alternative is most advantageous to the farmer. Combinations of annual and perennial species such as alley cropping maize, sorghum, or grain legumes between strips of *Leucaena* or other woody legume illustrate both spatial and temporal complementarity.

Potentially important for the limited resource farmer is the accumulative use of nutrients that are internally produced or available and that cycle through systems on the farm. Nitrogen fixed by a woody legume species or by an annual leguminous grain or green manure crop can provide a partial or complete alternative to expensive and/or unavailable chemical fertilizer. Accumulated organic matter from intensive systems can provide additional nitrogen. If carefully managed, this can be a more sustainable system, and one which might be called "regenerative" in its improvement of the soil fertility resource for future cropping seasons (Harwood, 1983).

Another set of biological variables in multiple cropping involves the complexity of insect, plant pathogen, and weed interactions discussed by Altieri and Liebman (Chap. 9). Potentials of multiple species systems, whether intensified in time or space or both, appear to contribute to integrated pest management. Competition with weeds from an increased density of crops or from a combination of species occupying two or more niches in the cropping environment can effectively reduce weed germination and growth, and thus increase crop productivity without expensive herbicide inputs. The potential of multispecies systems, as well as the upland/lowland rotations or wet season/dry season alternating culture in some parts of the tropics can contribute to weed control with a cropping pattern that is counter-cyclical to that of the weed species (Francis and Harwood, 1985). The weeds that predominate with one crop in the sequence may be quite different species from those in a succeeding crop, and thus their reproductive cycle may be broken, resulting in a cultural control of weeds.

Insect patterns may also differ in multiple species cropping systems compared to monoculture. Although the same insects may be present, their distribution and reproduction appear to be altered by the mixture of species. This generally results in less damage to crops (Altieri and Liebman, Chap. 9). There are a few cases reported where increased insect damage occurred in multiple cropping, but these reports are minimal. A number of factors may explain why insects are inhibited by a multispecies system. There may be more natural enemies—predators and parasites—in the association of crops, and these would

provide a biological control of damaging insect species. The diverse species present in a multiple-crop situation may promote and maintain a wider range of these natural enemies due to the greater and more diverse habitats provided. There may be less opportunity for an insect to land on a crop of choice, when more than one crop is present in the field. "Visual and chemical stimuli from both host and nonhost plants affect both the rate of colonization of herbivores and their behavior" (Altieri and Liebman, Chap. 9). Again, these methods of suppressing insect populations and reducing their damage can contribute to a nonchemical control that makes use of the biological structuring of the system and internal resources on the farm.

Diversity of crop species in an intercropping pattern gives a dispersion of potential host plants for pathogens that is similar to natural ecosystems. The differences in occurrence and damage from plant pathogens are not as striking nor as consistent as the differences with insects (Altieri and Liebman, Chap. 9). Yet there is evidence that mixtures of crops buffer against losses to plant diseases; there may be reduced spore dissemination, delayed infection of plants, or modification of the microenvironment in a way that reduces pathogen development and economic loss. With a few diseases, this modification in microenvironment may promote greater pathogen spread and damage, but there are fewer of these cases listed in the review (Chap. 9). A multiline variety of wheat or other cereal is a parallel breeding solution to disease problems, and this is one approach that could be used to diversify a monoculture and promote this type of "resistance" in the crop (Jensen, 1952).

Another biological reality is the complex set of physiological reactions of plants when grown in mixtures, as explored by Trenbath (Chap. 4) and reviewed by Willey (1979a, 1979b). When greater total density is used in a mixture of species, there is a greater total demand for resources, although this may be spread differently over time or space. This may result in stress on one or more components of the mixture or sequence; the stress may be different from that found in monoculture. One example is the reduced light intensity on a lower story crop, such as bean or soybean grown under maize, while the maize suffers only from an increased competition for moisture or nutrients. Careful examination of an intercrop system and the physical organization of the components could lead to ideas about how to better arrange or sequence two or more crop species. More precise measurement of their yields, total dry matter production, and yield components could confirm these hypotheses and lead to design of more productive multiple cropping systems.

