Significance of Intercropping in Cropping Systems

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Abstract

We do not know when intercropping began nor why early civilizations fostered its use. Whether by design or accident, intercropping dominated early agriculture and is still practiced in many areas of the world. With the advent of "modern" agriculture, intercropping began disappearing from many areas. This shift was driven primarily by mechanization and specialization. Despite pressures to abandon intercropping, it has survived and flourished. Increasing interest in sustainability and environmental concerns have shifted attention back to intercropping as a means of better utilization of resources while preserving the environment.

The large volume of literature that involves intercropping can be divided into two categories. The first is a collection of descriptive papers on existing intercropping systems. This collection provides extensive information on what farmers do but very little insight on why. The second is an even more voluminous collection of production descriptions of intercropping. What the first lacks in "why", the second lacks in its utility to effectively improve intercropping systems.

Quantitative descriptions of productivity in intercropping systems began in ernest with extensive use of the Land Equivalent Ratio (LER). Modifications of this methodology have been proposed but are not extensively used. Attempts to understand overall production increases in intercropping systems have led to discipline-based studies involving resource use with little or no consideration of pest and disease constraints. Numerous studies have demonstrated improved sunlight utilization in intercropping systems. Efforts to better understand the below-ground dynamics and nutrient utilization in intercropping systems are less numerous and have conclusions based on indirect measurements. Understanding these dynamics will improve our knowledge of why intercropping systems are more efficient and productive; but will this understanding lead to improved systems? We would be well advised to remember that, with rare exceptions, previous work has been carried out on research stations using designs and cropping mixtures seldom used by farmers. It is not known if the problems addressed in these studies actually represent farmers' constraints; thus, intercropping research has, for the most part, become "solution driven." We must be aware of this in our deliberations and seek to identify avenues of research that will result in real

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improvements in the systems we are studying.

History of intercropping

Andrews and Kassm (1976) state that intercropping is "growing two or more crops simultaneously on the same field. Crop intensification is in both the time and space dimensions. There is intercrop competition during all or part of crop growth. Farmers manage more than one crop at the same time in the same field". Intercropping is a practice quite possibly as old as settled agriculture. We may never know how the first "real" intercropped field appeared, but historians (Baker 1970; Chang 1983; De Wet et al. 1975; Harlan et al. 1976; Rindos 1984; Turner and Miksicek 1984) assure us that intercropping probably existed early in agriculture's evolution. What we have been able to establish is that intercropping is part of a process of species domestication. Plucknett and Smith (1986) summarize this process and indicate the second stage of domestication as "protection of preferred plants" that resulted in the protection of wild plants along trails and around camps. This stage was followed by "gardening" that was a conscious planting or transplanting of wild species in a specific area. From this activity over many centuries evolved commercial farming as we know it today.

Despite formidable difficulties in establishing the exact times when intercropping appeared in the form of mixed garden plots, it has been established that such gardens were widespread throughout the world during Paleolithic times (Plucknett and Smith 1986). The process of evolving to formal mixed garden plots did not occur quickly but can be regarded as a gradual process extending back to Paleolithic times.

Information on exactly which cultigens were planted and where these first cultivations took place are questions that remain unanswered. It has been argued (Sauer 1969; Johannessen 1970; Gade 1975) that organized intercropping first occurred in areas where root crop agriculture was predominant. The reasoning is that root crops can be easily propagated by cuttings or corms, thus maintaining cultigen purity in humid tropical areas was relatively simple.

Cereals and pulses were not easily domesticated and have a long history of crossing with related wild species, usually considered as weeds. Many of the cereal and pulse crops have evolved from wild species which are, even today, found mixed with domesticated cultivars. We must thank our predecessors, farmers and biologists, for allowing, and in some cases promoting, weedy fields. Crops such as rye (*Secale cereale*), oats (*Avena spp.*), amaranths (*Amaranthus hypochondriacus and A. cruentus*), chenopodium (*Chenopodium nuttaliae*), beans (*Phaseolus spp.*), squashes (*Cucubita spp.*), and maize (*Zea mays*) evolved from weedy gardens (Wolf 1959; Sauer 1969). Whereas some farmers choose to not remove certain weed species (Wilkes 1977) that might enhance cultivated species production, breeders look to early cultigens for resistance to specific pest and disease problems. The goals of these two plant selection systems may or may not be the same, but it is in these somewhat divergent laboratories that our future genetic resources will evolve.

