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RESOURCES ON
DEVELOPING COUNTRIES

CHAPTER 6

Development of Plant Genotypes for Multiple Cropping Systems

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IN THE RECENT BOOK, *To Feed the World: The Challenge and the Strategy* (Wortman and Cummings, 1978), the current food situation in developing countries is reviewed in detail, and strategies are presented for the application of technology to overcome the world's growing food deficits. Multiple cropping has been practiced over the centuries to produce basic food crops, but has been relatively unaffected by research and technology.

BACKGROUND ON MULTIPLE CROPPING

Traditional Cropping Systems

Small farm agriculture predominates in most regions of the developing world. The cropping systems are characterized by low levels of purchased inputs, intensive labor use, traditional cultivars, and relatively low yields of component crops. Multiple cropping systems provide a stability of production, diversity of diet and income sources, and a distribution of labor through the year. These characteristics are summarized in Table 6.1 with suggested implications for plant breeding. Multiple cropping systems make efficient use of land—usually the most scarce resource—through much of the potential cropping year. New technology has had little impact on these systems. It is difficult to generalize about multiple cropping

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Table 6.1. Comparison of monoculture and multiple cropping systems with implications for crop improvement. (Adapted from Altieri et al., 1978; Dickinson, 1972.)

Characteristic	Monoculture	Multiple Crop	Breeding Implication for Multiple Crop Genotypes
Net production	High (with fossil fuels)	Moderate (near monoculture)	Specific cultivars may be needed for some multiple cropping systems.
Species diversity	Low	Moderate-high	System approximates native vegetation and crop variability may be desirable.
Nutrient/light use	Poor-moderate	Moderate-high	Component crops may complement each other in light interception and rooting patterns.
Nutrient cycles	Open (leaching losses)	Closed (with perennials)	More efficient use of lower levels of applied fertilizer desirable.
Weed competition	Intense	Moderate	Crop competition suppresses some weeds; more difficult to use herbicide mixes.
Insects/diseases	Severe	Moderate	Some insect control from system; less difference in disease incidence.
Labor requirements	Seasonal	Distributed	More operations possible by hand on small areas; multiple hand harvests possible.
Diet contributions	Low	High	Nutritional quality a desirable trait for most consumed crops.
Economic stability	Low	High	Risk reduced by diversity, range of crop maturities to spread income.
Social viability	Volatile	Stable	Different client groups and levels of technology generally involved.

systems. Nevertheless, the table lists comparisons that generally describe the differences between contrasting systems in most zones where a dichotomy of farm size and use of technology exists in the tropics.

National production of many food crops has not kept pace with increased demand in most developing countries, partly due to their production in multiple cropping systems at the subsistence level, and the use of the best land for production of export crops. The net result has been a manyfold increase in food imports over the past 40 years (Wortman and Cummings, 1978). An increased awareness of the importance of multiple cropping systems by scientists in the tropics is leading to greater emphasis on research to improve components of these systems.

There was much early work in the U.S. on maize-soybean mixtures for silage (see Wiggans, 1935, for other references), but this practice apparently was never widely accepted. More recent work on double and triple cropping in temperate zones has emphasized agronomic aspects (ASA, 1976, Chaps. 3, 6, 10, 13, 16).

Reviews of multiple cropping systems have appeared through the years (Aiyer, 1949; Dalrymple, 1971; Kass, 1978; Willey, 1979a, 1979b), and recently as the result of technical symposia (Papendick et al., 1976; Jain and Bahl, 1975). The concept of improving traditional cropping systems as an alternative to complete renovation and introduction of massive technology is receiving increasing support from some research leaders in the developing world.

The potentials for increased production through the integration of appropriate technology into traditional systems have been summarized (Francis, 1979). Crop cultivars in present systems often represent years of natural evolution for survival and selection by the farmer for production. Though relatively low in yield potential compared to improved cultivars grown in monocultures with high levels of technology, these traditional cultivars generally are good competitors with weeds and other associated crop species, are relatively resistant to prevalent insect and disease pests, and possess a high level of variability. This low potential yield level may be due in part to the coevolution of pests that limit productivity in the centers of origin of basic food crops (Jennings and Cock, 1977). Moreover, there has been very limited use of improved cultivars from the experiment stations in these traditional cropping systems.

Cultivars Used in Cropping Systems

Broadly defined as the culture of more than one crop in a given

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area in one year, multiple cropping is further described by a range of more specific terms: associated cropping, double or triple cropping, intercropping, mixed cropping, relay cropping, and ratoon cropping. An attempt to reach agreement on the definitions of these terms was made in the symposium sponsored by ASA in 1975 (Andrews and Kassam, 1976). Some of the most frequently used terms are:

Multiple Cropping: intensification of cropping in time and space dimensions; growing two or more crops on the same field.

Sequential Cropping: growing two or more crops in sequence on the same field; crop intensification in the time dimension only.

Double cropping: growing two crops in sequence.

Triple cropping: growing three crops in sequence.

Ratoon cropping: cultivation of crop regrowth after harvest.

Intercropping: growing two or more crops simultaneously on the same field; crop intensification in both time and space dimensions.

Mixed intercropping: growing two or more crops simultaneously with no distinct row arrangement.

Row intercropping: growing two or more crops simultaneously where one or more crops are planted in rows.

Strip intercropping: growing two or more crops in different strips wide enough to permit independent cultivation, but narrow enough for crops to interact agronomically.

Relay intercropping: growing two or more crops simultaneously during part of the life cycle of each with second crop planted before harvest of first.

Related Terminology:

Sole cropping: one crop grown alone in pure stands at normal density; synonymous with solid planting.

Monoculture: repetitive growing of the same sole crop on the same land.

Rotation: repetitive cultivation of an ordered succession of crops on the same land; one cycle often takes several years to complete.

Associated cropping: general term synonymous with intercropping.

Simultaneous polyculture: synonymous with intercropping.

Cropping pattern: yearly sequence and spatial arrangement of crops, or of crops and fallow, on a given area.

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Cropping system: cropping patterns used on a farm and their interactions with farm resources, other enterprises and available technology.
Mixed farming: cropping systems that involve the raising of crops, in combination with animals, and/or trees.
Cropping index: number of crops grown per annum on a given land area x 100.
Land equivalent ratio (LER): ratio of area needed under sole cropping to that of intercropping at the same management level to produce an equivalent yield.

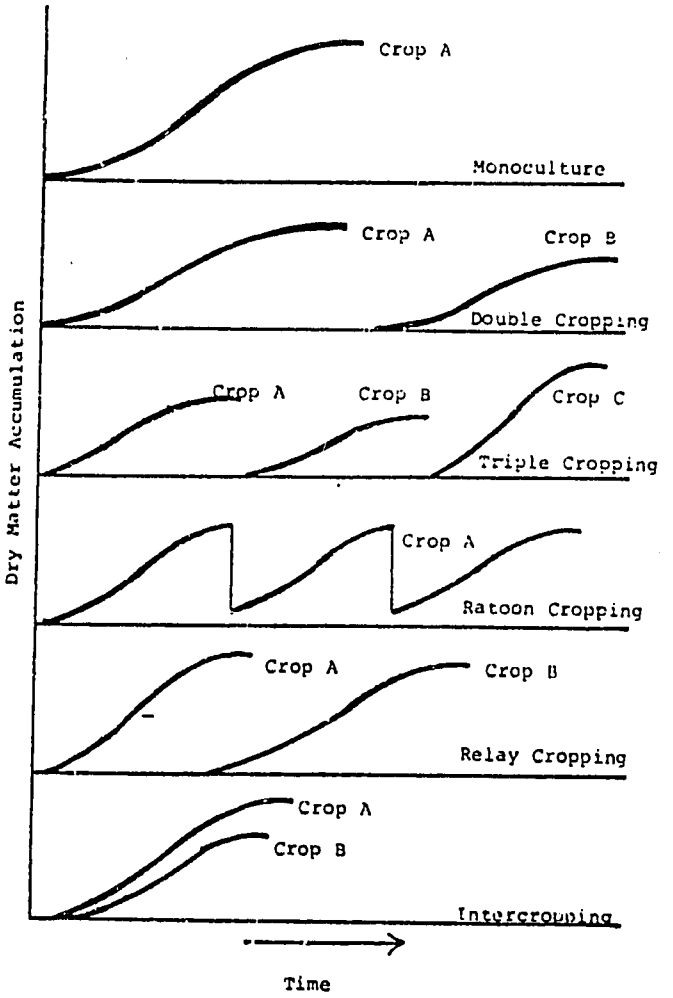

Fig. 6.1. Diagrammatic comparisons of principal multiple cropping systems.

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A comparison of several common systems is diagrammed in Fig. 6.1. This summary illustrates the complexity of systems and our limited ability to research and communicate about them.

There is no clear definition of a multiple cropping system from the genetic point of view. But there is no question about the diversity of genotypes in a 15-crop mixed culture of food crops, including perennial species, in the humid tropics of West Africa. Nor is there debate about a potato-maize-bean system in Colombia, a rice-maize association in Ecuador, nor a traditional wheat-barley-oat cereal mixture in northern Europe. A multi-line cereal variety is genetically diverse, as is a maize (*Zea mays*) composite or population, or a mixture of bean types grown by small farmers in the tropics. Yet we generally would not consider these multiple crops. Figure 6.2 illustrates schematically the range of genetic diversity which exists in cropping systems, from the extremely diverse shifting cultivation and 15-crop mixtures to the extremely narrow single-cross maize hybrids. For this discussion, multiple cropping will refer to those systems that include more than one species in the field during the same year, or the same species grown in ratoon, relay, or sequential plantings. From a multiple genetic system interpretation, the world's cropping systems clearly represent a

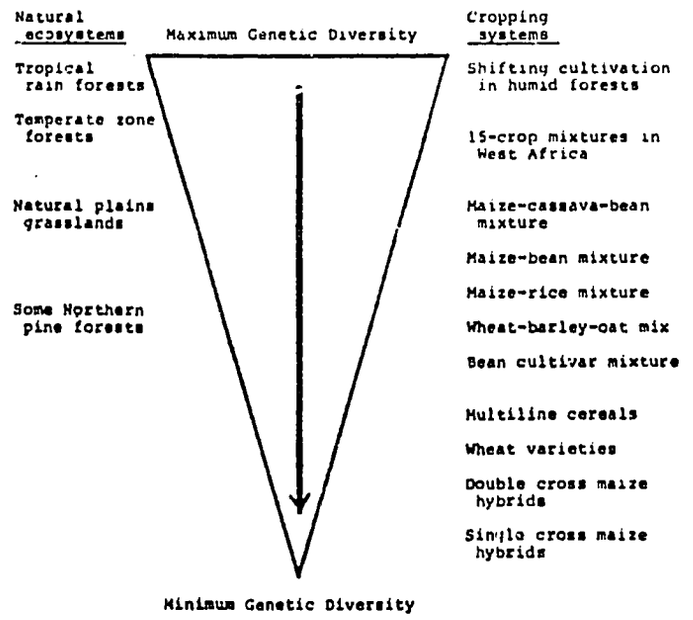

Fig. 6.2. Schematic representation of genetic diversity in cropping systems and natural ecosystems.