Breeding crop varieties or hybrids for complex systems presents some different challenges than breeding for monoculture (Francis, 1985b; Smith and Francis, Chap. 10). There is a wide range of traits that will be needed in new varieties for either system. These traits include general adaptation to temperature and rainfall patterns in a region, resistance to prevalent insect and disease problems, and seed color and quality characteristics that are acceptable to the producer and the marketplace. Yet other traits may be more important to success in an intercrop: competitive ability, tolerance to stress under lower light levels or less

available moisture, ability to climb the maize in the case of indeterminate beans, and efficient use of available nutrients.

There also may be differences in the economic and resource bases of the farmers who predominate in the use of these systems, and the crop quality factors may be more important to the subsistence farmer. Productivity may be important, but profitability also must be considered by most farmers. Some production constraints which have been identified cannot be solved easily through agronomic manipulation of the cropping system. When plant breeding holds promise to solve these constraints, an important focus must be on breeding objectives, and how these vary among systems. Although a number of the same traits may be important for certain species in several systems, there will no doubt be a difference in the relative importance of these traits. Since progress in a breeding program is inversely proportional to the number of traits for which selection is practiced, it is important to concentrate on those traits that are most critical for success of the crop variety in the system of interest. The most critical final evaluation in a breeding program is testing new varieties in the system or systems of interest. These need to approximate as closely as possible the systems into which the varieties will be introduced. A logical final step in the process is testing by farmers under their own farm conditions.

The methodology for deciding on research priorities and for analyzing and interpreting results has been examined by Parkhurst and Francis (Chap. 13) and by Mead (Chap. 14). There are some unique differences and complexities introduced into cropping systems by including more than one species. The number of potential interactions is increased vastly by increasing the number of species in a system, and this makes the choice of research problems even more critical than in monoculture research. There is some debate about the optimum types or combinations of experiments that should be utilized in the field to efficiently explore the questions of component technology in multiple cropping systems. At one end of the spectrum is the complex factorial design with all factors included in at least two levels. This gives the maximum number of comparisons and the most comprehensive evaluation of interactions in the systems. At the other extreme are simple experiments which study only one or two factors at a time, with many of these experiments carried out each season to get an idea of how to manipulate the many potential changes in a cropping system. This gives less information on interactions, although there is greater experimental control over each trial and less potential loss if a few treatments are lost from the trials. Careful reading of the two cited chapters will reveal advantages and disadvantages of each of these approaches, and the best recommendation is probably to work with some reasonable combination of factors in each trial, to explore the most important interactions, and then to move on to another series of experiments in subsequent seasons. There is a growing interest in designs and treatments that provide illustrated results as response surfaces rather than as comparison of discrete treatments (Barker et al., 1985). It is critical to combine the research on the experiment station with testing under farm conditions to ensure that information and recommendations are relevant to the farmer. This is important

with multiple cropping systems, since the limited-resource conditions of many farmers who practice multiple cropping systems may dictate a need for realistic low-input recommendations. This focus is quite different than the emphasis at many experiment stations on high-input technology.

These factors in the biological environment—crops, weeds, insects, and pathogens—can be manipulated through agronomic practices and genetic change. The several chapters that deal with agronomic and breeding approaches, plus those on methodology for research, provide a survey of the importance of the biological potentials of multiple cropping systems and how to study them. To complicate the application of this information, the economic and social factors involved in limited-resource agriculture, often practiced by small farmers, must be considered during the research and development process. No biological potential can be successfully exploited if the practices or varieties are not accepted by the farmer. These aspects are explored in a later section.