Intercropping activities have historically been identified in many parts of the world, e.g. cereal mixtures in temperate regions (Francis 1986). Intercropping is especially important and continues to be widely practiced in the tropics. There is extensive natural genetic diversification in both crops and systems found in these areas (Lathrap 1970; Harris 1971; Eden 1974). Frequency of farmer use of intercropping decreases as temperature and rainfall decrease (Harris 1976). This trend is the result of fewer plant species being adapted to harsh growing conditions and farmers' favoring species that have a better probability of producing something in a bad year.

With the advent of modern agriculture, intercropping began to disappear from many industrialized countries. This trend was driven by mechanization and specialization. Crop species and cultivars were viewed as isolated components of the system in which they were grown, and research was centered on individual commodities. Specialization was considered the best strategy for increasing crop production. This may have been successful with single commodities, however, the question of improved system production remains unanswered.

Descriptions of intercropping systems

Interest in systematic studies on intercropping was first expressed by botanists studying plant communities and by social scientists studying food systems (Carneiro 1961; Conklin 1957; Rappaport 1968). These studies were not concerned with the efficiency of intercropping systems, but rather they described existing plant species and their frequencies. Numbers of plant species found in some areas were substantial. Eden (1980) described small gardens in the Colombian Amazon containing 5 to 18 cultivated species. These tropical gardens are multi-storey in nature and may be planted in geometric patterns (Cowell 1974).

The plant species used in intercropping can vary across regions and with specific gardens within a region. In tropical West Africa, root crops such as yellow guinea yam (*Dioscorea cayenensis*), white guinea yam (*D. rotundata*), kafir potato (*Plectranthus esculentus*), yam pea (*Sphenostylis stenocarpa*), and piasa (*Solenostemon rotundifolius*) dominate intercropped gardens. In semi-arid and arid areas of Africa, pearl millet (*Pennisetum glaucum* (L.) R. Br.) and sorghum (*Sorghum bicolor*) are intercropped with cowpea (*Vigna unguiculata* (L.) Walp.).

In many areas of the world, intercropping still dominates the cropping systems. This is particularly true of specific plant species. Okigbo and Greenland (1976) estimate that 80% of the cultivated area of semi-arid West Africa is intercropped. In Latin America, Francis (1978) estimated that 60% of the maize and 80% of the field beans are intercropped. In India, the majority of pigeonpea is intercropped. In tropical Asia and the Pacific, multi-storey intercropping is common with tree species that dominate the upper canopy. Currently there is renewed interest in strip-intercropping in developed countries. As our environmental and production concerns increase it is likely that intercropping will provide some profitable alternatives.

Measuring productivity in intercropping system

Yield comparisons

Early methodologies used to describe population dynamics were associated with animal ecology (Lotka 1925; Volterra 1928). From these works came the Lotka-Volterra differential equations that express population changes over time in terms of the inhibitory effects of competing populations and environmental limits. De Wit (1960) successfully applied these equations to interacting plant communities. By 1965, De Wit and van den Bergh characterized the performance of different species in a replacement series design by using the relative yield total (RYT) concept. The RYT is the sum of the relative yields (total biomass) of the species in the mixture and is expressed as the ratio of the yield of a species in the mixture to its yield in monoculture:

$$RYT = r_a + r_b + ---- + r_n$$

where r_a and r_b are the relative yields of species a and b, respectively, computed as the ratio between intercropped and sole crop yields. Values greater than one indicate that the two species are at least partially complementary, whereas values less than one indicate that the two species are competitive and, thus yield more when grown separately. This approach is not suitable for describing how the yield will behave in a mixture in which plant density is not constant (Inouye and Schaffer 1981).

