A Role for Intercropping in Modern Agriculture

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Agriculture in developed nations relies on mechanization and petrochemicals and typically uses monocultures. Monoculture is subject to several problems that intercropping can alleviate. Intercropping has potential as an economic and ecological alternative fully compatible with modern agriculture.

Intercropping, the practice of growing more than one crop in a field at the same time, was commonly used in the United States before 1940 (Kass 1978). It continues to be widely used in much of the developing world, where farmers have only limited access to the agricultural equipment and products that transformed agriculture in the industrialized world (ASA 1976, Kass 1978, ICRISAT 1981). Modern industrialized agriculture, which typically uses monocultures, has increased yields enormously in the developed countries, but the improvement has not been without its costs. The production and operation of machines and the synthesis of fertilizers and pesticides cost an enormous amount of energy. Other costs can be high as well, ranging from degradation and disruption of the environment to human pesticide poisonings. An increasing number of agricultural scientists are sufficiently concerned about the environmental and health risks of modern agricultural practices that they are reassessing several low-technology alternatives like intercropping for use in developed countries (Schultz et al. 1982, see *Environmental Management* 7(1) 1983).

This article examines several problems associated with monocultures, particularly those that intercropping can alleviate. Intercropping may have been abandoned partly for convenience and not because it is inherently incompatible with modern agricultural techniques. To redefine the potential role of this preindustrial technique in today's world, I attempt to identify the explicit and implicit assumptions that define our concept of modern agriculture. I concentrate on the United States because of its leading role in agricultural modernization, but because the benefits and problems of modern agriculture are global, I have drawn my examples from both the developed and developing worlds.

MECHANIZATION AND THE TRANSITION TO MONOCULTURES

Machines promised to reduce labor: For farmers who farmed their own land, machines reduced back-breaking tedium. For landowners, they provided a cheap substitute for hired labor and could ensure harvests if the labor supply was low or if farm labor's attempts to organize proved successful (Friedland et al. 1981). Mechanization became an important impetus in the switch from intercrops to monocultures because equipment to plant and harvest a single crop per field was easiest to design (Rasmussen 1977). Development of new hybrids and synthetic compounds that synchronized ripening made once-over harvesting possible, stimulating further mechanization. Without synchronized ripening, harvesting required multiple trips through the field; mechanical harvesting was less productive than hand-harvesting on multiple trips because machines often severely damaged plants with immature fruits.

Before the development of low-cost

Intercropped tomatoes and beans have consistently overyielded in trials by the New World Agriculture Group on a small farmers' cooperative outside of Managua, Nicaragua. Photo: John Vandermeer.

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synthetic fertilizers, farmers periodically had to rotate crops with nitrogen-fixing legumes or leave fields fallow to maintain soil fertility. For example, farmers could grow corn for only two to three years without adding fertilizers because corn demanded so much nitrogen (Borman and Crossley 1911, Pierre et al. 1967). Synthetic fertilizers made it possible to simply add specific nutrients. Crop rotation also lost favor because the crops substituted in alternating years could not be harvested by the same specialized machinery. And the expense of purchasing mechanical harvesters, seeders, and other equipment discouraged farmers from taking land out of production to be left fallow. Monocultures grown in continuous sequence resulted.

PROBLEMS WITH MONOCULTURES

The low cost of synthetic fertilizers may have been a double-edged sword. The inexpensive and seemingly inexhaustible supplies helped create a false sense of security among farmers, contributing to the abandonment of soil conservation practices (Bernal 1969). Soil loss from erosion is occurring at an alarming rate (Larson et al. 1983), exacerbating the need for synthetic fertilizers, a need that could be reduced by more rational land-use practices. Addressing the problems of soil erosion and lowered soil quality is now a top priority for USDA and other government agencies (CEQ et al. 1981, USDA 1977).

Abandoning crop rotation also increased weed problems (OTA 1979). Weed species were able to proliferate that were preadapted to the fixed annual planting and harvesting schedules for growing monocultures in continuous sequence. Although mechanical cultivation to remove weeds continued, herbicides rapidly became the primary means of weed control. They are now the principal component of the multibillion-dollar pesticide industry, accounting for nearly 55% of the pesticides applied in the United States. This percentage will increase with the trend toward no-till and other forms of reduced-tillage agriculture (Eickers et al. 1978).

As the petrochemical industry developed, inexpensive and potent insecticides became widespread. Initially these were used to control pest outbreaks, which are frequently more severe in monocultures than in intercrops. One explanation offered for the greater pest problems in monocultures is that their lower plant diversity supports a less diverse insect community. Because many pesticides are relatively nonspecific, they kill both the pests and their natural enemies, further reducing diversity in the insect community. Some measure of control is provided by the biological diversity inherent in most natural ecosystems, which reduces the possibility that any one species will proliferate (Goodman 1975, Paine 1974). For example, the most dramatic insect outbreaks often occur where relatively few species populate vast areas, as in northern coniferous forests. There the spruce budworm periodically devastates whole sections. Huge monospecific stands of annual crops may be even more susceptible to disruption because they are simple, human-made communities that have not been "tested" on an evolutionary time scale (Andow 1983, Cox and Atkins 1979, DeBach 1974, Murdoch 1975, van den Bosch 1978, Way 1977).