ECOLOGICAL AND ENVIRONMENTAL ASPECTS OF ALTERNATIVE CROPPING SYSTEMS

There are some obvious parallels between multiple species cropping systems and naturally occurring plant communities. These often include (from Francis, 1985b):

1. Genetic diversity in plant species
2. Resulting diversity in the insect and pathogen populations that are associated with crops
3. Nutrient cycles that are relatively closed, with much of the nutrient requirement of succeeding crops supplied by a previous crop or cover crop residue (in low-input systems)
4. Vegetative cover over the land through much of the year
5. High total use of available light and water through the year because of the presence of growing crops
6. Low risk of complete loss of crops in a given season or year because of the different ecological niches they occupy and the different patterns of demand for growth factors
7. High level of production stability (compared to monoculture) as a result of compensation by other components of the system when one component fails

These characteristics of multiple cropping systems, especially those with two or more species together in the field at the same time, make them desirable for the limited-resource farmer. The comparative biological advantage of multiple cropping systems under a high-input situation is less dramatic, although the double cropping (winter wheat/soybean or rice/rice), ratoon cropping [sugarcane (*Saccharum officinarum*), sorghum, rice], and relay cropping [maize/sesame (*Sesamum indicum*) or maize/soybean] of a number of commercial crops all illustrate the benefits of these systems when resources are not limiting.

One of the widely debated theories in multiple cropping and ecology circles

is that greater genetic diversity leads to greater productivity. Hart (Chap. 3) presents evidence on both sides of the question, and gives examples of where this is not true. Systems with high productivity, such as intensive rice or sugar cane production, are the result of high nutrient subsidy and low genetic diversity. Subsidizing a system with external resources—fertilizers, pesticides, irrigation water—can bring high levels of productivity through dominance of the production environment, but these systems are sustainable only at a high external cost. The diversity and cropping intensity of multiple cropping systems, especially an intercrop pattern such as maize/bean, can bring moderate to high levels of productivity through manipulation and exploitation of the resources internal to the farm, and this can be sustained at a lower cost (Francis and Harwood, 1985). In this way, the stability of production or sustainability over time in an intensive multiple species cropping system is similar to a natural ecosystem.

The concept of energy and nutrient cycling is important in cropping systems that are designed for sustainability over a long period. In multiple cropping systems, and especially in low-input systems with reliance primarily on internal resource cycling, the increased production of crop residues and their use by subsequent crops are important factors in promoting stability of production. Systems that are gaining in favor, such as minimum or conservation tillage ("ecofallow" production systems), conserve and rely on residues for reducing runoff losses of nutrients and moisture and for supplying organic matter and nutrients to crops in the next year. The cycling of carbon, nitrogen, phosphorus, potassium, and other elements in an agricultural system is promoted by those cropping patterns that include a range of species, especially when the crops are dissimilar in rooting patterns and growth cycle.

The so-called "phosphorus pumping" activity of some deep-rooted species can bring this critical nutrient up to the annual crop root zone and keep it cycling in the strata where needed. The preservation of a high proportion of nutrients in living and decaying organic matter also ensures that these nutrients will be available for subsequent crops rather than leaching down through the profile and being lost from the immediate crop environment (Fig. 15.2). This is how tropical rain forests and other natural ecosystems maintain fertility and plant growth (Nye and Greenland, 1960).

Hart (Chap. 3), Harwood (1983), and Rodale (1983, 1985) further suggest that multiple cropping systems could apply what is known about natural ecosystems, plant communities with their associated microorganisms, and plant populations to design useful alternative cropping systems that would meet the objectives of the farmer and be dependent on internal resources. It is critical to understand how individual components of technology that are proposed to improve a farmer's cropping system fit into the overall farm system and the ecology of the region. If this concept is taken into account in the evaluation of new technology, there is a greater chance that the eventual choice of new practices will be more ecologically sound and be more sustainable over time. Francis and Kauffman (1985) present a series of resource-efficient technologies that rely on internal resources and can apply both to large and to small farms. These include

Figure 15.2 Multistoried tree crop agroecosystem with coffee, cacao, and *Erythrina* shade trees; note sapling of forest tree *Cedrela mexicana* in the right foreground, near Cárdenas, Tabasco, Mexico. (Photo by Dr. Stephen Gliessman.)

fertility regeneration through multiple cropping and nutrient cycling, pest protection through species diversity in crops and genetic resistance, integrated pest management, minimizing tillage and coexistence with a low level of weed population, mixed cropping of annuals and perennials, and integration of animals into the cropping/farming system. These factors all contribute to development of systems that are more sustainable, in part through a mimic of natural ecosystems in each area.