Agronomic research methodologies that could provide useful evaluations of differences between sole and intercropping plantings were developed between 1970 and 1980. Most notable was the proposal and eventual widespread use of the land equivalent ratio (LER) (Willey and Osiru 1972; Willey 1979; Beets 1982; Spitters and van den Bergh 1982). A number of reviews of these works have been presented (Francis 1986; Ofori and Stern 1987; Francis et al. 1976; Fukai 1993). These summaries have been supplemented by a number of international workshops. Common to all these approaches is the use of replacement series plot designs where intercropping mixtures (two crops) are compared with sole plantings of each crop. The systematic requirement of this approach often results in crop mixtures not found in farmers' fields. Another major problem in using the LER in additive experiments is the effect of total plant density that occurs when a high density of one crop is combined with a low density of the other, i.e., the proportional composition and density of the mixture and their effects cannot be determined (Harper 1977; Trenbath 1976; Spitters 1980). Such problems have been addressed by standardizing sole crop populations (Willey and Osiru 1972; Mead and Willey 1980). Snaydon (1991) argues that LER values consistently underestimate complementarity because plant densities are held constant. This conclusion was reached by comparing the results from a number of replacement and additive experiments. Ultimately the derivation of LER values reflects the experimenter's objectives in comparing intercropping with sole cultures, whether or not these are the objectives of the farmers.

Using relationships described by his predecessors (de Wit 1960; Willey and Heath

1969), Spitters (1983) developed a method of estimating the degree of intra- and inter-specific competition from the total biomass yield of species in a mixture. This approach differed from earlier attempts in that two independent expressions are used that estimate the competition effects in situations where the species in a mixture are complementary in resource use and the condition of fixed density is not met. This work was carried farther by Ranganathan (1992), who introduced an economic component to these expressions. Calculation of economic returns provides an alternative measure of potentials for various intercropping combinations.

These later studies provide us with an acceptably robust means of describing intra- and inter-specific competition in various intercropping combinations. Use of a specific index is often driven by researcher objectives. Such indicies can give the necessary qualifications to relate to farmers' conditions but will remain open for criticism on their ability to relate to real conditions or express desired changes or outcomes in existing intercropping systems.

Sunlight comparisons

Measurements that indicate overall yield advantages or disadvantages of intercropping tell us little about which environmental resources are limiting and how competition is affected by different planting arrangements. Measurements of resource utilization in different intercropping systems have been carried out at a number of locations and with a wide range of plant species. Understanding how resource utilization is affected by changes in planting patterns allows researchers to predict changes in crop management and implement strategies that will result in more efficient resource use.

Total system light interception is determined by crop geometry and foliage architecture (Trenbath, 1983; Tsay, 1985). Advantages individual species might have in a mixture can be temporal and spatial. A slow-growing crop might not be affected by a faster growing species because the faster growing species might be harvested before the slower-growing one competes for sunlight. Successful intercropping combinations are oftentimes those that capitalize on both spatial and temporal complimentarity, thus resulting in an overall increase in light intercepted by the system during a season.

Two factors that affect yield in relation to incident radiation in an intercropping system are the total amount of light intercepted and the efficiency with which intercepted light is converted to dry matter (Keating and Carberry 1993). There have been studies in which sufficient measurements have been taken to derive such estimates. Willey et al. (1983) measured leaf area duration (LAD) in a sorghum (*Sorghum bicolor*)/pigeonpea (*Cajanis cajan*) intercropping system. Sorghum dry matter production in this study was only 5% lower than sole crop yields, whereas pigeonpea dry matter production was 53% of a sole crop. In this system, the faster growing crop (sorghum) was planted at a density close to that of the sole crop and received little competition from the slower growing species (pigeonpea) early in the season. Similar results have been obtained from intercropping mixtures of two slow-growing understory species that have shorter maturity times than pigeonpea i.e., pigeonpea/soybean and pigeonpea/groundnut.

Efficient light distribution through a canopy is a strategy found in intercropping systems that achieve greater light energy capture. This approach is most common in tropical areas where the upper canopy is a tree species. In such systems, light levels below the tree canopy are relatively constant but lower, thus plant spacings in the understory can be adjusted to make full use of available light. Whereas this same approach may contribute to over-yielding in annual intercropping systems, it is more difficult to quantify or manage. Studies that have compared genotypes of different heights in intercropping reported no significant advantages (Pendleton et al. 1963 - maize; Osiru 1974 - sorghum).

