Chapter V

Multiple Cropping Systems: A Basis for Developing an Alternative Agriculture

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Chapter V

Multiple Cropping Systems: A Basis for Developing an Alternative Agriculture

ABSTRACT

This paper presents a general discussion of the concept of multiple cropping, including a description of the different types of systems, and the advantages and disadvantages of their widespread use, both biological and socio-economical. These systems are designed to intensify agricultural production both in terms of yields per unit area and through the more efficient use of space and time.

Examples of yield increases with multiple cropping systems are expressed in terms of Relative Yield Totals (RYT) or Land Equivalent Use (LER) where the production per unit area with the multiple crops is greater than the sum of equivalent areas planted to monoculture. This increase in production is explained by higher overall efficiency of resource use.

Specific examples of the effects of multiple cropping systems on resource use, conservation, and management are discussed, Variables considered include microclimate, light, soil, water, pests, diseases, weeds, crop interactions, space, and time. The special case of agroforestry, which combines trees with crops and grasses, is discussed.

In conclusion, the socioeconomic implications, both advantageous and disadvantageous, are discussed. Also, the great potential for multiple cropping systems in agriculture in the United States is presented. Research needs to be directed to test these alternatives.

INTRODUCTION

Multiple cropping is not a new form of agricultural technology, but instead is an ancient means of intensive farming. Multiple cropping has been practiced in many parts of the world as a way to maximize land productivity in a specific area in a growing season. Generally, the practice of planting two or more crops on the same field is more common in tropical regions where more rainfall, higher temperatures, and longer growing seasons are more favorable for continual crop production. As population has increased, increasing the need for agricultural production, the use of multicropping systems is more prevalent. Though the history of multiple cropping is old, the concept has received very little attention from agricultural scientists, and what limited interest exists has come about very recently.

Why was this interest increased so dramatically in such a short time? Food shortages in many parts of the world, as well as the threat of insufficient supplies in the near future, continues to stimulate more intensive agricultural investigation in a search for more productive alternatives. As a consequence, it appears that we are about to embark on a new phase of agricultural research. Exactly what form it will take is still not known, but the reasons for this new approach are rapidly becoming apparent.

First, we have begun to observe a leveling off in yield increases brought about by the types of genetic manipulation that gave us such rapid and impressive yield increases during the "Green Revolution." It is as if we have reached a "yield plateau" with the current lines of research and crop selections. Large-scale use of single varieties (e.g., some of the International Rice Research Institute (IRRI) varieties of rice), with broad adaptability, produced major breakthroughs in yields. But it appears that these varieties have almost reached their maximum yield potentials. In many areas with specific soil and climatic conditions, they have not performed as well as hoped, especially on land more difficult to mechanize or irrigate. Thus we must begin to look for varieties with more specific adaptability and selected for specific environments, or else consider alternative cropping systems.

Second, most of the dramatic yield increases during the past few decades have been on the best agricultural lands–areas with good soil and easy water control. Future increases in production, therefore, will demand a new and innovative way of managing these highly productive lands, as well as looking for methods to make marginal lands increasingly productive. Only **20** percent of Asia rice land, for example, is irrigated, and the new high yielding rice varieties (which also require high levels of fertilizers, water use, and pest control) have not penetrated much beyond this boundary *(16)*.

The third factor is the oil crisis. Oil prices continue to soar, and with them, the cost offertilizers, pesticides, and fuel needed to build and run farm equipment and move irrigation water. Costs continue to mount for those inputs most responsible for achieving the dramatic yield increases of the "Green Revolution. " We are faced with the necessity of having to consider other alternatives that might allow us to substitute innovative biological or agronomic practices and varieties for these high cost inputs. Multiple cropping offers one of the most important and promising of these alternatives.

CONCEPTS AND DEFINITIONS

Multiple cropping systems use management practices where the total crop production from a single piece of land is achieved by growing single crops in close sequence, growing several crops simultaneously, or combining single and mixed crops in some sequence. The most important aspect of multiple cropping is the intensification of crop production into additional dimensions. Multiple cropping includes the dimensions of time and space; for example, when two crops share the same space at the same time.

A classification of types of multiple cropping systems is presented in table *1*. Note that special emphasis is placed on the distinction between intercropping, where two or more crops are grown at the same time, and sequential cropping, where two or more crops are grown on the same piece of land, but one following the other.

Some additional terms used in multiple cropping are presented in table 2. Agroforestry, as a particular type of intercropping system, will be discussed in some detail. Also, "mixed cropping," "polyculture," and "multiple cropping" will be used interchangeably in this review. By combining different aspects of simultaneous and sequential cropping systems, it is possible to visualize a truly complex pattern of different multiple cropping systems. This classification will be used throughout the following discussion, based on a symposium sponsored by the American Society of Agronomy, in support of the need to standardize terminology (34).