ECONOMIC AND SOCIAL IMPACT OF MULTIPLE CROPPING

Discussion of economic and social factors must necessarily focus on two distinct applications of the concepts of multiple cropping. First is the intensive cash grain double cropping or relay cropping of commercial crops in the developed world or in favored areas of developing countries. Where these crops are grown with high technology, adequate fertility and other inputs, and with mechanization of planting, cultivation, and harvest, there is little to distinguish the systems from commercial monoculture, at least in the economic and social sense. Cropping decisions are made on costs of production and market factors, and the commercial nature of these systems leads to decision making that is similar in most ways to decisions for monoculture systems.

In the small-farm situations where most intercropping is practiced by farmers with limited resources, the economic and social situation is much different. The complexity of these farming systems is due to the many climatological, biological, economic, and social factors that interact in the total small farm environment (Francis, 1985a). In addition to the complexity of these factors and their interactions, there is a wide range of objectives of the farm family, including production of food and income, minimizing risk and providing stability of production, and sustaining both food and income through as much of the year as possible. This must all be accomplished with a minimal land resource and with limited or no capital on many farms. Multiple cropping is one of the strategies that farmers use to meet these challenges.

Lynam et al. (Chap. 11) suggest that degree of market integration of the farmer is important, and that there are few truly subsistence farms: most farmers in the developing world have some commercial and some subsistence objectives, and thus the consumption and production decisions are interrelated. They also describe the uncertain nature of agriculture, and that with limited resources to invest in the production process and an uncontrolled environment, the farmer becomes more concerned with security and maintaining subsistence needs. Intercropping is seen by the farmer as a strategy to achieve both biological and economic, as well as nutritional, diversity which has a better chance of sustaining the family through a wide range of variable and usually uncontrolled cropping seasons.

Profitability of the cropping system depends on the biological success of the component crops and on relative prices, costs of production, and the ways crops complement each other over time. Net profit thus is site, time, and input-

level specific. Multiple crop systems are not always more profitable, but they do appear to be more stable over time and give a higher probability of providing the farmer with a specified level of net income (Francis and Sanders, 1978; Rao and Willey, 1980). Thus biological diversity appears to provide greater economic stability. The economic diversification that results from multiple species plantings can also be achieved by planting a diverse series of crops in monoculture on the same farm. These two strategies for providing greater stability need to be recognized and compared.

Structural changes in the rural economy, such as prices of inputs, availability of a market, and relative prices of commodities can influence the decisions of the farmer on what crops to plant and in what proportions (Lynam et al., Chap. 11). Greater access to markets, wider availability of inputs such as fertilizers, pesticides, and irrigation, plus credit or other government incentives to use these inputs, can influence the farmer toward higher-technology approaches to food production. This shift may result in a higher proportion of export crops and less basic food production, a dependence on external resources that must be purchased and transported to the farm, a reliance on government participation and infrastructure, and timely payment and favorable world market price for commodities (Francis and Harwood, 1985). In spite of the apparent advantages of specialization and the relative comparative advantage for producing one specific well-adapted crop, many farmers are currently short of food and income because they have deemphasized food and subsistence crops.

Also important are the sociocultural factors involved in the farmer's decisions on type of cropping system to employ (Bradfield, Chap. 12). There are strong psychological factors involved in the adoption of new technology. The behavior of farmers is rational, but the extension agent and researcher must understand the total economic, cultural, and nutritional environment within which decisions are made.