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spectrum of genetic diversity as illustrated above. A combination of high productivity and long-term stability of production probably can be maintained by choosing an appropriate point on this spectrum in each ecological situation. This is a rational alternative to the trend of current agricultural technology which is moving rapidly to monoculture and to genetic uniformity across large areas. The dangers of genetic uniformity have been described in Adams et al. (1971), Allard and Hansche (1964), Borlaug (1959), Browning and Frey (1969), Jensen (1952), and Trenbath (1975a).

Use of improved cultivars to better exploit total available resources in a specific crop environment is central to applied plant breeding. In complex traditional cropping systems, or where the growing season is long enough to permit alternatives to monocultures, the concepts of time, space, and production per day must be considered in the design of cultivars to best use total available moisture, light, and nutrients (Bradfield, 1970). The plant breeder's challenge is to develop new cultivars appropriate to the range of cropping systems and microclimates which characterize many small farm regions. The questions of whether specific cultivars should be developed for multiple cropping systems, or for different levels of technology, have not been addressed by the majority of our crop improvement programs.

The following sections emphasize the more intensive intercropping systems that combine two or more crops in the field at the same time. This is not to minimize the importance nor the potential that double and triple cropping systems have today or will have in the future. There are problems to be solved agronomically, as well as a challenge to improve cultivars specific to new planting dates (with changes in day lengths, temperatures, and moisture levels). These problems can be solved through application of known technology, use of existing improved cultivars, and the techniques of traditional agricultural research. A concentration of the discussion on intensive intercropping is justified because only limited work has been done in genetic improvement for these systems, and new methodology may be needed to efficiently and rapidly achieve the genetic advances necessary to increase productivity.

Variables Inherent in Multiple Cropping Research

Before addressing the central theme of improved cultivars, it is useful to consider carefully the limitations of existing research results. Cultivars used to evaluate cropping systems have been of two types: traditional genotypes grown by farmers, often with limited

yield potential, and improved genotypes developed for high input monoculture systems. Subjecting traditional cultivars to increased levels of fertilizer or higher densities in multiple cropping systems often meets with the same lack of yield advance that this approach achieves in monoculture. Introduction into multiple cropping systems of new and high-yielding strains developed in monoculture has met with greater success, especially when done in coordination with well designed and comprehensive agronomic trials with these same systems. With maize and climbing beans (*Phaseolus vulgaris*), the best combinations of improved cultivars, high plant densities, adequate fertility, and plant protection have given yields of 5000 kg/ha and 2000 kg/ha for maize and beans, respectively, in about 140 days in the Cauca Valley of Colombia (Francis, 1978). With genotypes developed for monoculture and without a specific program to select genotypes that are optimum for the intercrop system, these yields cannot be expected to approach the genetic potentials possible in multiple cropping.

To evaluate genotypes for multiple cropping systems, or to evaluate the contribution of any other single component, it is necessary to hold a number of other factors constant. A summary of the more important factors—genetic, cultural, and climatic/soil—is shown in Fig. 6.3 for a monoculture system. Genetic and cultural factors

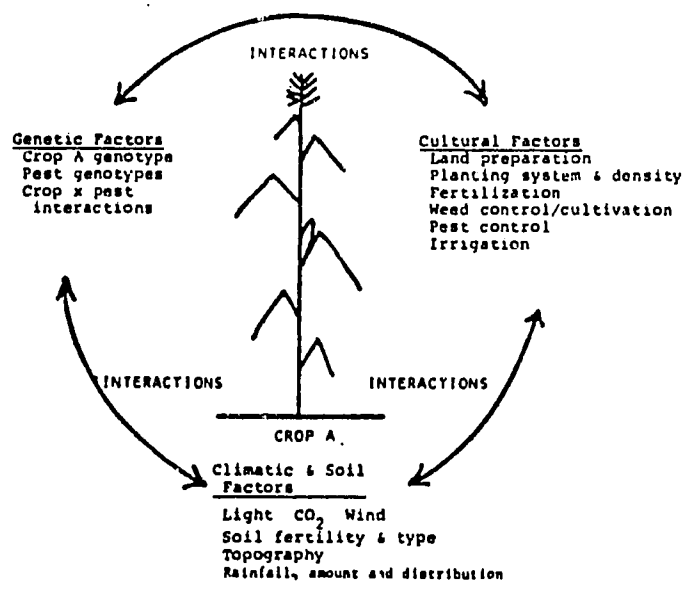

Fig. 6.3. Factors which may vary and interact in a monocrop system in one location.

generally are under control of the researcher and to some degree are controlled by the farmer. Interactions among these three groups of factors add to the complexity of research and to the uncertainty of farming, especially for the small farmer with little control over his natural environment.

Consider next a simple case of multiple cropping, with two crops planted at about the same time in the same field. Figure 6.4 illustrates additional variables which must be considered when two crops are grown in association, with the increased number of possible interactions between and among these new genetic and cultural variables and the environment. With 17 factors in the monocrop situation, there are 136 combinations of two factors which might possibly interact. With 26 factors listed in Fig. 6.3, there are 325 such combinations—and this is among the simplest of possible multiple cropping situations.

Varying one or more cultural factors in an experiment vastly increases the amount of seed, space, and other resources needed. Thus evaluation of cultivars should take place at a specified level of fertility, water control, pest and disease management, and weed control. If one component of a two-crop association is to be evaluated, the simplest procedure is to choose and maintain an appropri-

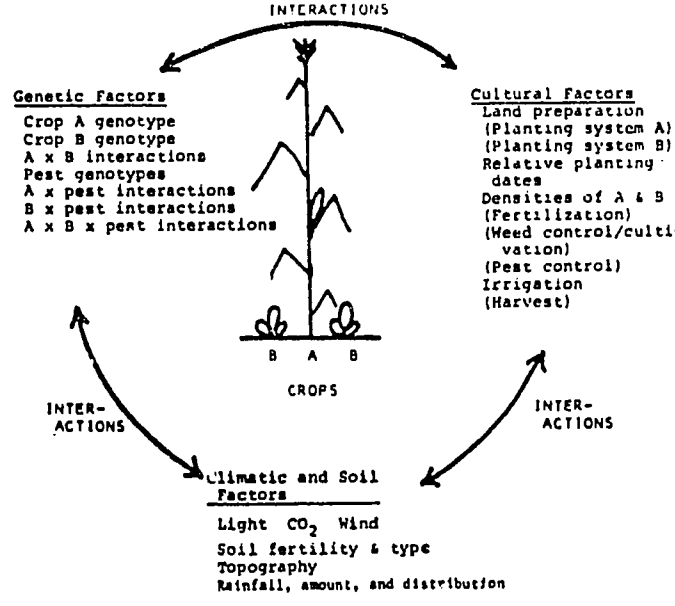

Fig. 6.4. Factors which may vary and interact in a two-crop multiple cropping system in one location; cultural factors complicated by intercropping are in parentheses.

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ate genotype of the other. A more complex scheme to simultaneously improve two species may be possible. Densities, planting dates, and spatial location of each component should be held constant. As in any experimental design, uniformity of soil and topography will enhance the precision of the experiment. This series of constraints is complicated by the possibility that results and conclusions could be specific to the location, soil type, and prevailing climate in each season. The complexity of genetic improvement for multiple cropping systems is clear. Within this context and these limitations, we can consider the improvement of cultivars.

SPECIES CHOICE AND GENETIC SELECTION

Species Choice in Cropping Systems

Most research on multiple cropping systems has focused on agronomic aspects—planting dates, densities, spatial orientation, fertilization, pest control, and other appropriate cultural practices. There has been some emphasis on the selection of appropriate crops to associate under a specific set of conditions. Since this does not involve what breeders consider genetic selection, species choice is preferred to describe this type of agronomic activity.

Historical data indicated an interest in the testing of species in combinations to seek yield advantage over monoculture (Zavitz, 1927). Most studies have appeared in the past decade. Agboola and Fayemi (1971) found that cowpea (*Vigna sinensis*) and greengram (*Phaseolus aureus*) have less effect on maize yields, and were more tolerant to shade, than seven other legumes in Nigeria. Short cycle pulse crops were found to fit best into double and triple cropping sequences in India (Saxena and Yadov, 1975). Studies in Tanzania (Enyi, 1973) explored the best combinations of cereals and legumes for total food production, with sorghum/pigeon pea (*Sorghum bicolor/Cajanus cajun*) giving the highest total yields. The screening of twelve potentially useful shade tree species in India was accomplished by measuring tea (*Thea surensis*) yields as the criterion for evaluation (Hadfield, 1974). These are but a few examples of the many trials which have been conducted in many parts of the world to determine which species to choose in combination with appropriate agronomic practices. The crop species by system interactions which are obvious in these tests led to the logical question of which cultivars of each species are most appropriate for multiple cropping systems.

Cultivar Choice in Cropping Systems

Having determined which species to emphasize in a multiple cropping system, researchers often have screened or tested a range of available genotypes for their performance under some set of environmental and cultural conditions. This is a logical first step in genetic improvement for multiple cropping systems. Examples are many. A late cotton (*Gossypium hirsutum*) cultivar associated with groundnut (*Arachis hypogaea*) is preferred over an early cultivar, since late flowering produces most of the cotton after harvest of the understory crop (Rao et al., 1960). Several authors who tested pigeon pea cultivars reported that early and dwarf genotypes (Singh, 1975), nonbranching and heavy terminal bearing genotypes (Tarhalkar and Rao, 1975), and spreading plant types (Tiwari et al., 1977) were preferable under each specific system and set of conditions. This illustrates the specificity of plant type needed for contrasting intercropping systems.