Table 1 .—Definitions of the Principal Multiple Cropping Patterns

- **Multiple Cropping:** The intensification of cropping in time and space dimensions. Growing two or more crops on the same field in a year.
- **Intercropping:** Growing two or more crops *simultaneously* on the same field per year. Crop intensification is in both time and space dimensions. There is intercrop competition during all or part of crop growth. Farmers manage more than one crop at a time in the same field.
  - —*Mixed intercropping:* Growing two or more crops simultaneously with no distinct row arrangement.
  - —Row *intercropping:* growing two or more crops simultaneously with one or more crops planted in rows.
  - —*Strip intercropping:* Growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically.
  - —*Relay intercropping:* Growing two or more crops simultaneously during part of each one's life cycle. A second crop is planted after the first crop has reached its reproductive stage of growth, but before it is ready for harvest.
- **Sequential Cropping:** Growing two or more crops in sequence on the same field per year. The succeeding crop is planted after the preceding one has been harvested. Crop intensification is only in the time dimension. There is no intercrop competition. Farmers manage only one crop at a time.
  - —Double *cropping:* Growing two crops a year in sequence.
  - — *Triple cropping:* Growing three crops a year in sequence.
  - —*Quadruple cropping:* Growing four crops a year in sequence.
  - —*Ratoon cropping:* Cultivating crop regrowth after harvest, although not necessarily for grain.

SOURCE Andrews and Kassam, 1976 (5)

Table 2.— Related Terminology Used in Multiple Cropping Systems

Single Stands: The growing of one crop variety alone in pure stands at normal density. Synonymous with "solid planting," "sole cropping." Opposite of '(multiple cropping."

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

Rotation: The repetitive growing of two or more sole crops or multiple cropping combinations on the same field.

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

Cropping System: The cropping patterns used on a farm and their interactions with farm resources, other farm enterprises, and available technology that determine their makeup.

Mixed Farming: Cropping systems that involve the raising of crops and animals.

Cropping Index: The number of crops grown per annum on a given area of land multiplied by 100.

Relative Yield Total (RYT): The sum of the intercropped yields divided by yields of sole crops. The same concept as land equivalent ratios. "Yield" can be measured as dry matter production, grain yield, nutrient uptake, energy, or protein production, as well as by market value of the crops.

Land Equivalent Ratios (LER): The ratio of the area needed under sole cropping to the one under intercropping to give equal amounts of yield at the same management level. The LER is the sum of the fractions of the yields of the intercrops relative to their sole-crop yields. It is equivalent to RYT, expressed in commercial yields.

Income Equivalent Ratio (IER): The ratio of the area needed under sole cropping to produce the same gross income as is obtained from 1 ha of intercropping at the same management level. The IER is the conversion of the LER into economic terms.

SOURCE Sanchez, 1976 (39)

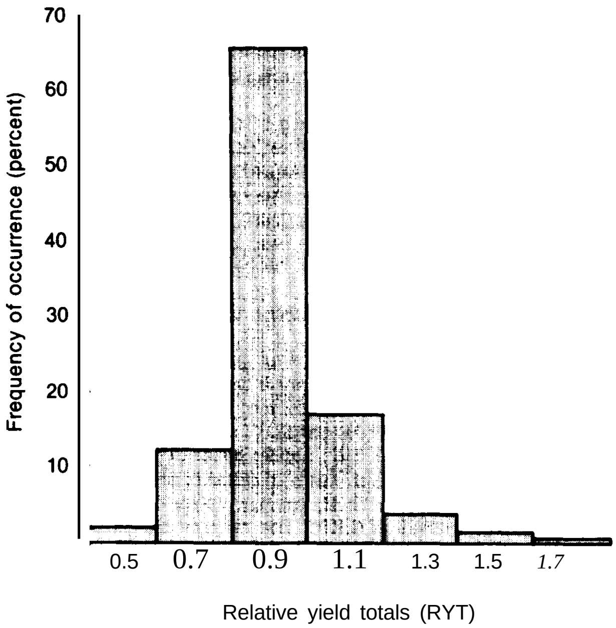
THE BASIS OF MULTIPLE CROPPING

Yield Advantages of Crop Mixtures

In areas of the world where multiple cropping is a common aspect of agroecosystem management, productivity generally is more stable and constant in the long term (24,45). Farmers often are able to achieve a combined production per unit area greater with a crop mixture than with an equal area divided among separate crop units. In such cases the Relative Yield Total (RYT) is greater than *1.0*. It may be that each crop in the mixture yields slightly less than the monoculture, but the combined yield of the mixture on less total land area is the important aspect.