Many of the perceived advantages in managing light in intercropping are based on the ability to use a faster growing species (C_4) at the top of the canopy and a slower growing species (C_3) at the bottom of the canopy. To a large extent this represents what is found in natural plant communities and many traditional intercropping systems. Such advantages in intercropping will be best utilized if two species used do not compete for sunlight at the same time. For intercropping combinations like soybean/pigeonpea and groundnut/pigeonpea, the issue of light is less important because each species has a significantly different growth curve (Ranganathan 1992).

As we strive to improve our understanding of resource use in intercropping systems it is quite likely that modeling of different factors will become a more powerful tool. A number of models have been developed that simulate canopy development (Saeki 1960; de Wit 1965; Duncan et al. 1967; Trenbath 1972). Through validation and further development, these models hold great potential in helping us develop a better understanding of light use in intercropping systems and a better basis for developing improved intercropping systems (Keating and Carberry, 1993).

Water use comparisons

For the arid and semi-arid areas of the world, water use is of great importance in determining resource utilization in intercropping systems. Problems abound in selecting research methodologies that will allow partioning of intercrop competition components. Because of these problems, many studies that have reported increased water use efficiency (WUE) in intercropping systems arrived at their conclusions through indirect measurements. Snaydon and Harris (1979) and Baker and Norman (1975) feel that below-ground competition and, more specifically, competition for water may result in intercropping advantages and disadvantages.

Species differences in rooting depth, lateral root-spread and root densities are factors responsible for water use competition and complementation (Babolola 1980; Haynes 1980). Although we have little direct knowledge of these factors and their interactions in intercropping systems, complementarity in water use has been cited as an advantage in intercropping (Natarajan and Willey 1980; Reddy and Willey 1981).

Plant species react differently to water stress conditions, thus it is unlikely that intercropping mixtures of cereal and legume species will compete uniformly when water becomes a limiting factor. Species that have higher water use or extraction will become stronger competitors. This is illustrated by a maize-cowpea study (Hulugalle and Lal 1986) in which WUE was higher in the intercrop when water was not a limiting factor, but under drought stress conditions WUE decreased rapidly in the intercrop and sole cowpea plantings but increased in the sole maize planting. Morris and Garrity (1993b) report no significant differences in total water uptake between intercrops and sole crops, but WUE by intercrops ranged from 18% to 99% greater than in sole crops. Mechanisms they propose as being responsible for increased WUE include: (a) capture of a larger portion of evapotranspiration (ET) as transpiration by intercrops; (b) interception of more light by intercrops; (c) greater efficiency in dominant species components; (d) higher transpiration efficiency by crop mixtures; and (e) reduced boundary layers in the "rough" canopy of intercropping patterns (compared with uniform canopies of monoculture).

Nutrient use comparisons

Nutrient use in intercropping systems has received considerable attention despite difficulties in quantifying beneficial or competitive effects. Increased nutrient uptake in intercropping systems can occur spatially and temporally (Morris and Garrity 1993a). Differences among species in nutrient uptake and among various nutrients in their uptake mechanisms make the measurement of competition effects difficult. Soluble ions, such as nitrate, move freely in the soil solution and may travel up to 1.5 cm to roots (Barber 1962; Trenbath 1976). Nutrients not found in high concentrations in the soil solution but held on the clay surfaces (calcium, phosphorus, potassium) move to plant roots primarily by diffusion. These nutrients move only short distances, thus increasing their uptake is more related to increased root mass. Temporal advantages in nutrient uptake occur when crops in an intercropping system have peak nutrient demands at different times (Willey 1979).

Of the major nutrients, nitrogen (N) has received the most attention. This is both because N is most often limiting in areas where intercropping is practiced, and because combinations of legumes and non-legumes most often dominate intercropping systems (Ofori and Stern 1987). In these combinations, popular wisdom says that the key role of the legume component is its contribution to the N-economy of the system. Though often stated, this remains a point of debate (Fujita et al. 1992). Tree intercropping, a common system in tropical regions, gains substantial nutrient input from decomposed litter (Sanchez et al. 1985).

To what extent legumes contribute to the N-economy of intercropping systems is not fully understood. There is evidence that legumes capable of fixing atmospheric N_2 will reduce competition for N from the cereal component (Trenbath 1967; Fujita et al. 1992). Thus the absence of an N-fixing system will result in both crops competing for the same N-source, particularly when soil-N levels are low (Chang and Shibles 1985; Ofori and Stern 1986).