Traditional cultivars of maize provided better support than improved cultivars of maize for associated climbing beans in Guatemala (ICTA, 1976). Maize of medium maturity gave best total system yields when double cropped with legumes in Florida (Guilarte et al., 1974). Crookston and colleagues (1978) followed winter rye (*Secale cereale*) with three maize hybrids and achieved highest total biomass yields per year with a maize about 14 percent later maturing than normal full season, planted at two times normal density (total dry matter 25.9 MT/ha).

Dry beans (*Phaseolus vulgaris*) commonly are planted in association with maize in Latin America. Among four cultivars tested in Brazil, the strong climber was lowest yielding in simultaneous planting and highest yielding in a relay system, compared to bush and weakly indeterminate types (Santa-Cecilia and Vieira, 1978). In contrast, research in Peru indicated higher yields from indeterminate climbers planted simultaneously with maize, and higher yields for bush types planted near harvest time of the maize (Tuzet et al., 1975). Prostrate cultivars of cowpea generally were less affected by shading of intercropped maize than erect types tested in Nigeria (Wien and Nangju, 1976). The leafy and semierect type 'VITA-4' has proven to be one of the best individual genotypes in association with maize (IITA, 1976). In another test at the International Institute for Tropical Agriculture (IITA), the strong climber 'Pole Sitao' was least reduced in yield in association, compared to potentials in monoculture.

Choice of cultivar may depend on its effect on another principal

crop. In sugarcane (*Saccharum officinarum*) culture in Taiwan, sweet potato (*Ipomoea batatas*) may be intercropped during the early part of the cycle; short, dwarf-vined types of early maturity must be selected to minimize competition with the cane crop (Shia and Pao, 1964; Tang, 1968). Vegetable crops developed for these intercrop systems need to be shallow rooted (to plant with sugarcane), shade tolerant (if designed for relay systems), or relatively drought tolerant if developed to follow rice (*Oryza sativa*) at the end of the rainy season (Villareal and Lai, 1976). Thus cultivar choice depends on the relative importance of the two or more crops in the system, the potential growing season and optimum planting system (simultaneous, relay, sequential), and the genotype by system interaction of available germplasm with predominant cropping systems. Conflicting results from different studies with the same species reflect the complexity of interactions already described for these traditional systems, as well as the specificity of environmental conditions which surround each research location.

Genotype by Cropping System Interactions

Several examples of genotype by system interaction were given in a previous symposium (Francis et al., 1976). Significant interactions were described for cultivars of beans (intercrop with dwarf maize vs. intercrop with normal maize; Buestan, 1973), soybeans (*Glycine max*) (monocrop vs. intercrop with maize, sorghum, or millet; Finlay, 1974), and mungbeans (monocrop vs. intercrop with maize over three seasons; IRRI, 1973, 1974). The only significant correlation of monoculture yield with that in intercropping was reported by Baker (1975) for sorghum, though only four genotypes were included. We concluded that interaction of genotype by cropping system was an important reality in some crops and deserved study by the plant breeder.

Additional data now are available on various crop species and over a wide range of environments. Genotypes by system interaction may be evaluated by calculating the correlation of monocrop with intercrop yields. This is a rapid and uniform method of evaluating data from the literature and from annual reports (Francis et al., 1976).

Sorghum, millet (*Setaria italica*), and maize data are summarized in Table 6.2. A number of comparisons from the University of Philippines College of Agriculture-International Rice Research Institute-International Development and Research Center (UPCA-IRRI-IDRC) Program in Los Baños, Philippines (Gomez, 1976, 1977)

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Table 6.2. Correlations of monocrop with intercrop yields in cereals.

Crop	n	Average Yield (kg/ha)		r_{yield}	r_{rank}	Reference
		Monocrop	Intercrop (system)			
Maize	18	4413	4220 (climbing beans)	.44	.36	Torregroza, 1978
Maize	20	5619	4681 (bush beans)	.90**	.83**	Francis et al., 1979
Maize	20	5003	5768 (bush beans)	.40	.27	Francis et al., 1979
Maize	20	5619	3479 (climbing beans)	.89**	.83**	Francis et al., 1979
Maize	20	5003	3836 (climbing beans)	.73**	.67**	Francis et al., 1979
Sorghum	4	2393	3056 (millet)	.95*	.80	Baker, 1975
Pearl Millet	40	1050	1270 (pigeon pea)	.68**	.64**	ICRISAT, 1977
Pearl Millet	40	1050	1040 (sorghum)	.61**	.61**	ICRISAT, 1977
Sweet Maize	15	584	2481 (40% shade)	.28	.29	Gomez, 1977
Green Maize	5	3200	2450 (40% shade)	.07	.38	Gomez, 1976
Popcorn	7	2730	2120 (40% shade)	-.30	-.50	Gomez, 1976
Flint Maize	38	3770	2540 (40% shade)	.37*	.35*	Gomez, 1976
Glutinous Maize	10	671	1816 (40% shade)	.12	.27	Gomez, 1977
Flint Maize	58	588	1149 (40% shade)	.35**	.35**	Gomez, 1977
Sorghum	16	2644	2706 (40% shade)	.65**	.67**	Gomez, 1977
Sorghum	16	2920	1670 (40% shade)	.43	.46	Gomez, 1976

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contrasted monoculture following rice with the same series of genotypes in monoculture under 40 percent shade. Artificial shading in this ambitious tropical screening program simulates in monoculture the competition for light from an associated taller crop such as maize. Average yields in the trials range from less than one MT/ha to more than five MT/ha, and cereal yields in association are neither consistently lower nor consistently higher than monoculture. The correlations of monoculture with intercrop yields likewise are variable, generally positive, but not always significant. Though a number of the r-values are significant, this statistic must be greater than 0.7 to give a coefficient of determination (r^2 value) greater than 0.5; only in four of the comparisons does genotype explain more than half of the variation in yields across systems. Correlations for rank generally follow the yield results and may be more important than yields if a breeder intends to select a certain percentage of the tested lines without evaluating in both systems.

Though no specific data were presented, Kass (1976) indicated a positive correlation of rice yields in monoculture and association, when six cultivars were grown in three locations. Sayed Galal et al. (1974) reported strong positive correlations ($r = 0.91$, $r = 0.98$) in two consecutive seasons between intercropping tolerance of parental stocks and their topcrosses of maize. They concluded that this indicated a hereditary component to intercropping tolerance.

Data for grain legumes and sweet potato are summarized in Table 6.3. A number of correlations are significant between monoculture and intercropping. These correlations are not always consistent from one season to the next, as illustrated by lines 2 and 3 where the same 20 climbing bean cultivars were tested in two consecutive seasons with the same intercropped maize hybrid. The correlation coefficient was highly significant in one season (0.82) and nonsignificant in the next (0.41). Two consecutive seasons with the same 20 bush bean cultivars (lines 5 and 6) gave more consistent results, with significant correlation coefficients in both seasons. Mungbean correlations in lines 14 and 15 were not consistent in two seasons. Correlations consistently were positive in these comparisons. Of special interest is the unreplicated trial with 500 genotypes screened in two systems (line 8); the correlation was 0.33 between yields in monoculture and those with intercropping. Significant correlations between bean yields in monoculture and in association with maize also were reported by Clark et al. (1978) and by Chiappe and Huamani (1977).

Soybean and mungbean data from the Philippines were similar

Table 6.3. Correlations of monocrop with intercrop yields in legumes and sweet potatoes.

Crop	n	Average Yield (kg/ha)		r_{yield}	r_{rank}	Reference
		Monocrop	Intercrop (system)			
Beans, climbing	9	1700	377 (maize)	.90**	.88**	Francis et al., 1978b
Beans, climbing	20	2024	615 (maize)	.32**	.80**	Francis et al., 1978b
Beans, climbing	20	2897	1038 (maize)	.41	.09	Francis et al., 1978b
Beans, bush	9	1318	954 (maize)	.91**	.93**	Francis et al., 1978c
Beans, bush	20	1873	1157 (maize)	.88**	.58*	Francis et al., 1978c
Beans, bush	20	2295	971 (maize)	.51*	.54*	Francis et al., 1978c
Beans, climbing	64	2212	995 (maize)	.82**	.83**	Francis (unpublished)
Beans, climbing	500	2531	1118 (maize)	.33**	...	Francis (unpublished)
Beans, climbing	10	2986	840 (maize H210)	.61*	.44	CIAT, 1978
Beans, climbing	10	2986	847 (maize Suwan)	.24	.52	CIAT, 1978
Beans, climbing	10	2986	649 (maize LaPosta)	.41	.37	CIAT, 1978
Soybeans	16	1019	714 (40% shade)	.53*	.50*	Catedral & Lantican, 1977
Mungbeans	20	1149	368 (40% shade)	.53*	.48*	Lantican & Catedral, 1977
Mungbeans	18	1511	558 (maize)	.13	.24	IRRI, 1973
Mungbeans	20	1170	570 (maize)	.67**	.61**	IRRI, 1974
Sweet Potato						
Group I	11	16850	2640 (40% shade)	.14	.22	Gomez, 1977
Group II	12	14140	2730 (40% shade)	.87**	.89**	Gomez, 1977
Group III	12	13600	1700 (40% shade)	.58*	.44	Gomez, 1977
Group IV	12	20100	3400 (40% shade)	.46	.52	Gomez, 1977

to those of beans. Sweet potato correlations were positive but variable in screening trials comparing normal monoculture with a 40 percent shade situation, analogous to the light environment when an understory crop is associated with maize.

A number of authors have observed the importance of genotype by system interaction, and concluded that it cannot be ignored by the plant breeder. Working in wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*), Sakai (1955) found no consistent relationship between yield of a cultivar in mixture and its yield in pure culture. Over the years, the experience with mixtures of pasture species has led some researchers to the conclusion that genotypes expected to yield well as components of a mixture must be selected specifically for that objective (Dijkstra and de Vos, 1972; Fyfe and Rogers, 1965; Harper, 1967). Bean cultivars tested across environments led Hamblin (1975) to conclude that relative performance of genotypes in mixtures in one environment is not necessarily the same as relative performance in another set of conditions, since competition between genotypes interacts with the environment. This same conclusion has been reached by Lantican (1977) working with field crops in the Philippines and by Villareal in the Asian Vegetable Research and Development Center (AVRDC) in Taiwan (Villareal and Lai, 1976; Villareal, 1978) with sweet potato, tomato (*Lycopersicon esculentum*), and other horticultural crops.