In one study **(43),** the results of **572** comparisons of crop mixtures demonstrated that the majority **(66** percent) had RYTs close to *1.0,* indicating no distinct advantage to the mixture (fig. *1).* On the other hand, **20** percent of the mixtures had RYTs greater than *1.0,* ranging up to 1.7, indicating advantages to the mixtures. Only 14 percent had less than *1.0,* indicating distinct disadvantages. It must be remembered that most of the cases studied

Figure 1.—Distribution of the Relative Yield Totals of Mixtures Based on 572 Published Experiments



SOURCE Trenbath, 1974(43)

were experimental planting and not actual multiple cropping systems. Farmers would tend to choose the systems that yield more, as we have observed in traditional agroecosystems in the lowland tropical areas of southeastern Mexico (24,25).

The fact that advantageous mixtures do exist demonstrate the need for detailed research to take proper advantage of such systems. But for such systems to be considered as actual alternatives we need to understand thoroughly the biological and agronomic basis responsible for the observed response, as well as the advantages and disadvantages to their use. Before beginning a discussion of each aspect, a basic outline of such characteristics is presented, separated broadly into biological and physical aspects (table 3) and socioeconomic aspects (table 4). In many cases it is understood that there may be overlap between the two classifications, yet it is hoped that in the course of the following discussion that such aspects will be clarified.

Table 3.—Biological and Physical Factors: The Advantages and Disadvantages of Multiple Cropping Systems Compared to Sole-Cropping or Monoculture Systems (priority is not established)

Advantages

1. It is possible to obtain a better use of vertical space and time", imitating natural ecological patterns in regards to structure of the system, and permitting efficient capture of solar energy and nutrients.
2. Greater amounts of biomass (organic matter) can be returned to the system, sometimes even of better quality.
3. There exists a more efficient circulation of nutrients, including their "pumping" from the deeper soil profiles when deeper rooted shrubs or trees are included.
4. The damaging effects of wind sometimes can be reduced.
5. Systems can be designed that are appropriate for (but not restricted to) marginal areas because multiple cropping systems can better take advantage of variable soil, topography, and steeper slopes.
6. Multiple cropping systems are less subject to variability in climatic conditions, especially extremes of rainfall, temperature, or wind.
7. Reduction of water evaporation from the soil surface.
8. Increased microbial activity in the soil.
9. Avoidance or reduction of surface erosion.
10. Fertilizer use can be more efficient because of the more diverse and deeper root structure in the system.
11. Improved soil structure, avoiding the formation of a "hard pan" and promoting better aeration and filtration.
12. Legumes (as well as a few other plant families) are able to fix and incorporate nitrogen into the system.
13. Heavier mulch cover aids in weed control.
14. Better opportunities for biological control of insects and diseases.
15. Crop mixtures better permit the functioning of complex mutualisms and beneficial interactions between organisms.
16. Better use of time, with more crops per unit time in the same area.

Disadvantages

1. Competition between plants for light.
2. Competition between plants for soil nutrients.
3. Competition between plants for water.
4. Possibility for allelopathic influences between different crop plants due to plant-produced toxins.
5. Harvesting of one crop component may cause damage to the others.
6. It is very difficult to incorporate a fallow period into multiple cropping systems, especially when long lived tree species are included.
7. It is sometimes impossible, and many times very difficult, to mechanize multiple crop systems.
8. Increased evapotranspiration loss of water from the soil, caused by greater root volume and larger leaf surface area.
9. Possible over-extraction of nutrients, followed by their subsequent loss from the system with the increased exportation of agricultural or forest products.
10. Leaf, branch, fruit, or water-drop fall from taller elements in a mixed crop system can damage shorter ones.
11. Higher relative humidity in the air can favor disease outbreak, especially of fungi.
12. Possible proliferation of harmful animals (especially rodents and insects).