Fujita et al. (1992) present an excellent review on the role of N-fixation in mixed legume-cereal systems. N_2-fixation is much better understood than N-transfer to non-legumes (Stern 1993). Legumes appear to contribute to the N-economy of intercropping systems by transferring N to the cereal crop during the growing period (Ofori and Stern 1987; Rerkasem and Rerkasem 1988; van Kessel and Roskoski 1988; Eaglesham et al. 1981; Ofori et al. 1987) or as residual-N that is available for the subsequent crop (Papastylianou 1988; Nair et al. 1979; De 1980). A number of mechanisms have been reported that affect N-transfer (Ta et al. 1986; Ofosu-Budu et al. 1990; Fujita et al. 1990; Brophy and Heichel 1989;

Hawes and Lin 1990). Despite numerous studies on this subject, N transfer mechanisms and what factors affect the functioning of these mechanisms are still poorly understood.

The amount of N available either during or following an intercrop containing legumes will depend on conditions that impact legume N-fixation. A number of studies have shown that indeterminant legume types fix more N than determinant types (Francis 1986; Graham and Ross 1978). These findings appear to be species dependent and are not supported by studies in which different species were used (Ofori et al. 1987; Ogata et al. 1986). These studies suggest strong species and genotype differences that have not been fully documented.

Native soil-N levels and the amount of sunlight reaching legume species will affect N_2 fixation. Nearly all legumes fix less atmospheric-N if the soil has a high N-content, through either high native fertility or the application of fertilizers to the intercropping mixtures. These factors support traditional strategies used by farmers who select indeterminant, climbing legume species that are intercropped in systems with little or no additional fertilizer input. In these systems, although legume benefits will be maximized, production levels may be unacceptably low.

Gross residual benefits from intercropping systems containing legumes are less difficult to measure, and thus have received more attention. These benefits are measured as the amount of additional N required in a subsequent crop to achieve a similar yield as a crop that does not follow an intercrop containing a legume component. Although such estimates are quite variable and depend on agro-enviromental conditions, they provide a general idea of expected benefits from legumes. Apart from yield increases there are reported beneficial soil effects attributed to legumes in intercropping systems (Phetchawee et al. 1986; Normal et al. 1990). These advantages appear substantial; however, there is concern that the nutrient benefits from legumes in intercropping are limited to low-input systems (Heichel 1987). To address this question it will be necessary to choose legumes for intercropping systems that will fix nitrogen at soil-N levels capable of supporting acceptable cereal yields.

Rooting patterns

Below-ground competition or complementarity is a possible reason for under- or over-yielding in intercropping systems. Although such interactions are likely to be important, studies that have effectively measured below-ground competition in intercropping systems are difficult to find. The argument exists that intercropping systems have an advantage over sole cropping systems because of spatial differences in root mass that allow the combination to explore a greater root volume.

The difficulty in obtaining accurate measurements of root interactions in intercropping has been a major impediment in advancing our knowledge in this field. Despite this, a number of researchers have documented root interactions (Assemat et al. 1981; Willey & Reddy 1981; Regnier et al. 1989; and Perera et al. 1992). Their results were obtained by using root partitions and giving data on no-competition, shoot-competition only, and full-competition. Other studies have used defoliation to partition root interactions (Jeangros & Nosberger 1990; Seager et al. 1992). However, results from these studies can be criticized because defoliation also reduces root competition in some species (Remison & Snaydon 1980).

Snaydon (1991) argues that below-ground competition is most often responsible for competition in intercropping stands. This argument is based largely on additive mixtures where relative yield total (RYT) values are compared. He also points out that in tropical and sub-tropical areas where intercropping is most frequently practiced, soil nutrients and water most often limit plant growth. We suspect that more attention has been given to solar radiation because it is easier to measure than the root-soil complex of interactions and function.