When cultivars are compared among different intercropping systems, these correlations generally are high. Examples in Table 6.4 indicate significant r-values for yields of maize, climbing beans, and soybeans across several comparable cropping systems. The differences in environments between two intercropping systems generally may be less than between a monoculture and an intercropping system. The interaction of genotype by cropping system is one type of genotype (G) by environment (E) interaction. The magnitude and significance of G X E interactions may vary over years, locations, and planting dates. These also will vary among cropping systems, depending on how great the differences are among the environments where genotypes are tested, and on how the specific genotypes in a trial react to the specific environments included.

Firm conclusions on the importance of the genotype by system interaction are difficult to achieve, and possibly misleading. It is dangerous to generalize at this point. The results of any specific comparison are highly influenced by the lines that are chosen for that comparison. This important point may explain the conflicting results which we observe (Hamblin, 1979).

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Table 6.4. Correlations of crop yields between two associated cropping systems.

Crop	n	Average Yield (kg/ha) Association 1 (system)	Association 2 (system)	r_{yield}	r_{rank}	Reference
Maize	20	4681 (bush bean)	3479 (climbing bean)	.93**	.89**	Francis et al., 1979
Maize	20	5768 (bush bean)	3836 (climbing bean)	.68**	.58**	Francis et al., 1979
Bean, climbing	10	840 (maize H210)	847 (maize Suwan)	.67*	.60	CIAT, 1978
Bean, climbing	10	840 (maize H210)	649 (maize LaPosta)	.90**	.84**	CIAT, 1978
Bean, climbing	10	847 (maize Suwan)	649 (maize LaPosta)	.89**	.75**	CIAT, 1978
Bean, climbing	9	941 (dwarf maize)	829 (normal maize)	.26	.36	Buestan, 1973
Soybean	12	560 (maize)	650 (sorghum)	.60*	.39	Finlay, 1974
Soybean	12	560 (maize)	280 (millet)	.44	.34	Finlay, 1974
Soybean	12	650 (sorghum)	280 (millet)	.69**	.60*	Finlay, 1974

Statistical Alternatives for Genotype by System Comparisons

There are a number of statistical alternatives for evaluating the magnitude and nature of G × E interactions. The analysis of variance and partitioning of sums of squares due to the several sources of variation has been used most extensively. Though more rigorous and precise than correlations, an analysis of variance requires access to the original data by replication, which usually are not included in publications or annual reports where much of these data are found. Other estimates of G × E interaction are possible using the means of genotypes in each system.

Data are presented in Table 6.5 from three trials of climbing beans associated with maize; two trials of bush beans associated with maize; two trials of mungbeans associated with maize; and two trials of maize cultivars associated both with climbing beans and with bush beans, in which the contrasting monoculture systems for each cultivar were included for comparison. The bean and maize trials were conducted at the International Center for Tropical Agriculture (CIAT) in Colombia, and the two mungbean trials were conducted on the IRRI station in the Philippines (data from R. R. Harwood). Mean yields in each system, and average differences in yield (with their respective variances), are presented in the first seven columns.

Yield reductions ranged from a high of 69 percent in the first climbing bean trial to a low of 38 percent in the first bush bean trial, among the trials of legume species. It is interesting to note the similarities between paired trials, since these included most of the same genotypes of the test crops in two seasons. These comparisons in Table 6.5 are for climbing beans (lines 1 and 2), bush beans (lines 4 and 5), and mungbeans (lines 6 and 7). The standard deviations of the proportionate reductions in bean yield are remarkably similar in the trials with four replications each conducted at CIAT (lines 1, 2, 4, and 5); these range from 0.060 to 0.063 in the four trials. The other climbing bean (line 3) and two mungbean trials included only two replications in each cropping system, and have a range from 0.075 to 0.104 in standard deviations of the proportionate reductions.

The analyses of variance using replicated data from these same trials are summarized in the first five columns of Table 6.6. Genotype (G) by system (S) interactions were highly significant in four trials, and significant in two more. From this analysis, one may suggest that selection for specific genotypes in each system could be indicated in those systems with a highly significant G × S interaction. F-values for G × S from two seasons and the same genotypes, as indicated above, are similar.

If data were not available from replications, but number of

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Table 6.5. Statistical alternatives for comparing yields in two cropping systems, I.

Test Crop	n	Yield (kg/ha)				Proportionate Yield Reduction	
		Monocrop	Associated (crop)	Difference	$S_{difference}$	Reduction	$S_{reduction}$
Beans, climbing	20	2024	615 (maize	1409	429	.69	.063
Beans, climbing	20	2897	1038 (maize)	1859	323	.64	.061
Beans, climbing	64	2212	995 (maize)	1217	633	.54	.104
Beans, bush	19	1873	1157 (maize)	716	232	.38	.063
Beans, bush	20	2295	971 (maize)	1324	225	.58	.060
Mungbeans	18	1511	558 (maize)	600	182	.63	.075
Mungbeans	20	1170	570 (maize)	600	185	.51	.100
Maize	20	5619	4681 (beans, bush)	938		.17	
			3479 (beans, climbing)	2140		.38	
Maize	20	5003	5768 (beans, bush)	−765		(.15)	
			3836 (beans, climbing)	1167		.23	

specific plant to plant interactions suggests that no single breeding procedure will be indicated for all crops and cropping systems. The best recommendation which can be drawn from the limited experience to date is to concentrate on easily identified qualitative traits in the early generations: seed color; endosperm type; disease and insect resistance; plant growth habit; and gross adaptation to prevailing temperatures, rainfall, day lengths, and levels of soil fertility. When generations have been advanced and seed increased in self-pollinated crops under the most convenient system for evaluating these qualitative traits, the advanced generations can be tested in appropriate cropping systems for quantitative traits such as yield potential, competitive ability with associated species, and stability of production.

Where heterosis is important as in maize and sorghum, some form of dynamic recombination and testing such as full-sib or half-sib family selection could be practiced. This allows testing of promising families for quantitative characters in each generation. This system is used extensively by CIMMYT in the international maize program. It is not known whether hybrids with the specificity of adaptation of traditional single crosses or double crosses could be applied to these complex and variable cropping systems which characterize multiple cropping. Prolificacy in maize and tillering in sorghum would appear to be traits which would greatly enhance their potential yields at low densities, while allowing light to penetrate to an understory crop. An adequate testing program over locations and systems would allow the identification of lines, as well as the evaluation of a number of promising hybrids, if this route appeared desirable. Distribution of existing maize hybrids in the tropics to large numbers of small farmers has been successful only in a few countries.

PRACTICAL SCREENING AND TESTING OF NEW CULTIVARS

The first critical step in the development of genotypes for multiple cropping systems is the decision of whether a separate breeding and testing program is necessary. If that decision is affirmative, the most efficient possible breeding scheme must be devised for rapid handling of large numbers. Promising new genotypes identified in the program must be tested both on the experiment station and on the farm; this is crucial before seed increase and wide-scale application of a new component of technology. Finally, the diversity of systems which characterize many small farmer zones presents some unique challenges in the transfer of technology. Each of these questions is explored.

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Decision to Breed for Intercropping Systems

Results of trials conducted to date indicate no clear and generalized decision on whether or not a specific breeding program for intercropping systems is needed or justified. Factors which should be considered include the magnitude and nature of the correlations (significance of the G × S interactions), resources available for the total improvement program, similarity of traits and breeding objectives between the two (or more) breeding schemes under consideration, and relative importance of the two or more alternative cropping systems in the region into which improved genotypes are to be introduced.

The positive signs of almost all correlation coefficients in Tables 6.2 and 6.3 suggest that two separate breeding programs rarely would be justified. There generally is a positive association (though not always significant) between yields in the two contrasting systems. Prevalent insects and diseases likewise will affect each species in a region in almost any cropping system, although differences in severity between systems may dictate a change in relative priorities. Efficient response to applied fertility is vital in improved cultivars; but the modified natural fertility of an intercrop system which includes legumes, for example, may require less additional fertilizer for component cereal crops, and again may influence priorities. The relative importance of each crop in a system must be considered, as well as the contribution of each to total yield or income, and the interaction of yield of one crop with yield of the other. The most efficient combination of the two (or more) crops is the desired end product, with efficiency measured in yield, net income, nutrition, or other appropriate units.

Limited research personnel, facilities, and operating budget encourage the technician to make most efficient use of these scarce resources. With a fixed resource base in a breeding program, any dilution of funds to support two or more primary improvement activities would be expected to give less genetic progress in any specific direction than a single effort with one system and a relatively small number of breeding objectives. If a decision is made to focus entirely on a multiple cropping approach, due to the predominance of one or more related systems in a region, this would suggest a potential for rapid progress in yield potential and adaptation in that system. The division of germplasm and breeding activities into two separate and unrelated projects with no interchange between them rarely would be justified. It is possible to design an efficient combination for critical selection of parents,

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early generation screening for disease and insect resistance, and systematic testing in more than one cropping system. Examples used in several programs in the tropics are given in a later section.

Extremely important among these biological and other variables is the potential production to be achieved in multiple cropping systems in a region through introduction of improved genotypes, and whether over the short or medium term farmers are likely to preserve these systems or change to monoculture. A complex decision based on availability of relevant technology, information and capital, past experience, risk and other nutritional and economic factors, and the willingness and capacity of the farmer to modify his current system must be taken into consideration in the design of a crop improvement program for multiple cropping systems.

Phenotypic Traits Desirable for Intercropping

When the predominant cropping system or systems have been identified, and when the most critical limiting factors to production have been established and quantified, and a decision has been reached on which system or systems will be used in the improvement program, the next focus is on specific breeding objectives for each component crop species. Selection criteria vary with crop, cropping system, prevalent pathogens and insects, unique stress conditions in each region, and eventual use of the product, including relative prices and demand for component crops. An early decision within the cropping systems context is whether to breed improved genotypes that are specific to the farmer's current system, or whether some agronomic modifications—planting dates, densities, spatial arrangement, crop species, rotations—should be considered in the design of new components for the systems. Genetic improvement projects rarely are efficient in this context if not linked to a dynamic and imaginative activity in agronomy. Given the complex combination of factors summarized in Fig. 6.4, it is difficult to generalize about traits desirable for genotypes in a multiple crossing system. There are many reports in the literature about specific traits, but only a cursory treatment is available on this aspect in the previous review (Francis et al., 1976).