Table 4.—Social and Economic Factors: The Advantages and Disadvantages of Multiple Cropping Systems Compared to Sole-Cropping or Monoculture Systems (priority is not established)

Advantages

1. Dependence on one crop is avoided so that variability in prices, market, climate, and pests and diseases do not have such drastic effects on local economics,
2. Less need to import energy, pay for fertilizers, pay for externally produced materials, or depend on machinery,
3. Wildlife is favored, and with rational use it can be an important source of protein.
4. Greater flexibility of the distribution of labor over the year
5. Recovery of investments can occur in much less time, especially where trees are combined with short term agricultural crops,
6. Harvest is spread over a longer period of time,
7. In areas and times of high unemployment, multiple cropping systems can use much more labor.
8. Farmers can produce a large variety of useful products, depending on the type and complexity of the multiple cropping systems, such as firewood, construction materials, flowers, honey, crops for home consumption, thus lowering the outflow of funds,
9. Certain multiple cropping systems permit a gradual change from destructive farming practices to more appropriate technologies, without a drop in productivity,
10. Multiple cropping can promote a return to the land, and its maintenance.
11. In systems which include trees and/or animals, such components can constitute a type of "savings" for the future, while short term crops satisfy immediate needs.
12. Because of their diverse nature, multiple cropping systems promote interdisciplinary activities, stimulate interchange and group activities, and lead to social cohesion in the long term,

Disadvantages

1. The systems are more complex and less understood agronomically and biologically. Statistical designs for experimental analysis are much more complex.
2. Yields sometimes are lower, providing only subsistence level production.
3. In many systems, multiple cropping is not considered to be economically efficient due to the complexity of activities necessary.
4. These systems require more hand labor, which can be considered a disadvantage in some circumstances.
5. Some mixed crop systems do not offer sufficient reward to lower income farmers to raise their standard of living.
6. For producers with limited economic resources, it may take longer to recover the entire initial investment.
7. Farmers initiating multiple cropping systems may encounter opposition from the prevalent social, economic, and political system.
8. There is a shortage of trained personnel (technical and scientific) capable of installing and managing multiple cropping systems.
9. There is a general lack of knowledge or understanding of multiple cropping by "decision makers, " affecting especially funding for research to make such systems viable alternatives.

General Resource Use

The most commonly accepted reason explaining why it is possible to obtain better yields with crop mixtures is that the component crops differ in their growth requirements. Such combinations of components can be said to be "complementary" (46).

A mixture makes better overall use of available resources. Negative influences (e. g., competition for light, water, or nutrients) between the component members of a successful multiple cropping system would be reduced considerably. To maximize the advantages of such a system, it is important to maximize the degree to which one component complements another. With a greater range of requirements between different elements of the mixture, theoretically the greatest advantages would be achieved.

One way to achieve complementarily is by varying the crop components temporally—using sequential planting to achieve a multiple cropping system that ensures that antagonistic interactions between the components are avoided, Following a crop with another that has different growth requirements would enable the maximum use of resources. This concept has been used for a long time and is the basic rationale behind crop rotations.

The most advantageous use of soil, for example, would be to follow one crop with another that requires different soil nutrients. A subsequent crop would thus be able to absorb fertilizer residues left over from the previous crop, thus reducing the need for fertilizer applications. For the Eastern United States, it has been concluded (31) that double cropping systems such as soybeans after wheat or barley, or the production of silage crops after grain corn or sorghum, can function well,

Depending on the length of the growing season, numerous sequential plantings can take place during a single year. Such systems require special management, with timely harvest, use of proper varieties, alteration of the standard planting distance, special selection of herbicides so as to not create antagonisms or residual effects, and also the possibility of using no-tillage planting with certain of the row crops.

Another form of complementing different crop components is through an intensification of the sequential cropping system known as relay planting. The same avoidance of overlapping plant growth requirements is gained, as well as the avoidance of direct plant interference, by planting a second crop after the first one has completed the major part of its development, but before harvest. Relatively little research on relay cropping has been done in the United States, and most has demonstrated little if any yield advantage (31). On the other hand, in Mexico and Latin America innumerable examples of relay planting with definite yield advantages have been reported, especially for corn and beans (35,39).

Again, the important, and as yet little studied, aspect of relay planting success depends on the correct combinations of timing and varieties so as to avoid shading, nutrient competition, or inhibition brought about by toxicity produced by the decomposition of a previous crop residue.

Finally, maximum complementarily can be achieved by growing two or more crops simultaneously, either in rows, strips, or mixed, but taking advantage of the spatial arrangement of the different crops and knowledge of their individual growth requirements. Again, most examples of such systems come from outside the United States. One particularly well-documented example is a traditional corn, bean, and squash system in Tabasco, Mexico (4].