More than any other environment shared by intercrops, the underground portionis is the least understood. Accurate, direct measurements of root complementarity and competition are difficult. Continued use of indirect measurements will not provide complete answers. Recently introduced methods, such as the use of mini-rhizotrons and micro-sensors used to determine plant rhizophere conditions, will greatly assist us in obtaining the direct measurements necessary to better understand below-ground interactions in intercrops. These developments will be enhanced by further model development, resulting in a fuller understanding of the mechanisms and interactions responsible for beneficial effects measured in intercropping combinations.

Pests and diseases in intercropping systems

A large body of literature exists on how specific insects are affected by crop mixtures (Litsinger and Moody 1976; Perrin and Phillips 1978; Altieri and Schmidt 1986; Risch et al. 1983). With the interest in integrated pest management (IPM) it is highly likely that intercropping in its current forms will provide a logical base for future IPM programs.

Central to IPM issues are changes in pathogen populations as a result of diversification in a cropping system (Eguinjobi 1984). Hasse and Litsinger (1981) have summarized the effects of intercropping on insect pest populations. They have listed camouflage, crop background, masking or dilution of attractant stimuli, and repellent chemical stimuli as factors that interfere with insect host-seeking behavior. Factors such as mechanical barriers, lack of arrestant stimuli, microclimatic influences and biotic influences can interfere with insect population development and survival. It is likely that in many intercropping systems more than one of these factors is operational (Tahvanainen and Root 1972).

Specific references to each of those factors are presented by Hasse and Litsinger (1981). Since that time many research reports have been published on the effects of different intercropping systems on insect populations. Much of this work has been aimed at understanding insect population dynamics as they might relate to developing and implementing IPM programs. In some cases, reported results contradict each other. In India, *Helicoverpa armigera* populations were higher in sorghum/pigeonpea intercropping systems than on sole pigeonpea plots, and these higher numbers led to higher grain losses in the sole crops (Bhatnagar and Davies 1981). Later findings on the same intercropping system (Duffield 1993) indicated that egg parasitism in *H. armigera* by *Trichogramma spp.* (*Hymenoptera: Trichogrammatidae*) in sorghum resulted in low damage levels in sorghum but that there was little transfer of this parasite to pigeonpea plants, relulting in severe yield losses in pigeonpea from *H. armigera*. These results suggest a potential IPM strategy of synchronizing the timing of flowering of both species so that maximum parasite transfer to pigeonpea can take place. It has been observed that chemical control of *H. armigera* in medium-duration sole pigeonpea plots is difficult, whereas control in intercropping plots is considerably easier once the sorghum has been removed. This difference is attributed to a better spray coverage because of increased distances between pigeonpea rows once the sorghum has been removed.

A study of intercropping pigeonpea and cotton found that LER advantages in the intercropping system were the result of improved insect control in the intercropping treatments and not complementarity between the two plant species (Potdar et al. 1994). Because this intercropping system is commonly used in parts of India and because there is no clear evidence of complementarity between the plant species, it is thought that the popularity of this system rests on its advantages in controlling *Heliocoverpa armigera*, a major pest of both species in the mixture. In a study that compared *Heliothis* damage in cotton intercropped with corn, soybeans, alfalfa, peanuts, and sorghum, Robinson et al. (1972) found that insect damage in cotton was less when it was intercropped with sorghum. In the same study, they found that the frequency of *Heliothis* predators was higher for sorghum.

In many intercropping studies, plants are protected against insect attack, a practice not often found in practical on-farm intercropping settings. This raises the question of how appropriate are the improved genotypes that are bred and screened in protected environments to intercropping settings managed at low input levels. Ehlers (1994) reports that the yields of cowpea genotypes tested under protected conditions were similar in sole and intercropped plots, whereas the intercrop plots yielded less in unprotected conditions. Ehlers suggested that identifying genotypes under protected conditions will not result in the selection of genotypes well suited for conditions generally found in farmers' fields. Current ongoing work at ICRISAT has shown that sorghum genotypes that perform better than farmers' varieties under protected, irrigated, and well fertilized conditions, will not necessarily perform better in farmers conditions. This work has identified the pest shoot fly as a major constraint that is highly interactive with fertility and genotype.