Photoperiod and Temperature Sensitivity

The genetic capacity to grow and mature in a given number of days, independent of day length, is a trait often associated with successful genotypes for intensive multiple cropping systems (Dalrymple, 1971; Jain, 1975; Moseman, 1966; Phrek et al., 1978;

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Swaminathan, 1970). Photoperiod insensitivity has been among the important breeding criteria since the inception of rice improvement in IRRI (Coffman, 1977). This trait allows planting of a cultivar on any convenient date, with flowering and maturity controlled by genotype reaction to prevailing temperature patterns and to some degree to other cultural and natural fertility factors. Coupled with shorter duration cultivars, this capacity in rice and other crops encourages an intensification of the cropping system with additional crops during the same year. Photoperiod insensitivity is valuable in mungbeans (*Phaseolus aureus*) (Tiwari, 1978) and other legumes for intercropping, relay cropping, or double cropping with a principal cereal crop. In some specific situations, photoperiod sensitivity may be important in one component crop to assure that its major growth, flowering, and filling period do not coincide with another component of different seasonal duration. The suggestion that temperature insensitivity be incorporated (Tiwari, 1978) is useful in terms of broad adaptation and in tolerance to stress conditions (high and low extremes in temperature), but crop growth rates independent of temperature are biologically impossible.

Crop Maturity

Short crop maturity has been cited as a desirable trait in most reports (Moseman, 1966; Swaminathan, 1970) due to the potential this provides for intensification of the cropping system through addition of species or multiple plantings of the same species during the crop year. Short duration has been an important trait in most of the new rice cultivars released by IRRI, though genotypes currently being developed for low input agriculture include medium and long maturity alternatives (Coffman, 1977). Mungbeans (Catedral and Lantican, 1978; Gomez, 1976, 1977; IRRI, 1972; Phrek et al., 1978), soybeans, and cowpea (Gomez, 1977) are among the short cycle legume crops which fit well into these intensive cropping systems (Jain, 1975). Early and concentrated flowering to give uniform maturity is desirable in mungbean (Carangal et al., 1978). Sweet potato (IRRI, 1972) and maize (Gomez, 1977; Hart, 1977) cultivars with a short duration cycle likewise are desirable for intensive systems. Tall and long-cycle rice may fit better into some intercropping systems in Central America with maize of short duration, where the rice flowers and fills grain after the maize is doubled (Hart, 1977). In the international mungbean trials, Poehlman (1978) reported that vigorous late- and extended-flowering cultivars were most desirable for rainfed locations with low light intensity and

higher temperatures, while short-cycle genotypes were best under high light conditions, irrigation, and cooler temperatures.

More important than the maturity characteristics of one component are the ways in which the two or more crops fit together in a system. Generally, the combination of an early and a late maturing crop is desirable, to better utilize available growth factors at different times (Andrews, 1972a, 1972b). Sorghum-millet intercrops at International Crop Research Institute for the Semi Arid Tropics (ICRISAT) (1977) were most successful when the earliest sorghum was combined with the latest millet, or when the earliest millet was combined with the latest sorghum, and these maturity differences were found to be more important than height differences of the two components. Selection of component crops with appropriate maturities is a critical part of the improvement program.

Plant Morphology

Short erect cereals have been developed for nitrogen responsiveness (Coffman, 1977), and this same trait is desirable for most multiple cropping applications. Medium to short cereal crop plants provide less competition to an understory legume or intercropped cereal of another species (Andrews, 1972a). Determinate growth habit and medium to short plant height are desirable in most legumes (Catedral and Lantican, 1978; Gomez, 1976, 1977; IRRI, 1972). In the maize-bean system, however, a climbing cultivar of beans appears to have greater yield potential than a bush type with simultaneous planting (Francis, 1978; Hart, 1977). Yield of a taller maize cultivar was less affected than yield of a dwarf hybrid by an associated climbing bean (CIAT, 1978), and which type is most desirable depends on total system yields and relative prices of the two crops (Francis and Sanders, 1978). Height differences between two components may be more important than the absolute height of each component (ICRISAT, 1977), and the interaction of component crop height with relative planting densities must be considered (Zandstra and Carangal, 1977). Leaf angle of crops affects the amount of light transmitted to lower components of a system, and influences distribution of light to different levels of leaf area within the canopy (Trenbath and Angus, 1975; Wien and Nangju, 1976).

Rooting Systems

Shallow rooted mungbean cultivars are most desirable for intercropping with a more permanent crop such as sugarcane to minimize

competition for water and nutrients (Catedral and Lantican, 1978; Gomez, 1977). In general, the combination of two or more crops with different rooting patterns, such as a shallow-rooted species with a deep-rooted species, should give a better total water and nutrient extraction potential than either crop grown alone, or than the combination of two crops with similar rooting patterns (Krantz, 1974; Swaminathan, 1970).

Population Density Responsiveness

Component crops which respond to increased density give greater flexibility in the design of cropping systems with varied proportions of each crop in a mixture (Francis et al., 1978a; IRRI, 1973; Swaminathan, 1970). Optimum mixtures vary with the species, density response of each component, type of intercropping system, relative prices for the crops, and alternative schemes for the greatest total exploitation of the growth environment.

Early Seedling Growth

Particularly in low input cropping systems, early and competitive seedling growth is highly desirable to partially control weed growth (Catedral and Lantican, 1978; Gomez, 1977; IRRI, 1972). Growth of one species in a mixture also may be suppressed by allelopathy, an important interaction in weed/crop combinations or in multiple cropping systems (Trenbath, 1976). There is apparently genetic variation within some species tested for ability to alter weed growth (for cucumber [*Cucumis sativus*] example, see Putnam and Duke, 1974).

Insect and Disease Considerations

Pests that attack a given crop species in each region can be controlled or the attack modified to some degree by crop rotation and design of cropping systems (Altieri et al., 1978). Intercropping tall and short species may reduce attack on one or the other due to physical interference with insect movement (Chiang, 1978). Shorter duration crop cycles result in a shorter exposure time of each species to pests, and a longer total system cropping period may lead to higher population levels of naturally occurring biocontrol agents (Litzinger and Moody, 1976). Trenbath (1977) reviews the situation of reduced attack by insects on crops in mixed culture relative to monoculture, and, in a previous report, classified pest and disease interactions with crops according to several possible mechanisms: fly paper effect, compensation effect, and microenvironmental ef-

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fects (Trenbath, 1975a). There is apparently less difference between intercropping and monoculture in the incidence of diseases, compared to insects, although the advantages of crop diversity for preventing widespread disease epidemics have been discussed (Day, 1973; Harlan, 1976). These insect and disease interactions with cropping systems are important because of the relative importance which must be placed on each resistance trait in a breeding program, and the stability which host plant resistance lends to these intensive cropping systems for the small farmer.

Screening Techniques for a Breeding Program

The first step in screening germplasm has involved large tests of available germplasm under alternative systems (see Tables 6.2 and 6.3). An example of the extension of this methodology to a double cropping system with rice was described by Carangal et al. (1978) for the evaluation of mungbean cultivars. Seven locations in Southeast Asia, as well as seven locations in the Philippines, were used to test a standard set of genotypes. 'Bhacti' was the best cultivar across countries, while 'CES-1D-21' was the best cultivar across locations in the Philippines. This is an international approach to cultivar choice; it is helpful in the identification of limiting factors and in the appropriate selection of parents for a breeding program.

Theoretical considerations for breeding of two or more species have been published by Hamblin and colleagues (Hamblin and Donald, 1974; Hamblin and Rowell, 1975; Hamblin, Rowell, and Redden, 1975). Comparisons of the use of pedigree breeding vs. bulk breeding are discussed, and a theoretical design is described for the simultaneous selection of two species for yield and ecological combining ability. Practical applications of the methods were not found in the literature.

The cowpea breeding program in IITA (IITA, 1976; Wien and Smithson, 1979) has focused on intercropping in the evaluation of some advanced lines. Tests in several locations in Nigeria during 1976 and 1977 revealed large differences among lines tested, and 'TVu1460' and 'TVu1593' were identified as cultivars with promise for this intercropped system.

Maize breeding in the ICTA program in Guatemala had concentrated on monoculture improvement in the lowlands until Poey and colleagues (1978) established a new and innovative selection and recombination program. They are farm testing 500 full-sib families in nonreplicated 5-m rows, with half of each row associated with beans. These results, analyzed using five locations (five different

farms) as replications, lead to recombination of the best families on the experiment station and another cycle of farm testing. Two subregions—1500 to 1800 meters elevation and above 1800 meters elevation—are included, each with a separate set of families. Though no results are available yet for evaluation, this selection scheme appears likely to meet its objective of minimizing the genotype by environment interaction which has plagued highland maize improvement schemes in Central America and the Andean zone for years.

The climbing bean improvement program in CIAT can be used to illustrate a series of logical steps in the breeding process which leads from problem identification through agronomic testing, crossing, early generation, and advanced line evaluation. Recognition of the need for improved cultivars of climbing beans in association with maize (Mancini and Castillo, 1960; Francis et al., 1976) led to an early screening of available germplasm from the *Phaseolus* germplasm bank in Centro Internacional Agricultura Tropical (CIAT). This initial screening of almost 2000 accessions and seed increase on trellis supports in monoculture was followed by a screening of 500 promising lines in two cropping systems: intercrop with maize and monocrop on trellis (see line 5, Table 6.3). A subset of the best cultivars was tested in a replicated trial with the same two systems (see line 7, Table 6.3) in the next season. Concurrent agronomic trials explored the optimum planting dates for climbing beans with maize (Francis, 1978), densities of the two crops (Francis et al., 1978a), and the interaction of genotype by system with a small set of cultivars. Subsequent research on maize cultivars (CIAT, 1978) revealed that 'Suwan-1,' a cultivar with intermediate height, relatively narrow leaves, and lodging resistance, gave the greatest expression of differences in yield among bean cultivars.

Testing of 30 potential climbing bean parent materials in three highland locations (CIAT, 1978) showed highly specific temperature adaptation and a range of reaction in growth habit and flowering pattern to this range of environments. Preliminary evaluation of germplasm in association with maize is now conducted in hills which include three bean plants and three maize plants per bean progeny; this allows a cheap and effective evaluation of large numbers in a small area. Cultivars with good pod set, growth habit stability, apparent disease resistance, and a range of seed color were selected as parents and intercrossed. Because of the relatively high and positive correlations between intercrop and monoculture yields in climbers (Table 6.3), and because of the difficulty of testing for yield in early generations, these progeny were tested in early generations for re-

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sistance to rust, bean common mosaic virus and anthracnose, and given a preliminary yield evaluation in monoculture (CIAT, 1977). At least 1000 progeny per cross are evaluated (CIAT, 1978).