Corn is planted at a density of 50,000 plants/ha, climbing beans in the same hole at a density of 40,000 plants/ha, and the squash intermixed among the rows of corn and beans at a density of 3,330 plants/ha. All are planted at the same time in this case. Beans begin to mature first, using the corn stalks for support; the corn matures second; the squash is the last to mature. Aerial space is divided such that corn occupies the upper canopy, beans the middle, and squash covers the ground. Better weed control is achieved, and insect pests are largely controlled by natural enemies. Corn yield was significantly higher for the polyculture as compared to different densities of monoculture, but beans and squash suffered a distinct yield reduction (table 5). Interestingly, the LER (Land Equipment Ratio) value of 1.73 tells us that the sum of the yields in the mixture can only be equaled in monoculture by planting 1.73 times the area divided proportionally among the three sole crops,

Table 5.–Yields of Corn, Beans, and Squash (kg/ha) Planted in Polyculture as Compared to Low and High Densities of Each Crop in Monoculture

	Total grain or fruit yields				
Crop	Monoculture				Polyculture
Corn:					
Density ... ,	33,300	40,000	66,600	100,000	50,000
Yield	990	1,150	1,230	1,170	1,720
Beans:					
Density	56,800	64,000	100,000	133,200	40,000
Yield	425	740	610	695	110
Squash:					
Density	1,200	1,875	7,500	30,000	3,330
Yield	15	250	430	225	80
Crop	**Total biomass dry weight**				
Corn	2,822.9	3,119.4	4,477,5	4,870.9	5,927.2
Beans	852.9	895.1	842.6	1,390.4	253.1
Squash	240.9	940.9	1,254.0	801.9	478.3
		Total	Polyculture	Biomass	6,658.6

LER (Land Equipment Ratio) = Sum *of yields of each polyculture* / Sum of highest yield each monoculture

$$LER = \frac{1,720}{1,230} + \frac{110}{740} + \frac{80}{430}$$

LER = 1.73

SOURCE Amador, 1980 (13)

The advantage of producing a greater yield altogether on less land is obvious. The much higher total yield of biomass in the mixture is also important because much of this organic matter is returned to the soil, bringing important consequences in soil fertility, humidity conservation, microbial activity, etc., all related to the success of the following crops, Currently, studies are being conducted to determine if the higher yields are the result of more efficient resource use, or if in fact some mutually beneficial effect between crop components is taking place, for example, the bean producing nitrogen that the corn can absorb (12). This example demonstrates the enormous potential that multiple cropping systems offer for the future.

Specific Resource Use, Conservation, and Management

An intensified land-use system of agriculture will certainly put greater pressures on the available natural resources of our crop and rangelands. Considerable discussion has focused on the harmful or beneficial aspects of this intensification, and a review of some of the more important aspects can aid greatly in understanding this problem:

1) *Microclimate and Light:* In any agroecosystem, a very important aspect of productivity is related to the amount of light converted directly to carbohydrate, hence to vegetative material, through photosynthesis. Each cropping system has a photosynthetic potential, based on its capacity of conversion (2). Monoculture, especially of annuals, generally have a lower potential because either the plant cover is not complete, or the soil is occupied only during one short season, leaving the surface bare of photosynthetic capacity until the next crop is planted. Light is not like other resources, where a reservoir exists and the plants tap it as the need arises, Rather, it has to be used when it is available, thus leaf area becomes a very important factor. A multi-layered polyculture would be able to capture much more light energy, raising efficiency, and potentially, production.

Apart from the quantity of light absorbed, its quality is also important. Light that has passed through a leaf layer is altered as certain light waves are absorbed and others penetrate. Plants in the lower layers of the canopy need to be adapted to this alteration—an aspect well studied only in natural vegetation (7). For cropping systems, light has been studied in detail only for monoculture systems (2) from the point of view of increasing effective photosynthetic leaf area for the single crop, By manipulating species with different light requirements, greater photosynthetic potential can be achieved. This is made easier by using dominant species in the polyculture that do not develop a closed canopy, allowing considerable penetration to the next levels. The most shade-tolerant plants should be in the lowest levels. In such a system, the soil surface is in essence completely covered by plants. This manipulation of plant architecture has been studied in detail ecologically (28) and has considerable application in multiple cropping systems.

Other aspects of the crop microclimate are also affected. Crops in the lower layers would be subject to less water stress, but care must be taken that root system competition for water does not become a problem. Water loss by soil surface evaporation could be reduced, but transpiration from leaf surfaces might be increased in the crop mixture. Soil temperatures would be lowered, an advantage especially in warmer and drier environments, aiding in the conservation and buildup of organic matter in the soil. Protection from wind would be provided for the lower canopy species. Care would need to be taken that the increased humidity in the lower canopies does not promote higher incidence of certain diseases, especially fungi, either of the roots or foilage.

2. *Soil-Plant Relations in Multiple Cropping Systems:* Any time that we try to combine two or more crops simultaneously in one area, there exists the possibility for complex interactions between the plants and their soil environment (39). When total complementarily is achieved, the roots of the component species occupy different soil horizons, reducing considerably the potential competition between species and increasing the efficiency of total nutrient uptake. In combinations of deep-rooted with shallow-rooted species, especially when trees are planted with grasses or annual crops, the trees are capable of absorbing uncaptured nutrients as they are leached into the

soil. Then, through their transport to foliage, they can be deposited on the soil surface again as the leaves drop (47).