Pesticides can be extremely useful tools, but recognition is growing of complications that arise when pesticides, especially insecticides, are abused (DeBach 1974, van den Bosch 1978). For example, in 1977 Pimentel and colleagues reported that in the 30 years since the widespread introduction of pesticides, insecticide use in the United States had increased twelvefold, yet preharvest crop losses to insects had nearly doubled (Pimentel et al. 1977). Insecticides have often aggravated a pest problem by reducing the population of the pest's natural enemies and/or hastening the development of pest resistance (Brown 1978, Edwards et al. 1979). The potential severity of the problem is illustrated by the well-documented, insecticide-induced collapse of the cotton industry in northeastern Mexico and southern Texas (Adkisson et al. 1982).

More pests have developed resistance to insecticides than other pesticides, but all forms of pesticides have been affected. From 1970 to 1980 the number of arthropod species exhibiting resistance almost doubled from 224 to 428. Over 150 resistant species of plant pathogens are known, and an estimated 50 herbicide-resistant weed species have been reported (Dover and Croft 1984). Even more alarming is the continued dramatic increase in the rate of resistance (Georghiou and Mellon 1983; see also April 1985 *BioScience* 35: 216–218). In a recently released study, Dover and Croft offer a resistance management strategy that includes intercropping among several alternative pest-control methods (Dover and Croft 1984).

Certainly as important as the agricultural complications from pesticide use are the health risks. As the tragedy in Bhopal, India, illustrates, there are direct risks in producing pesticides. Less dramatic, but affecting a greater number of people—farmers, fieldhands, and laborers—are poisonings from pesticide use. This health risk is difficult to assess because the toxic effects are often cumulative, frequently with substantial time lags between exposure and the onset of symptoms (Task Force on Occupational Exposure to Pesticides 1975, see *Residue Reviews* 75, 1980). Perhaps of even greater concern is the widespread resurgence of malaria and other insect-transmitted diseases, a resurgence that has paralleled the increase in insecticide use. From the mid-1960s to 1980, the incidence of malaria in the Central American nations of El Salvador, Guatemala, Honduras, and Nicaragua increased two- to threefold. It has been estimated that, because the incidence of malaria correlates strongly with DDT use, each kilogram of insecticide added to the environment will generate 105 new cases of the disease (Chapin and Wasserstrom 1983).

The amount of petrochemical-based pesticides applied to our land continues to increase exponentially. For example, the amount of pesticides used in the United States has a doubling time well under ten years (van den Bosch 1978). The detrimental effects of many of these chemicals are widespread and well understood; in the case of many others, the risks have been inadequately studied (Davis 1977, Smith 1982, von Stackelberg 1981). According to a 1984 report by the National Academy of Sciences, less than 10% of agricultural chemicals used in the United States have been fully tested for their ability to cause chronic health problems (NAS 1984). Concern for human health, as well as for the health of our environment, argues strongly for prudent use of petrochemicals and expanded research into alternative, ecologically sound agricultural practices.

ADVANTAGES OF INTERCROPS

Interactions between species include both negative (competition) and positive (facilitation) components. For example, one species, even while diminishing the supply of available nutrients, may provide the shade necessary for successful establishment of a second. Yet at a later stage both species may compete for light. In addition, the second species may produce toxins that slightly inhibit the first but prevent growth of competitive weeds. Understanding ecological interactions like these in agricultural systems, rather than focusing only on the net outcome, may suggest ways to change the outcome by manipulating the system. The intercrop species and their relative densities can be varied, for example, as can the pattern and timing of planting.

Companion Plant Compensation

Perhaps the most obvious advantage of growing two crops simultaneously is the substantially reduced risk of total crop failure (Anderson et al. 1980, Pearce and Edmondson 1982, Rao and Willey 1980). Crops differ in their response to physical and environmental stress, and it is not uncommon for one crop species to do poorly while a different crop grown under the same conditions thrives. In fact, even varieties of the same species differ enormously in their response to the variable climatic conditions that typically occur. At present, many farmers gain security simply through diversifying, replacing a single large stand of one crop with smaller monocultural stands of several crops (Anderson et al. 1980).

Planting both crops together in the same field, or intercropping them, provides an additional benefit because the resources that become available through the failure of one species can be used by the surviving crop (Willey 1979, see Schultz 1984 for a fuller analysis of risk assessment in intercrops and monocultures). The remaining companion crop can use resources, such as synthetically produced fertilizers, which would otherwise have been lost due to leaching or run-off, thus increasing the efficiency with which these expensive inputs are used.