There are institutional factors that influence decisions as well. High government prices, and thus incentives to produce cotton for export, may be viewed as a viable solution for income generation and purchase of food by small farmers. On the other hand, farmers may have had a previous experience where markets have disappeared, or prices have gone down drastically, or government agencies have not delivered the needed inputs for production on a timely schedule. The farmer may be rational in rejecting the apparent short-term incentives to produce this new export crop based on past experience that led to shortage of income and food as a result of factors beyond the family's control. Many economists expect that subsistence food production will become less important as agricultural development moves ahead and markets become better developed and more stable.

Other factors in the governmental and political area may influence decisions to adopt or not to adopt a new technology. Bradfield (Chap. 12) presents the example of a recommendation to introduce certain soil conservation, cropping pattern, or other technology practices which would enhance the long-term fertility status of the soil. Perhaps not known to the extensionist, the land ownership patterns, tenancy conditions, lack of credit to buy inputs, lack of assured markets

for the products, or lack of other infrastructure make the recommendation impossible or very difficult to adopt. This could easily cancel its obvious biological and physical environmental advantages in the region. Although many new technologies in developing countries were thought to be scale neutral in application, they are still out of reach for the majority of farmers with limited resources. The development of more productive intercropping techniques may in fact be the scale-specific type of technology that will be well suited to the resource base and the multiple and complex needs of the small farmer.

FUTURE RESEARCH IN MULTIPLE CROPPING

Each of the preceding chapters has presented a section on future research in multiple cropping from the perspective of an expert on that topic and discipline. In this chapter an overview of research is presented from the perspective of total cropping and farming systems. The needs for research in broader aspects of multiple cropping that transcend disciplines and require a team approach to research and extension would appear to be a valuable route to understanding complex systems, and to working with farmers to improve them (Gilbert et al., 1980).

In the areas of ecology and environment, there are a number of research directions that could be pursued to develop more productive cropping systems in the context of sustainability of food supply and regeneration of the production environment (Chap. 3 and 5). Continued study of natural ecosystems and how plants interact in those systems can lead to basic information on crop competition, complementation, and interdependence. This information can be applied to cropping systems in an attempt to make them more sustainable and more ecologically sound than currently recommended monoculture or available multiple species systems. The processes of soil fertility maintainance, nutrient cycling, and pest suppression are especially active in natural ecosystems, and information from this research could lead to useful clues about how to design cropping system alternatives. The active and growing field of agroecology is providing improved methodology for this research.

Another fertile area for study is the identification and characterization of successful traditional and sustainable cropping systems still used by small farmers (Gliessman et al., 1981; Chap. 5). This study could lead to an understanding of the vital elements of those systems that promote their productivity and success, and provide an information base to inform other farmers about successful and proven practices. When useful practices and systems are characterized and their elements understood, this information can be combined with the practices that have come from technical research into new or modified cropping practices that have a high probability of success. This combining of traditional knowledge with scientific approaches to gaining insight on their productivity and stability is a new and promising avenue to pursue. Much of the current success of monoculture technologies in the maize belt of the United States and other productive zones has come from the innovation of farmers combined with the potentials of modern technology.

A growing body of information on agroforestry will become a useful resource to the agronomist and research administrator interested in multiple cropping systems. This integration of the long-term sustainability and contributions of forest species to food and income, and the close integration of annual crop plants with perennials holds great promise for improvement of farming systems. In many areas where clear cutting of economic species has occurred, there is a potential to regenerate a part of this forest resource concurrently with development of food crop growing potentials. There are hillside areas that are prone to erosion and nutrient and water loss where some combination of permanent or semipermanent trees with shorter-term economic crops would be highly desirable. This field is receiving increasing interest and support in the research community, and the International Center for Research in Agroforestry (ICRAF) in Kenya is leading efforts in this research.

Agronomists and plant physiologists agree on the need for more research on the components of cropping systems and how the components interact in the use of growth resources. There may be additional data that can be collected from existing experiments that will make them more useful in gaining an understanding of how systems work. With yield trials of intercrops, the study of components of yield can often reveal some insight on the timing of competition for growth resources (Carter et al., 1983). This can lead to new combinations or physical/spatial organizations of crops that will reduce competition at a crucial stage, or help the crop mixture compensate in some way for a reduction in one component crop. These studies of the detailed yield components and biomass of an intercrop can also give the agronomist insight on system design and the breeder direction in setting priorities in a selection and testing program, and help researchers focus on the most important factors in the evaluation of new alternative systems and varieties.