Intercropping systems have been shown to extract more nutrients from the soil than do single crop plantings per unit area of land. In a very complete study with corn and pigeon peas in Trinidad (19) (table 6), various parameters of crop response were measured. The highest single crop yields of grain were obtained in monoculture, but by adding yields of two crops planted mixed or in intercropped rows, Relative Yield Totals (RYT) were higher. Total dry matter production was higher in the mixtures as well. The most interesting aspect is the uptake of nutrients (N, P, K, Ca, and Mg). The total uptake is based on the sum of the two crops together, and in all cases the total nutrient content of the dry matter production was higher for the mixtures, demonstrating the greater extractive capacity of the multiple cropping system. Apparently, for corn and pigeon peas, row intercropping gave the best results, demonstrating that at times two crops together can negatively influence each other, but the total yield makes up for the reduction. Each crop mixture needs to be examined in detail.

The greater uptake of nutrients in crop mixtures could deplete the soil more rapidly. But an aspect of multiple cropping that needs to be considered is what proportion of this nutrient content is removed from the system with the harvest, as compared to the part reincorporated back into the system. In table 7, a corn/bean polyculture is compared to a corn monoculture. Total biomass production, as well as yield removed from the system, is considerably higher from the mixture (10,24 tons/ha versus 6.68 tons/ha total biomass). The percentage of this total that leaves the system is slightly lower for the mixture (61 percent versus 66 percent), but the actual amount of organic matter returned to the soil in the polyculture (3.98 tons/ha) as compared to the sole

Table 6.—Effects of Mixed and Row Intercropping on Yields and Nutrient Uptake of Corn (C) and Pigeon Peas (PP) in St. Augustine, Trinidad, Expressed as Relative Yield Totals (RYT)

	Sole crop		*Mixed intercrop*			*Row intercrop*		
Parameter	c	PP	c	PP	RYT	C	PP	RYT
Grain yields (tons/ha)	3.1	1.9	2.0	1.7	1.54	2.6	1.8	1,78
Total Dry Matter (tons/ha)	6.4	5.1	4.2	3.8	1.40	5.0	4.9	1.74
N uptake (kg/ha)	-66.0	119.0	48.0	100.0	1.56	54.0	127.0	1.88
P uptake (kg/ha)	13.0	6.0	9.0	5.0	1.52	11.0	7.0	2.01
K uptake (kg/ha)	51.0	37.0	37.0	32.0	1.59	46.0	33.0	1.79
Ca uptake (kg/ha)	10.0	22.0	10.0	15.0	1.68	9.0	19.0	1.76
Mg uptake (kg/ha)	12.0	14.0	9.0	8.0	1.32	9.0	12.0	1.61

SOURCE’ Adapted from Data, 1974, (19), cited by Sanchez, 1976, (39)

Table 7.—Biomass Distribution (in tons/ha) of Dry Matter in a Corn/Bean Polyculture as Compared to a Corn Monoculture, in Tacotalpa, Tabasco, Mexico

Crop	Roots	Crown	Leaves and stem	Grain[a]	(A) Total	(B) Removed matter	*(B)/(A)* percent	(A)-(B) Total reincorporated
Corn	0.49	0.60	2.29	4.76[b]				
plus					10.24	6.26	61 %	3.98
Beans	0.15	0.00	0.45	1.50[b]				
Corn Alone	0.34	0.41	1.57	4.36[b]	6.68	4.36	65 %	2.32

aWeight of grain of corn is unhusked, including cob and husk, in the manner that the harvest iS removed from the field in this region.
bIndlcates the removed portion of the biomass.

SOURCE: Adapted from Gliessman and Amador, 1979 (24) crop (2.32 tons/ha) demonstrates that although more material is produced by the intercrop system, a greater amount returns to this system. This possibly offsets any increase in extraction of soil nutrients and permits the long-term management of the system.

Another way to increase the return of nutrients to the system is to plant "nurse plants." These plants do not contribute directly to the biomass harvested and removed from the system, but their capacity to capture nutrients and continually recycle them in the soil would be an advantage. Local farmers in Tabasco, Mexico, use this concept in the management of weeds (14), leaving those that don't interfere with the crops and removing those that are harmful. This practice also provides a constant cover over the soil and helps maintain better soil structure, conserves water, fosters more microbial activity, and over the long run, requires fewer chemical fertilizers. By including plants that "trap" nutrients, such as legumes, such benefits can be improved even more. The widespread use of legume trees for shade in coffee and cocoa plantations is a classic example (27).