This compensation mechanism can operate when physical factors such as drought affect the companion crops differentially. But the benefits from compensation can be equally significant when biological agents cause crop failure. In an experimental test of this "compensation" hypothesis, researchers at the University of Michigan released hornworms (*Manduca* spp.), a caterpillar pest on tomato but not cucumber plants, into half of the tomato-cucumber intercrop plots. Cucumber yields were higher in the plots where hornworms were released. Although hornworm defoliation of tomato plants reduced tomato yields, the resulting increase in light increased the cucumber yields. Cucumber yields increased more than tomato yields decreased, and consequently there was overyielding of the system as a whole.[1]

Differential Use of Resources

When the distance between plants reaches some critical point, they begin to compete for at least some of their resources. Given a set of fixed conditions (environment, planting pattern, etc.), competitive interactions between two intercropped species can have three possible outcomes:

- Intraspecific competition can be less than interspecific competition for both species.
- Intraspecific competition can be greater than interspecific competition for both species.
- Intraspecific competition can be less than interspecific competition for one species, while the reverse is true for the other species.

One of the few widely accepted axioms in ecology states that coexisting species must differ, at least to some extent, in their use of resources (Gause 1934, see also *American Naturalist* 6 (5), 1983 for a special issue critically reexamining this topic). It is highly improbable, therefore, that intraspecific competition will always be less than interspecific competition for all resources. If intraspecific competition were always less, however, then from the standpoint of competition alone, it would be better to grow each crop in monoculture. But even in this case, factors other than competition, such as pest insect reduction and weed control, might still argue for intercropping.

If interspecific competition were less than intraspecific competition for all resources between two species, then it would be clearly advantageous to grow them as intercrops.

More commonly, however, interspecific competition is less than intraspecific for many, but not all, resources. For a particular resource, one species may suffer greater intraspecific competition, and the other species greater interspecific competition. Under these conditions the net outcome of the competitive interactions will be that one species does "better" when grown in intercrop than in monoculture (relative yield [RY] > 0.5), but the other species does "worse" by the same criterion (RY < 0.5).

[1] B. Horwith et al. unpublished data.

The relative yield of a species in an intercrop is the ratio of its intercrop yield to its yield in a monoculture. The sum of the yields of both species is the relative yield total (RYT). A term equivalent to but intuitively more understandable than RYT is the land equivalent ratio (LER), which is a measure of the amount of land that would need to be planted in monocultures to give a yield comparable to a unit area of land planted as an intercrop. Overyielding is said to occur when LER > 1.0.[2] Whether the intercrop system overyields depends, of course, on the relative magnitude of the increase and decrease in yields of the two crops.

Competitive interactions are usually evaluated for a fixed environmental situation, but outcomes of the interspecific interactions may be different under other conditions (Harper 1977, Trenbath 1976). For example, adding nitrogen to clover-grass swards can reverse clover's competitive advantage over several grass species when the mixture is grown in low-fertility soils. Since the requirements and the ability to satisfy them differ for each species, it follows that interspecific competition will be least in more spatially and temporally heterogeneous environments. The probability of realizing an intercrop advantage should be greatest when the two crops can draw from a patchwork of resources within a field and when they demand these resources at different times (Vandermeer 1981).

Facilitation: Reducing Fertilizer Requirements

In many situations the presence of a second species may actually enhance nutrient availability for the first. For example, although competition between a legume and nonlegume in an intercrop inevitably occurs for some resources, the legume, through a mutualistic association with nitrogen-fixing bacteria (e.g., *Rhizobium*), may provide additional nitrogen to the nonlegume (Nutman 1963, Quispel 1974, Reid 1983, Simpson 1965). The amount of nitrogen made available

[2] Technically, the overall plant density of the monoculture and intercrop must be the same to evaluate the relative strength of inter- and intraspecific competition; this condition is often impractical when studying crops. However, if the experiments use empirically determined optimal density monocultures, then obtaining an intercrop yield of species 1 greater than half of the monocultural yield (i.e., $RY_1 > 0.5$) suggests that more of species 1 can be obtained per unit area by planting it in intercrop.

to the nonlegume may be increased by timing the planting of an annual legume (e.g., dry beans) so that the legume senesces and releases nutrients when the nonlegume's nutrient demands are high.

Legumes also form mutualistic associations with a fungal group, vesicular arbuscular mycorrhizae (VAM), as do many other agriculturally important plant families (Gerdemann 1975). This mutualism enhances the host's ability to procure nutrients, particularly phosphorous (Hayman and Mosse 1972, Pairunan et al. 1980). Furthermore, *Rhizobium* and VAM can act synergistically for the host legume, greatly increasing nutrient availability (Crush 1974, Redente and Reeves 1981). Recent reports suggest that if the nonlegume in the intercrop can also associate with VAM, VAM may mediate interspecific nutrient exchange (Chiariello et al. 1982). The nonlegume may thus receive nutrients from the legume while the latter is alive as well as when it dies.