Advanced generation testing in four locations—monoculture in Popayan, intercrop with maize in Palmira and Obonuco, relay with maize in La Selva—recently was completed. Following seed increase in the first season of 1979, the best selections from this initial set of crosses will be entered by Davis and colleagues into the International Bean Yield and Adaptation Nursery for Climbers. This is the first time that an international trial has been developed by crossing, selecting, and testing specifically for use in a multiple cropping system. It supplements the 1978 international trials of climbing beans which were selected and increased from the germplasm bank.

The CIAT climbing bean improvement program concentrates on development of cultivars for simultaneous intercropping or relay systems, with sufficient testing at the different stages to identify superior types for monoculture. The bush bean improvement program, conversely, is directed toward efficient types for monoculture, or for double or relay cropping. The most promising bush selections likewise are tested in association with maize at regular intervals in the breeding process. Other bean plant ideotypes of a semi-determinate nature are being selected for relay and other intensive cropping systems (CIAT, 1977; Laing, 1978). Concentration of bush bean culture and a unique set of insect/disease problems in the lowlands, compared to the climbing beans and associated cropping systems in the highlands, simplifies this process somewhat in the Andean zone.

These breeding programs are all recent, and procedures have not been compared to alternative methods nor across several crops. They will give the first germplasm specifically developed for intensive systems. Over the next few years they should give relevant comparisons from which researchers in other regions, working on other crops, may be able to gain some perspective and save time and resources when designing new programs.

On-Farm Testing and Transfer of Technology

Critical to success in any crop improvement program is the testing of promising cultivars in the cropping systems and environment in which they will be grown by the farmer. Mechanisms for evaluation of new cultivars vary with the type of research organization and national policies on extension and agricultural development. Whatever the mechanism for validating new technology,

several problems must be considered which are inherent in multiple cropping systems and the biological, economic, and cultural environment in which they are used.

As mentioned previously, it is difficult to generalize about multiple cropping systems and the farmers who use them. Many small farm regions are characterized by a multiplicity of systems, with much variation in planting systems, densities, species composition, and microclimatic influences. Planting dates often are dependent on rainfall patterns; thus they are somewhat uniform in a region. The number of species and major cropping systems also may be limited due to crop adaptations, markets, and preferred species in the diet and tradition. Thus it may be possible to identify a small and discrete number of systems in which to test cultivars in a zone.

If cultivars are to be introduced into existing systems, the procedure is less complicated than if cultivars are one component of a new or modified production package which includes other inputs and requires education of the farmer. Testing must be realistic, and any validation on the farm cannot depend on a transplanting of experiment station technology which is unrealistic or unavailable to the farmer. Enough replication throughout the region of application must be accomplished to assure an adequate evaluation over the range of possible soil and climatic conditions to be faced by a new cultivar. This replication of testing generally is limited by lack of resources, but many ingenious schemes have been devised which maximize farmer participation and input, and thus extend as much as possible the scarce funds available.

Although broad adaptation is desirable in improved cultivars from the breeder's or seed producer's point of view, the individual farmer's immediate concern extends only to his own range of cropping system variations and the soil and climatic conditions which he has experienced on his farm. If yield potential in specific systems and cultural conditions must be sacrificed for genetic adaptation to a wide range of conditions, some compromise must be attempted between these conflicting objectives.

Several examples of on-farm testing have been cited. The maize selection procedure in the Guatemalan highlands (Poey, 1978) involves farm tests during the initial stages of family evaluation, and presumably these same collaborators may be willing to test resulting populations or synthetics from the program. The Philippine program in collaboration with IRRI is sending new crop cultivars from the screening activity to additional sites in Southeast Asia. The CIAT

bean program already has begun wide testing of bush cultivars in various systems, and has initiated through national research programs the first climbing bean trials in areas where these bean types are grown with maize and other support systems. There is no single scheme that is superior or to be recommended for this testing step; the most important issue is that adequate emphasis and resources should be put on this critical phase of research.

Economic and cultural factors may be more important than biological variables in the eventual adoption of new cultivars. Certainly the economic advantage of a new cultivar alone or as a part of a modified cultural system, as compared to the current cultivar, will be critical to success. Genetic characteristics such as seed color, size, taste, and cooking qualities may influence acceptability of a basic food crop cultivar. The nature and cost of the change in cropping system which may be needed for a new cultivar could negate any advantages of the technology, if these modifications are not understood and accepted by the farmer. If additional inputs are required, is the farmer capable of financing them, or is credit available to him at a realistic rate of interest? These questions plus others specific to each zone and crop must be considered in the design of new technology by the breeder who hopes to improve production through new cultivars and cropping systems.

POTENTIAL PRODUCTIVITY OF MULTIPLE CROPPING SYSTEMS

Traditional multiple cropping systems with unimproved cultivars and low levels of technology have been preserved by farmers to reduce risks, to provide a nutritious and varied diet, and to make better use of available land than would be possible with a comparable monoculture. With few outside inputs and traditional management, low crop densities, and limited moisture and/or plant nutrition, neither the combined crop components in a mixture nor a single species in monoculture is fully exploiting available resources, such as light, energy, and other nonlimiting growth factors. Thus it is not surprising that researchers have found in these low management systems that intercropping generally has an advantage over monoculture, sometimes up to 400 percent (Herrera and Harwood, 1973). When available components of technology—new cultivars, fertilizers, pest control, irrigation, density recommendations—which have been developed for monoculture are introduced into both systems, yields increase and the relative advantage of intercropping is reduced to

levels of 10 to 40 percent in the better species combinations (Francis, 1978; Herrera and Harwood, 1973; Hiebsch, 1978; Lohani and Zandstra, 1977).

The potentials of a multiple cropping system depend on the competition of component crop species for available growth factors and some types of complementation between (among) species. Those cases in which overyielding (intercrop yield greater than yield of most productive component in monoculture) occurs are of greatest interest to the farmer, and this is the principal objective of crop improvement for multiple cropping systems. According to Andrews (1972b), overyielding of intercropping over monoculture occurs in those combinations in which: (1) intercrop competition is less than intracrop competition; (2) arrangement and relative numbers of the contributing crop plants affect the expression of the difference in competitive ability; (3) competition between crops is alleviated when their maximum demands on the environment occur at different times (either by choosing crops with different growth cycles or by planting at different times); (4) the seasonal period of growth is long enough to permit better total exploitation of this total season by two or more crops; and (5) legumes can be intercropped with nonlegumes under poorer fertility conditions.

The classic papers by de Wit (1960) and by Donald (1963) should be consulted for the basis of quantitative interactions between species. One of the most comprehensive recent reviews on crop interactions in multiple cropping is that of Trenbath (1976), to which the reader is referred for more complete treatment of the nature of competition in mixed culture. Only those aspects with direct relevance to crop improvement are discussed here.

Competitive Ability and Yield

Reports in the literature disagree on the association of competitive ability with yield in pure stand. Successful competition for scarce resources is critical to crop production by components of a mixture. An early report on barley and wheat cultivars (Suneson and Wiebe, 1942) found that survival in mixtures was unrelated to yield of component cultivars in pure stand. A good correspondence between high yields in monoculture and good competition in mixtures has been reported for barley (Allard and Adams, 1969; Harlan and Martini, 1938), for wheat (Allard and Adams, 1969; Jensen and Federer, 1965), and for maize (Kannenberg and Hunter, 1972). A negative relationship between yield in pure stand and competitive ability was reported in barley (Wiebe et al., 1963) and

in rice (Jennings and de Jesus, 1968). Donald (1968) explored the theoretical basis for this negative association and suggested that a weak competitor in mixtures actually makes a minimum demand on resources per unit dry matter produced, and thus produces more in pure stand.

Competitive ability and the selective value of genotypes appear to be influenced strongly by environment, including the effects of neighboring plants (Allard and Adams, 1969; Hamblin, 1975). When genotype performance over a series of environments is plotted against the environmental mean yields (average of all genotypes in each environment, see Eberhart and Russell, 1966; Finlay and Wilkinson, 1963), the rate of response by individual genotypes to improving environments is variable (Hamblin, 1975). Likewise, it has been shown in the section on genotype by system interactions that in several species the relative performance of genotypes varies with the cropping system. Add to this the possible complication cited by Hamblin and Donald (1974) in barley, where yields of progeny in the F_3 were not correlated with yields in the F_5. There also was a negative correlation of F_5 grain yield with F_3 plant height and leaf lengths, factors favorable to competing ability.

If experience with one species suggests that the best yielding genotypes in a population will be eliminated by competition in early generations, then evaluation of spaced plants and a pedigree system probably is indicated (Hamblin and Rowell, 1975). If the individuals which compete well in a population are the best sources of germplasm for increased yields in later generations, then a bulk breeding scheme could be used in self-pollinated crops (Hamblin and Rowell, 1975). Further research on breeding methodology is badly needed to advance our understanding of which approaches are most appropriate and most efficient.

Species Interaction and Resource Utilization

Crop species present in the field at the same time—whether planted simultaneously or in relay pattern—interact by competing for available resources. There is rarely a competition for physical space, but rather for the light, water, nutrients, or CO_2 which that space receives or contains. Trenbath (1976) describes in detail the mechanisms by which genotypes compete for resources. Both field and greenhouse studies have attempted to quantify the nature of intra and interspecific competition and to determine how this division of resources is accomplished (for example, Donald, 1958;

Hall, 1974; Osiru and Willey, 1972; Trenbath, 1974b; Trenbath and Harper, 1973; Willey and Osiru, 1972).

The picture which emerges is of a dynamic and complex interaction in several dimensions among two or more crop species and their physical environment. Competition begins for an individual plant when growth and development is retarded or altered from what it would be if no other individuals were present. This interaction ends only when that plant is removed from the crop environment, or when it ceases to actively (in the case of root absorption of water and nutrients) or passively (in the case of light interception by a taller though mature plant) compete with neighboring plants of the same or a different species. The challenge to the plant breeder is to design each crop component to efficiently exploit resources in this environment with the maximum economic yield produced per unit of resources and per unit of time, and with a minimum effect on the same exploitation by the other species.