Fewer studies have been done on the effects of intercropping on plant diseases than those on insect pests (Francis 1986). There is evidence that intercropping reduces disease incidence in some crops when compared with sole crops (Larios and Moreno 1977; Palti 1981; Thresh 1982). In some cases, recorded advantages of disease control through intercropping were the result of reduced insect vector numbers; thus disease control was more a function of improved insect control. Natarajan et al. (1984) reported that intercropping sorghum and pigeonpea reduced fusarium wilt incidence in pigeonpea when compared with sole plantings. In these studies, pigeonpea yields were greater than partial expected yields, but no higher than sole crop yields. The reduction of fusarium wilt was consistent across 14 susceptible genotypes. Similar results did not occur when maize was used as the intercrop. These studies suggest a potential of managing disease problems through intercropping, however, more information is needed before intercropping systems can be designed to capitalize on disease control mechanisms.

The role of intercropping in controlling pests and diseases is likely to receive much attention as we become more concerned with pesticide use and environmental issues. It is quite possible that much of the renewed interest in intercropping will evolve around issues of pest and disease control. To date our understanding of crop/insect interactions in intercropping is incomplete, and the effectiveness of this type of protection is unpredictable (Trenbath 1993). Given the resilience of traditional systems it is evident we still have much more to learn.

Social and economic implications in intercropping systems

The mere fact that intercropping systems have maintained their importance through significant economic and structural changes in world agriculture is testimony to their resilience. Regardless of what levels we reach in understanding the physical and biological processes of intercropping systems, it is ultimately the farmers who make the choice to keep, modify, or discard any particular system. It is also the farmer who selects what plant species will be intercropped and how each mixture will be managed. It is difficult for physical and biological scientists to understand the social and economic forces that determine whether farmers' maintain or improve intercropping systems and to realize that it is these same forces that have made intercropping systems so difficult to change.

The most often stated reason for intercropping is risk reduction. This theory is supported by the fact that as agriculture moves to a better environment, intercropping becomes more prevalent (Norman 1974; Abalu 1976). This may be the case even if overall income is reduced (Sanders and Johnson 1982). Furthermore, Jodha (1977) reported that intercropping is more extensively practiced by small farmers. Risk, as it applies to subsistence farmers, relates more to net production and less to market forces. The fact that subsistence and commercial farmers exist in areas where intercropping is practiced suggests that we must consider prices or economic buffering in any evaluation made of intercropping systems. This is problematic in that prices on input and produce are variable over both time and space. These variations could offset or enhance any production gains from intercropping. Using risk as a criterion for evaluating stability of intercropping systems, Mead et al. (1984) showed that the probability of reaching a given income level was higher in an intercrop when compared with sole crops of the same component species. Such analyses are valuable when evaluating probabilities of success for experimental data and for predicting possible adoption of given management changes to intercropping systems. However, the analyses suffer from not being able to represent either the complexities of intercropping systems or the socio-economic conditions under which the farmers operate.

Future research needs

When we consider the future needs of intercropping research, it is important that we should not engage in "agronomic trivial pursuit" (Youngquist and Francis 1988). There have been sufficient studies indicating advantages in total dry matter production or grain yields in intercropping systems. To repeat this same research and not obtain data that will help us identify the mechanisms responsible for intercrop differences would indeed be a trivial pursuit. Given recent advances in data collection and modeling, it is time to move forward with better quantification of "why" intercropping is advantageous in many situations. Much of the current and future interest in intercropping will come from people with environmental concerns and from those who measure both total production and economic consequences of intercropping. We can build on this growing interest to better understand topics such as below-ground competition, nutrient management, system design, and applications of specific systems by farmers in each unique ecological and economic situation.

Lastly, but most important, we must strive to better understand why intercropping has remained such an important part of agriculture systems in many parts of the world. Through this understanding we may make useful recommendations to farmers on how they can improve current systems and not on how to eliminate well-established, sustainable systems. This implies that research must come much closer to addressing farmers' needs and should respect farmers' goals. In the field of genetic improvement it would be advisable to test new genotypes before they are released for their performance in intercropping systems, particularly when they are targeted to intercropping systems. The management of intercropping systems is complex and management changes will need to be carefully considered. Okali et al. (1994) point out that in 20 years of experience in Niger it is evident that agricultural extension programs based on technical recommendations that essentially restrict the farmers' choice will have little if any positive impact. What does that tell us about our research efforts?

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