Intercropping can also reduce the need for synthetic fertilizers by alleviating soil erosion (Siddoway and Barnett 1976). Most soil is lost between harvesting and establishment of the next crop. Differences in the phenologies of intercrops allow for continuous plant cover, reducing the amount of time the field is bare. Furthermore, the diversity of the root systems of the two crops enables them to use and stabilize a broader soil zone (Willey 1979). For soil conservation, living mulches should be especially effective. Typically, in such an intercrop system, a grass, legume, or grass-legume mixture is used as a cover crop (Nicholson 1983, Vrabel 1983). Into the perennial cover crop, rows for planting the principal crop are either rototilled or prepared with herbicides. Since only a portion of the field is cleared, this system requires less tillage than conventional tillage systems and less herbicide than so-called no-till systems, where herbicides are used instead of tillage to prepare the seed bed.

Facilitation: Reducing Pesticide Requirements

Intercrops have been shown to reduce the populations of numerous herbivore species under a wide range of conditions. Risch et al. (1983) reported that in 150 intercropping studies involving 198 herbivore species, 53% of the herbivore species were less abundant in the intercrop, 18% were more abundant, 9% showed no difference, and 20% showed a variable response. Two contrasting mechanisms of pest deterrence have been proposed: the "resource concentration hypothesis," where the presence of nonhost plants interferes with the search by a given pest for its host crop, and the "enemies hypothesis," where the diverse crop environment provides shelter and necessary alternative food sources for insect predators and parasites (Bach 1980, Risch 1981, Root 1973, William 1981).

An advantage of intercropping that has not received as much attention is the reduction of weeds (Altieri et al 1983, Glass and Thurston 1978, Yih 1982), but evaluating this benefit may be complex. If a species is used to control weeds, it will probably also compete with its companion crop. Therefore, we might expect that crop's yield to be less than it would be if grown in weed-free monoculture. However, the economic and/or ecological cost of maintaining a weed-free monoculture may be excessive (Doll 1980, Holm 1971). In Nigeria, for example, researchers are cautiously optimistic about growing a native legume as a mulch species with corn. The legume can enrich the soil with nitrogen, but its greatest advantage is in suppressing weeds. Farmers in this part of Africa devote nearly 50% of their time to hand weeding because herbicides are either too expensive or otherwise unavailable. Corn does best if weeds are completely removed. But it does better with some weed control by, as well as competition from, the legume mulch than it would do with no weed control at all and, therefore, strong competition from weeds.

Even in the developed nations, where herbicides are readily available, intercropping with living mulches may provide economically and/or ecologically viable alternatives for weed control. Many agricultural weed species require a disturbance like plowing to germinate and establish themselves. Since living mulch systems require less of the field to be tilled, the area suitable for weed development decreases. The life histories of several plant species may make them especially suitable for living mulches: They are vigorous early in the growing season and may be effective controls when many weed species must become established; later in the season, when the crops are most active, the mulch becomes dormant. For mulch species that are normally active during the growing season, it may be feasible to induce "summer dormancy" with low levels of herbicides that inhibit but do not kill the mulch. The cost-benefit argument for using living mulches to reduce herbicide application becomes more favorable when the yield of the mulch crop is included in the analysis.

CONCLUSIONS

Mechanization and dependence on synthetic chemical fertilizers has dramatically transformed agriculture. In that transformation, monocultures have been substituted for intercrops. Large areas of land are now farmed as monocultures, depauperate biological communities consisting of one major plant species. Enormous inputs of nonrenewable resources are used to produce the fertilizers and pesticides necessary to maintain monocultures, especially as practiced today. Monocultures are expensive economically, energetically, and environmentally, and we must question the wisdom of depleting resources while ignoring alternatives. Many of the problems associated with monocultural production are reduced or eliminated by growing two or more different crops together.

Our notion of modern mechanized farming connotes, but should not presume, the necessity of monocultures. Intercropping would undoubtedly have become mechanized, albeit much more gradually than did petrochemical-based monocultures. There is little question that, given sufficient motivation, appropriate technology could be developed to mechanize most, if not all, intercropping systems (Erbach and Lovely 1976, Hansen and Risch 1979, ICRISAT 1981).

In a comprehensive analysis of our agricultural systems, we should not only examine yields, but also the cost of the inputs used to obtain them. Intercropping may help eliminate unnecessary use of nonrenewable resources in modern agriculture or use them more efficiently. An innovative approach to the analysis of intercropping includes not only its advantages and disadvantages, but methods of manipulating the system for our benefit.

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