Total resource utilization is most complete when two or more species occupy different ecological niches within the cropping system (Loomis et al., 1971). Growth cycles of the intercropped species may be different (Lohani and Zandstra, 1977; Osiru and Willey, 1972), accomplished either through varied planting dates or choice of crops with different maturities. This complementary use of resources over time (Ludwig, 1950, as cited by Trenbath, 1976) holds potential in zones where two or more crops with shorter cycles and greater efficiency could occupy the field which now grows a single long cycle crop, or where a part of the potential cropping cycle is not utilized.

The complementarity of taller cereals and shorter legume species (Francis, 1978; Willey and Osiru, 1972) or of different component heights in related species (Khalifi and Qualset, 1974; Trenbath, 1975a) makes better use of light through the growing season. What has been called complementary competition for light describes the compensation for yield loss by one component by increased production in another. The nature of this compensation and complementary resource use will determine in part whether a mixture will overyield a monoculture. Spatial exploration of different layers by roots of two or more species is another type of complementation which may have advantages in deep soils (Trenbath, 1974a).

Differences in patterns of light interception or root exploration are useful not only in the choice of species and cultivars, but also in the conscious genetic selection of promising cultivars of each

component species to best complement others in a multiple cropping system. The degree to which two or more species, and new cultivars of those species, can more efficiently and completely exploit total resources will determine the potential success of multiple cropping systems compared to high input monocultures.

CONCLUSIONS AND RECOMMENDATIONS

The potential for improving multiple cropping systems at any level of technology or management depends on the ability of the researcher to combine genetic advance with new agronomic methods. The realization of this potential to increase production on the farm requires viable tests of the best combinations and the eventual transfer of the new technology. Relevant research in these systems requires: (1) a thorough knowledge of existing cropping systems and the reasons for their popularity; (2) a comprehensive understanding of the nature and variation of prevailing climatic and soil conditions, and both the growth potentials and stress which they will impose on growing crops; (3) a practical experience with the limiting constraints to production in prevalent crop species; and (4) enough perspective on breeding, agronomy, plant protection, cropping systems, economics, and politics to make rational decisions on priorities in a breeding program. This is a colossal task!

The challenge will not be met successfully by an isolated individual working in a single academic discipline. Nor will the answers to these complex questions arise from any single basic research project or one applied development effort. A research focus that crosses departmental lines and the traditional disciplines, and that includes the spectrum from basic to applied activities, will have the best chance of success.

Who will train the geneticists and plant breeders to carry out these activities, and how should a program be organized? Is it possible to give scientists a relevant preparation for improving complex cropping systems in the tropics with an academic program and field apprenticeship in the temperate zone? And will the existing rules and organization of universities and research institutions in all parts of the world allow this to occur?

We as educators must accept this challenge. The responsibility for training young plant breeders from the developing world requires a better appreciation on the part of those doing the training in crops and cropping systems in these countries. A graduate study program should reflect the importance to future success of a broad technical

preparation and capacity to communicate with specialists in other disciplines. The international centers have organized staff and research activities into interdisciplinary teams and can collaborate on thesis work for some students. Selection and development of thesis topics to give the best possible preparation for handling the complex types of biological problems that limit crop yields in the tropics are essential.

It is neither a small nor routine responsibility to design and direct a graduate program for a potential research leader in the developing world.

We as students and researchers have an even greater responsibility. The potential of crop species improvement for multiple cropping systems will not be realized without a concerted effort in the field, both on the experiment station and on the farm. We must explore the complexities of existing systems, sort out the components that are susceptible to research and improvement, and subject the most promising alternatives to rigorous evaluation under real world conditions. This is an application of the scientific method to solving practical problems of the farmer.

The world food crisis is upon us, and the geneticist and plant breeder have a significant role to play in its solution. Multiple cropping systems are complex, but they hold an exciting potential for increasing food production which has not yet been realized. Through the successful integration of our activities with those in other disciplines we can begin to focus on the complex problems which have limited the use of improved crop technology by most farmers in the tropics. The use of more intensive systems also opens a new and greater potential for increased production in temperate zones. We can each contribute in some way to a dynamic and imaginative research and training program which will make the greatest possible use of our talents in genetics and plant breeding to meet the challenge of increased world food production.

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Discussion

R. K. CROOKSTON
R. M. LANTICAN

1. R. M. LANTICAN. Breeding work in a tropical setting is challenging because one has to deal with a myriad of situations associated with year-round seasonable variability; many options in the use of energy, including labor; and an array of established cropping systems. This challenge can tax the limited manpower and resources of national breeding programs, so a unified and systematic approach to problems in crop production becomes imperative to a plant breeding program. Certainly, breeding programs must be confined to major crop production systems prevailing in a geographic region that create the greatest impact on the food supply and socio-economic situations.

In Asia, excluding China, Korea, and Japan, there are 39 million ha in the rain-fed wetlands that offer great potential for increased food output. This rain-fed area normally is used for growing a single crop of rice each year, and most of it remains idle for the rest of the year. With new early maturing rice cultivars, direct seeding on dry seedbeds replaces the traditional methods of transplanting seedlings, and as a result, cropping intensity can be doubled. The other major area available to crop production in the tropics is the space under plantation crops like coconuts, oil palm, and rubber, and between rows of sugarcane. In Asia, the coconut crop occupies 5 million ha. Thus, in tropical areas, the objectives when breeding plants for multiple or intercropping must be to adapt dryland crop strains for conditions of pre and postrice cultivation and to intercropping with plantation crops.

Postrice cultivation usually encounters low moisture supply, hot or cold temperatures, and poor soil granulation. Plantings under or

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between rows of plantation crops must contend with partial to full shading and competition for nutrients. So the breeding program must be done for a cropping and management system where the only available moisture is from rain; that is superior to traditional methods of second cropping.

In the Philippines, our first task was to establish the cropping system for which crop cultivars would be developed. So our objective became to develop cultivars of dryland crops for a postrice cropping system that is compatible with the soil puddling and seedling transplanting in rice cultivation. The second crop must rely on zero or minimum tillage. Seeds of the second crop are hand dibbled into the mud at the base of the rice stubble at a high density to make up for limited vegetative development of plants under stress. Sowing is done into the base of the rice stubble because that is where the residual moisture is located. Spaces between rice rows become cracked and dry quickly; thus they have no reserve moisture for germinating the second crop. Next, the soil is mulched to conserve residual moisture.

The second task is to screen crop species that will fit into the rice culture system. Dryland crop species researched to date are sorghum, mungbean, soybean, cowpeas, adzuki bean, rice bean, peanuts, and potatoes. Mungbeans produce especially good yields on residual moisture. Corn, watermelons, and tobacco are used by farmers traditionally, but they require supplemental irrigation.

For intercropping between rows of plantation crops, farmers generally use coffee, cacao, banana, papaya, pineapple, grain, and root crops. Once, I observed a farmer's intercropping which involved four species. The highest canopy was coconut trees, the second was papayas, the third was pineapples, and the fourth was sweet potatoes. The most successful species for intercropping with plantation crops are sorghum, peanuts, cowpeas, tomatoes, potatoes, ginger, and sweet potato. The most successful crops for growing between rows of a newly established ratoon crop of sugarcane are vegetables and grain legumes.

At issue is whether the establishment of a breeding program exclusively designed to select crops and genotypes for postrice cultivation is justified. My feeling is that it is not. Trials with elite lines of sorghum and dryland leguminous species that have been conducted under dryland cropping, cropping under shade, and paddy cultivation show that substantial degrees of cultivar by culture system interaction occur. However, high levels of yield are attainable already with elite cultivars of dryland crops grown under paddy

conditions. Any additional yield increment that could be obtained by exploitation of cultivar specificity through an elaborate breeding program designed for a rice-based system would not be justified, considering the high cost of maintaining a program, limited availability of trained personnel, and low level of skill in and adaptation to using innovative technology by the average Asian farmer.

More appropriate is a unified two-stage breeding and evaluation program for all conditions. The first stage of selection would be done under optimum dryland environments to exploit known cultivar features that relate to general fitness and greater yield stability over a range of cropping systems and seasonal patterns. As an example, soybeans, which have erratic behavior in the Philippines, will produce quite stably if they: (1) mature in 80 to 95 days; (2) have a leaf area index of 3.0 to 5.0; (3) have a harvest index of 30 percent or greater; and (4) have a seed weight of 150 g or greater per 1000 seeds. These traits can be assessed readily in the first stage of selection, and genotypes that possess these levels of the traits are generally widely adapted. With the relatively small number of genotypes that survive first stage selection, the second stage evaluation should be initiated to exploit unique adaptiveness of tolerance that individual genotypes may have to stress situations such as: (1) shading and competition effects from intercropping; and (2) soil compaction and drought unique to paddy field cultivation. With this two-stage selection scheme, soybean breeding has been quite successful in developing cultivars for the tropics.

2. R. K. CROOKSTON. Reports from the tropics suggest that land usage has been improved from 10 to 40 percent as a result of intercropping. It is such information that has aroused interest in intercropping in the temperate zone. In western Minnesota, one intercropping pattern that was recently tested consisted of temporary wind breaks of corn and 12 rows of soybeans in a repeating pattern. Soybean yield per acre as a result of this arrangement was increased by 14 percent and the corn yields were a bonus. Apparently, the reason for the soybean yield increase was that the relative humidity over the soybean canopy was increased, and soybean plants were able to avoid water stress.

We have also researched two other intercropping patterns with corn and soybeans in Minnesota. For the first pattern we used a spacing of 75 cm between rows. We alternated single rows of corn and soybeans, and also sets of 3 rows of corn and 3 rows of soybeans, 6 rows and 6 rows, 12 and 12, and finally 24 consecutive rows

of each crop served as a control. As we moved from the control to 12 and 12, 6 and 6, and the like, corn yields increased; but soybean yields decreased at the same time, so that our land efficiency ratio was held constant at a value of 1.0.

The second approach consisted for planting corn and soybeans with rows spaced 37.5 cm apart. The planting pattern was alternate single rows. Variables were maturity of the maize hybrids, maize planting date, and maize stand density. Planting date and stand density had dramatic effects on both maize and soybean yields, but all combinations of variables resulted in land usages less than the check.

My conclusion from these brief preliminary experiments is that more research is needed on management approaches before it is sensible to evaluate cultivars for their suitability in a multiple or intercropping system in a temperate region.