3. *Water Use in Multiple Cropping Systems:* Any discussion of water use should consider rooting patterns. In multiple cropping systems, especially with several crops with differently arrayed root systems, a greater volume of the soil typically is occupied and thus water use efficiency is higher. This is useful, on the one hand, in areas where water supplies are limited. It also helps make more complete use of costly irrigation water. It has been proposed that cover crops in orchards stimulate deeper rooting by the trees (10). Different peak periods of water use in the crop mixtures would avoid competition and increase overall water use efficiency (8). A crop such as corn that uses relatively little water in its early stages of development could be interplanted with an early maturing crop that could take advantage of the unused moisture (30).

In areas where water is severely limited, care must be taken not to plant crops with overlapping water requirements because in dry years one member of the mixture could be outcompeted by the other (36). Combining two crops with slightly overlapping water needs, on the other hand, could be used to an advantage in areas with widely fluctuating rainfall regimes. In a dry year, one component would be favored, and in a wet year the other, guaranteeing profitable harvests of at least one crop every year. Studies on water availability in each region, coupled with studies of water needs of each component crop of multiple cropping systems, are critical for proper management.

The important effects of multiple cropping on the conservation of water and soil are primarily achieved through the maintenance of a more complete vegetative cover over the soil **(26,40).** It is important to remember that apart from improving cover while the crop is growing, multiple cropping systems aim toward maintaining this cover between harvests. This is achieved by reducing the time between harvest and replanting in sequential systems, planting a new crop into another in relay cropping, and continually interplanting in an intercropped system. The use of trees, either as windbreaks, for soil stabilization on eroded hillsides, or in areas subject to desertification, can be enhanced greatly by combining them with crops or pasture grasses (see discussion on Agroforestry).

In summary, although it appears that multiple cropping systems use more water, their ability to obtain water not available to monoculture, use the water more efficiently, and contribute significantly to soil conservation, demonstrate a further potential for their more widespread use.

4. *Pest, Disease, and Weed Relations:* As discussed, possibilities exist for multiple cropping systems to be both advantageous and disadvantageous in relation to problems of pests, diseases, and weeds (29,32). The problem has to do with the great complexity of environmental factors and their dynamic interactions within the cropping systems. Where capital is not available or technical assistance has not been accepted, we observe that the main means of pest, disease, and weed control is through bio-

logical control, and through the management of a great diversity of cropping patterns, both in time and space (23).

It has been suggested that multiple cropping systems permit such a control because they are much less subject to attack (6,29,38). This comes about because the mixed cropping system: 1) prevents spread of diseases and pests by separating susceptible plants; 2) one species sometimes serves as a trap crop, protecting the others; 3) associated species sometimes serve as a repellant of the pest or disease to which the other crops are subject; and 4) a greater abundance of natural predators or parasites of pests are present due to a higher diversity of adequate microsites and alternate prey.

However, there are also reasons why a multiple cropping system may be more susceptible to attack: 1) reduced cultivation and greater shading due to the presence of associated species, 2) associated crops serve as alternate hosts, and 3) crop residues from one crop may serve as a source of inoculum for the others. All of these advantages and disadvantages can exist, and further study is necessary to achieve the combinations that give the most positive results.

A few examples might serve to demonstrate the potential of multiple cropping for biological control. In one study (22), it was shown that the planting of a locally used medicinal herb (Chenodium ambrosioides) in sequence with corn or beans reduced the incidence of nematode populations in the soil, demonstrating a potential for reducing attack on the roots of the food crops, The herb added substances toxic to the nematodes into the soil. In another study, yields of cotton untreated with insecticides, but interplanted with sorghum, were 24 percent higher than sprayed monoculture. The reason was that sorghum served as a microhabitat for cotton bollworm predators (18). In another case, fall army worms were less a problem on corn associated with bush beans than on pure-stand corn (21). Beans intercropped with corn were attacked less by rust compared to beans in pure stands, probably because corn functions as a barrier to the dissemination of the fungal spores (41).

Weeds, on the other hand, present another problem. It has been reported that weeds are much less a problem in multiple cropping systems, especially in intercropping (32), because the space normally available to weeds is filled with other crops, The aggressive nature of weeds is well known (9), but recent work has begun to show that weeds can fill an important ecological role in cropping systems, by capturing unused nutrients, protecting the soil, altering soil fauna and flora, serving as trap plants for pests and disease, and changing the microhabitat to allow for high populations of pest predators and parasites (3,17). In rural tropical Mexico, farmers understand and use a “non-weed” concept (14), where each is classified according to positive or negative effects. We need to understand in more detail the biological functions of each component of the agroecosystem to establish the structure that will allow adequate weed, pest, and disease control, If part of this control can be achieved by merely manipulating the crop mixture in time and space, great strides toward more efficient agricultural management can be made.