There is a serious need to investigate systems under conditions of low levels of production inputs and stress on the crops. Many of the most food-deficient areas of the world are in the arid and semiarid regions, and there has been less research carried out in these areas than in more favorable zones. Efficient use of low levels of resources may be more easily accomplished using a mixture of species, and this could lead to new lower-risk strategies and cropping systems for the farmer.

Studies of weed interactions with crops are important to an understanding of resource use and competition for scarce moisture in multiple cropping systems. Research now in progress shows that low densities of weeds are not necessarily harmful to yields, and may in fact contribute to organic matter and water and nutrient retention in the soil (Rodale Research Center, unpublished). This has not been studied adequately in multiple cropping systems. Root interactions also are poorly understood in comparison to the wealth of information on competition for light. This is a promising and little-understood area of competition, and an improved appreciation of rooting systems and uptake patterns would lead to design of genotypes and systems that can take best advantage of scarce growth resources.

Improvement of crop genotypes specifically for multiple cropping systems

sometimes will be necessary and sometimes not. There is no doubt that the current understanding of intercropping potentials is constrained by the lack of availability of varieties that have been developed for specific intercrop systems. The improved genetic component has come directly from monoculture breeding programs, and thus there is no reason why it should be adapted to the different types of interspecific competition that are unique to intercropping. Although some methodology has been proposed, there have been few programs implementing these procedures in the field. The agronomist will be saddled with this limitation for some time into the future. Current studies on genotype by cropping system interaction do provide some insight on which species are more likely to demonstrate specific adaptation to multiple species cropping systems (Francis, 1985b).

A more generic question revolves around the applicability of other available component technology from studies in monoculture to the complexities of competition and resource use in an intercrop. A systematic study is under way (Francis, unpublished data) to statistically test a series of recommended technologies and their interactions with cropping systems. This is analogous to the genotype by cropping system interaction evaluations. This study will lead to some guidelines on which types of results are most applicable to new cropping systems, such as those with multiple species, and which technologies need to be developed and tested specifically for these intensive systems.

Several of the authors of these chapters cite the importance of on-farm research (OFR) and evaluation of new technologies by researchers working together with farmers. The farming systems approach is mentioned frequently as the methodology which offers the most promise in this activity. There are many forms of farming systems research (FSR), and almost as many interpretations as there are practitioners of the trade. Yet a generalized experience is emerging from this activity and it is one that will be useful for multiple cropping research. When the search for successful traditional technology is combined with evaluation of current constraints to production, and when the farmer is directly involved with the choice of alternatives and the field testing, there is a high probability that the right questions will be answered and the technologies will be appropriate and adopted. The feedback activities that are emphasized in this process are also critical to its long-term success. A functional and rewarding association is thus created between the people involved in research, extension, and on-farm application of results.

There is a continuing need to develop more efficient evaluation tools for on-farm research and testing, and the elaboration of minimum data sets that will give the relevant information without unnecessary, though interesting, details on systems and families who are participants. The emerging methods for assessing research priorities will be useful for multiple cropping systems, as well as for other research areas. The development and articulation of new or revised statistical techniques are powerful contributions to the researcher's set of tools to effectively evaluate multiple cropping systems. In addition to the review by Mead (Chap. 14), there is a book in preparation by Dr. W. Federer at Cornell

University which will be another major contribution to this field (personal communication).