3. S. GALAL. When making a comparison of intercropping systems with monocultures for land equivalent ratios, it is important that optimum planting patterns and plant densities be used for both. In Minnesota, the pattern used for comparing solid planting and intercropping were the same, and under these circumstances it is unlikely that a land equivalent ratio greater than 1.0 could occur. In Egypt, when optimum but different planting patterns were used for monoculture and intercropping systems, a land equivalent ratio of 1.75 was obtained.

4. R. J. BAKER. Interactions among crop genotypes are of two types. One occurs when there are significant changes in ranks of the genotypes, and the second occurs without significant change in ranks. From a plant breeding point of view, only the first one is important. Unfortunately, the analysis of variance procedure fails to differentiate between these two types of interaction.

Dr. Francis computed correlation coefficients and argued that a high correlation was an indicator of no interaction. This argument is true, statistically, but the real question is, How high must that correlation be in order to conclude that indeed there is no interaction? It may be erroneous to conclude that interaction exists when a correlation is as low as 0.6 or 0.8. The low correlation may be due to random errors in one or both environments—not due to interaction.

The real caution, however, is involved when a researcher uses correlations to select one method over another. For example, one

correlation is not significantly different from zero, whereas the second is; so the researcher concludes that the research methodology used to obtain the data for computing the second correlation is the best to use in future experimentation. But if the two correlations are not significantly different, there is no real basis for choosing among the methods of experimentation.

5. S. JANA. An aim of plant improvement for intercropping systems, of necessity, is to select genotypes that are good interspecies competitors. Several studies with barley and wheat have shown that genotypes that produce well in monoculture are not always the best synergists when grown in genotype mixtures. Is this also true for tropical legumes such as cowpeas in Nigeria or beans in Colombia?

6. C. A. FRANCIS. The cereal data are confusing. Correlations between competitive ability and yield in pure stand are variable, that is, some are positive, some are negative, and some are zero. So the central question remains, Are the traits that give yield potential to a cultivar in monoculture the same traits that provide for good value in associated croppings?

7. R. SHABANA. In Egypt, a positive correlation of 0.9 was found between intercropping tolerance of maize inbreds and their corresponding hybrids.

8. S. N. NIGUM. With intercropping, there are different planting patterns for different intercropping species and also for different cultivars. So should planting patterns be superimposed upon the experiments designed to select complementary genotypes of two species that will be components in an intercropping system?

9. C. A. FRANCIS. Probably the most efficient way to investigate this whole area is to work on one species at a time while holding the rest of the system, such as density, planting dates, and the like, constant. This means selecting among variable genotypes of one component crop in one field, selecting among variable genotypes of a second species in another field, and eventually bringing the selected cultivars of the component species together. Concurrent agronomic research can fine tune the intercropping system. Selecting within two species at the same time, plus agronomic variables in a factorial system, can result in so many treatments and interactions that the experiments become unmanageable and the data uninterpretable.

10. R. L. VILLAREAL. Panel members feel that there is no need to have a specific program to develop cultivars of crop species for multiple cropping, relay cropping, and intercropping systems. Actually, there is good reason *for* having such a specific program. Crop cultivars should be custom-tailored for a specific environmental condition or planting pattern, and in research at the AVRDC in Taiwan, this has actually been done. Tomato and sweet potato cultivars have been developed for use on fields that remain idle after a rice crop has been harvested. Land after rice has only residual moisture which is enough to germinate a seed crop but not to see the crop through to maturity. One sweet potato genotype that followed newly harvested rice under minimum input conditions, that is, no supplemental irrigation, low level fertility, and no pesticide, could survive exceptionally well and produce many roots and support these roots to maturity. The main difference between a poor and a good performing sweet potato was in the ability of the good performer to fill the already initiated roots to maturity. In the poor performer this trait was absent or not well developed.

Also, several breeding lines of tomatoes have been found in the Philippines that will germinate, survive, and give economic yield following a rice crop.

11. F. MARQUIS-SANCHEZ. Intercropping systems that now exist in tropical countries have evolved throughout the evolution of agriculture as heterogeneous systems, so doesn't it make sense that breeding programs carried out to produce genotypes for this system of farming should be initiated from the very beginning under an intercropping system instead of having one phase of selection in monoculture?

Such a breeding program would capitalize on the positive interactions among genotypes under the intercropping system.

12. C. A. FRANCIS. That is an excellent point. Doing the selection work under real farm conditions might give very good progress, at least for that specific intercropping system. If one particular cropping system is prevalent in a zone, perhaps it would be well to work with that system only.

This approach will narrow rapidly the potential applications of new cultivars, however. A compromise may be to conduct preliminary trials under the appropriate system in the experiment station, and carry out some advanced cycles under a range of on-farm conditions.

13. O. LELEJI. The concept of intercropping is much more complex than most researchers realize. In indigenous agriculture in Nigeria, a farmer is apt to use from five to ten crops in his intercropping system. However, as researchers, we assume that the interactions in intercropping are simple. For example, in no study are more than three or four crops grown together at the same time in a mixed planting. Further, indigenous intercropping varies from farm to farm, and from year to year on the same farm, depending on what is more profitable for the farmer. Therefore, plant breeders cannot develop genotypes specifically for an intercropping system because there is no typical intercropping system.

14. C. A. FRANCIS. As stated earlier, the location where research on multiple cropping should be conducted is open to question. Perhaps research results from experiment stations cannot be extended to all real farm situations, to all other cropping systems, to all soil types, and the like. But this criticism or skepticism can be made for any agricultural research, whether directed to agriculture in developing or developed countries. It must be accepted at the outset that the extension of results from research to an individual farm requires a bit of experimentation by the farmer himself.

15. F. AGBO. There is an intrinsic high correlation between economic and biological yields. Can harvest index be a reliable measure of economic productivity?

16. C. A. FRANCIS. The correlation between harvest index and economic yield is well established for a number of crops, but generally harvest index has not been explored as a means of increasing the efficiency of tropical food crops. Many tropical crops have extremely low harvest indexes, so if more emphasis were placed on the carbon partitioning process in plants, very rapid progress might be made in improving economic yields in some tropical crops.

17. E. A. CLARK. It is said that one reason why small farmers in the tropics prefer mixed cropping is that this practice confers yield stability over years and environmental fluctuations. Conversely, some reports indicate that large year to year and season to season variations occur in yields from mixed cropping, both in terms of absolute yield and relative to monoculture systems. If mixed cropping systems are inherently more stable than monoculture systems, what factors confer this stability?

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18. C. A. FRANCIS. In a study of 80 comparisons that included monoculture maize, monoculture geans, and the bean-maize intercrop, the intercropping system was more stable both in production and in income. The main factor of yield stability is likely some kind of biologic buffering, that is, one condition is favorable for one crop and unfavorable for another, and vice versa. With this situation the intercrop somehow comes out better than the monoculture over years. The same holds on the economic side. As prices fluctuate, the more crops that are in the system, the better are the buffers from an economic standpoint. We need more information on nutrient cycling, root exploration, light interception, and other aspects of intimate crop associations.

19. K. DIESBURG. Perhaps insurance value or stability of intercropping would have its greatest advantage in marginal agricultural areas.

20. C. A. FRANCIS. Multiple cropping situations are just as susceptible to diversity of climate and soil as are monocultures, so we need to separate the advantages of diversity on a given farm from the advantages of multiple cropping. Diversity, even in monocrop systems, such as planting half a ha to each crop, gives the same buffering against economics as does multiple cropping. Unless there is a clear advantage in higher land efficiency ratio by putting crops together, as much diversity can be created within a given farm with monocultures of several crops as with multiple cropping.

21. J. GASKILL. Plant pathologists and entomologists know that growing the same crop year after year in the same field tends to cause a buildup in certain plant pathogens, insects, and nematodes with a consequent reduction in yield of that crop. Is the same tendency to be expected where a fixed mixture of crops is grown on the same land area year after year?

22. C. A. FRANCIS. Probably, over a long period, a simple intercropping system of two crops will succumb to disease problems, but much less rapidly than a single monoculture will. Apparently, the insect situation varies much more among cropping systems than the disease situation.

23. K. RAWAL. Across the continent of Africa, multiple cropping is indigenous to agriculture. But whenever introductions were made

of cash or commercial crops, such as cotton, peanuts, and cocoa, monocultures of these crops have developed. And such monocultures have been successful.

24. A. M. THRO. There has been some criticism of multiple cropping systems developed by experiment stations as being too labor intensive. Yet labor availability is purported to be no problem in developing countries. What is the labor situation for agriculture in developing countries?

25. R. LANTICAN. At the moment, developing countries tend to have an adequate supply of labor for the farming industry. In some countries such as Taiwan, where much manufacturing industry has developed, labor for farming is now in short supply and expensive, and cropping systems have had to adapt to this change. However, in most developing countries, there likely will continue to be some excess labor for some time into the future. This labor needs to be utilized, so why not utilize it in the farming industry?

26. O. LELEJI. That is a good point. Intercropping as practiced now is not amenable to mechanization. But how can we know that ten years from now, when our research is to be applied, that the developing countries will have an adequate labor supply to support multiple cropping as a way of agriculture? As changes occur in the society and economics of tropical countries, genotypes bred for today may no longer be useful.

27. R. K. CROOKSTON. Even in the midwestern USA, as land values continue to increase, it is becoming profitable for American farmers to use methods for intensifying the usage of their land. Intercropping or multiple cropping may be one way to accomplish this. In fact, this is the justification for inter and multiple cropping research in American experiment stations.

28. E. A. CLARK. It is commonly said that one of the primary limits to adoption of an intercropping system in the USA is that it cannot be mechanized. Is there any modification of existing machinery or new types of machinery that might permit mechanization of intercropping systems?

29. R. K. CROOKSTON. With conventional planters, there is no problem in designing the planter box arrangements for sowing crops

in an intercropping system. Herbicides are available that control weeds in a combination of corn and soybeans.

Harvesting is a real problem, however. In Georgia, two farmers grow corn and soybeans in combination, and the corn matures slightly ahead of the soybeans. It is a tall corn with the ears placed above the soybean canopy, so they drive through the field and harvest the ears of corn above the soybean plants. After the corn stalks have dried, they harvest the soybeans. This may not sound like a satisfactory approach. However, if agronomists can devise an intercropping system that will give a land efficiency ratio well above 1.0, engineers will invent a machine to take care of harvesting the component crops.

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