Finally, the use of simulation modeling has been suggested as a useful tool for multiple cropping research. When adequate data sets are available, or when enough is known about crop species interactions and responses to major agronomic practices to make informed assumptions about response curves, then modeling becomes a potentially valuable tool for the researcher. This does not replace the field trial. Models can be used to simulate a wide range of new production alternatives, using different combinations of inputs or techniques which may better exploit resources internal to the farm. Given the complexity and number of factors in multiple cropping systems, simulation could be more important here than in monoculture research. The models can take into account long-term rainfall and temperature data, and can project the relative success of a near-infinite number of combinations of practices, genotypes, and combinations. From these, the most promising can be chosen for testing in the field. As the basic data set grows, so does the power and predictability of the simulation exercise. This could be an efficient way to approach the complexity of site-specific recommendations for small farmers with different levels of limited resources.

Successful application of multiple cropping computer simulation models depends on accurate selection of evaluation criteria. Much more needs to be done than to just measure or predict yield, biomass, or net income. Food production from the system, the distribution of food or income through the year, the labor requirements for each alternative system, and the risk that would be assumed, to name a few criteria, need to be included. These can be established through discussions with farmers during the FSR approach, and can be modified through subsequent runs with the computer. The farmer can be given a list of potential consequences of a given set of practices. For example, if this new variety is planted on this date with these other two species, the effect on yield, income, food supply, risk of no food, and long-term fertility implications could be detailed, for this and alternative practices, as well as compared with the current variety and practices. The modeling approach is not well tested, but is just in the conceptual stage for multiple cropping. Given the power of the microcomputer, there is no reason why this type of analysis could not be run, given proper software and instructions on how to modify it, by people working at any experiment station or regional extension office. This is one tool that may soon be available to the researcher, extensionist, and farmer.

FUTURE PROJECTIONS FOR MULTIPLE CROPPING

In projecting the future importance of multiple cropping systems in different regions of the world, it is necessary to look at past trends and try to anticipate any modifications to those trends in the future. There is no question about the influence of mechanization on rural population and labor required in agriculture. This has promoted greater labor use efficiency and expansion of monoculture.

Farm work is difficult, and advances in mechanization have made food production a more enjoyable and profitable way of life for those farmers with the land resources and capital to develop them. High-technology, commercial exploitation has moved successfully to some areas of the developing world, and the impact on food production through intensive use of technology has been significant. This has also reduced the use of intercropping systems that may have been prevalent in those areas.

There are multiple cropping systems that are well suited to a high-technology approach to agriculture, and their use will certainly expand as food needs increase. Double and triple cropping, ratoon cropping of additional species, such as sorghum and rice in certain conditions, and overseeding of legumes into growing cereal grains and grain legumes will become more prevalent as the technology is developed for a wider range of climatic and cropping conditions. These are "high-technology" applications of multiple species systems, and they are likely to be adopted by progressive farmers in most countries where the alternatives are demonstrated to be biologically successful and adapted to production resources as well as profitable.

An informed prediction of the future of multiple cropping on low-input farms with limited-resource farmers is more difficult. The authors of these chapters are consistent in their prediction that multiple cropping systems will continue to be important as new technology becomes available and the advantages of intensive systems become better understood. Natural ecosystems have been successful as a result of centuries of evolution to fit specific conditions. Cropping systems have followed this same path, though the evolution was directed to a different set of objectives by the cultivator and family. Multiple cropping systems combine a number of attributes of natural systems, while taking advantage of the resources available to the farm family, to produce food and income according to some of the criteria listed above. This has not happened by accident, but rather has been the result of a concerted attempt by farmers to continuously improve their cropping systems to fit the climatic and resource constraints. A number of external factors have entered the farmer's environment (e.g., government programs to promote export crops and discourage production of basic food crops and commodities for local sale and consumption). This and other political decisions that impinge on the farmer must be examined as a part of any strategy for the rural sector in a developing country.

Multiple cropping systems continue to predominate on many farms with limited resources in the world. The research community is becoming increasingly interested in the potentials offered by this type of cropping pattern, as every possible alternative is examined as a part of the solution to the challenge of world food production and income for rural families. Those in the research and extension organizations of both developed and developing countries need to carefully examine the potentials of these traditional systems to contribute food, provide income, and minimize risk of failure for farmers with limited resources. These farmers and the systems they have preserved may be improved by modern science to provide a significant part of the future world food supply.

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