5. Mutualisms and Crop Coexistence: In natural ecosystems, a great number of interactions between different species are mutually beneficial for those organisms involved, leading us to believe that there is a strong selective pressure operating to select combinations that coexist rather than compete (37). On the long term, such a coexistence permits a more efficient use of resources, with the component organisms aiding one another rather than interacting negatively. This frees more energy for growth and reproduction.

To a certain extent, nurse crops or companion plants function in this way. Legumes, because of their symbiosis with nitrogen-fixing bacteria, can coexist with corn without competing for nitrogen. In fact, part of the legume’s nitrogen may be available for the corn (12), reducing overall need for fertilizers. Studies with coffee and cocoa shade trees have demonstrated the same relationship; the trees provide shade, nitrogen, and an organic mulch over the soil.

As mentioned, the presence of one crop may have beneficial effects on others through alteration in the microclimate, pest and disease protection, etc. Thus, apart from looking for crops that complement one another by avoiding overlap in requirements, we need also to look for crops that are interdependent and that mutually benefit from the association, This will be a very stimulating challenge for crop selection programs.

6. Use *of Space and Time:* One of the most important aspects of the management of multiple cropping systems is the facility they offer for the intensification of production through manipulation of space and time. By achieving the most ideal combination of the two, we will achieve the greatest productivity. On the one hand, we attempt to occupy the available resource space as efficiently as possible, combining species that complement each other, yet attempting to avoid overlaps that lead to negative interactions.

Resource use in space is then combined with its use in time, trying to achieve constant use of the resources available. For this reason, multiple cropping systems are intensified by sequential, relay, and mixed planting that establish constant resource use within the environmental limits imposed by the ecological conditions of each region. In this sense, we can even visualize the possibility of including cold resistant trees in association with annual crops or pasture, so that during the winter the trees continue to occupy the area. Thus, any yield reduction during the normal frost-free growing season is compensated for by the long-term tree production,

Additionally, multiple cropping systems permit greater stability in production, despite variability in climate or physical factors in the planting area. Whatever the conditions in one location and for one growing season, at least one member of the multiple cropping system will succeed. Since most of the better drained and structured soils are already in production, the more marginal lands will require special technology to make them produce. We cannot consider for the moment massive programs of soil and water manipulation needed to install mechanized high-yielding monoculture, To do so is economically, if not ecologically, prohibitive. The basic framework is available in multiple cropping, Innovative combinations need to be searched for and tested.

Agroforestry: A Multiple Cropping System

Agroforestry is a technology of land management that combines trees with agricultural crops, with animals, or any combination of the two. Combinations can be simultaneous, or staggered in either time and space. The major objective of agroforestry is to optimize production for each unit of surface area, keeping in mind the need to maintain long-term yield (11,13,42). Small-scale, traditional agriculture has always included trees as integrated elements of farm management, but only recently has interest been revitalized in the application of agroforestry practices into modern agriculture.

The renewal of interest in agroforestry is based on many of the same reasons for multiple cropping systems in general: the ever-increasing demand for production, yet the rising cost of obtaining it. The explosive demand for firewood and lumber has placed incredible pressures on the world's forests, especially in tropical and subtropical regions. Deforestation continues at an accelerated rate (20,44). But programs of reforestation or multiple-use forest management do not satisfy basic needs for food, clothing, and other necessities that come from crop and range lands. It would seem logical that these pressures for both forest and agricultural products would stimulate their combination in agroforestry systems.

Agroforestry practices can be broadly classified into three types (15): 1) combined agrosilvicultural (crop plus trees) systems, 2) combined forestry and grazing, and 3) simultaneous combinations of forestry with crops and grazing. Examples of each of these classifications are presented in table 8. The focus varies from soil improvement, erosion control, wind breaks, and shade to lumber, firewood, and reforestation. The combinations are essentially unlimited, depending on the needs of each region. At first glance it might appear that agroforestry systems are most applicable on marginal lands, on steep slopes, poor soils, or areas with widely fluctuating rainfall regimes. But agroforestry should also be considered for widespread application, even on prime agricultural or grazing land, because production needs to be increased—both by opening up new areas and by looking for innovative ways to increase productivity of lands already in use.

The principle limitations to widespread use of agroforestry practices are economic and technological. Ecologically, the advantages are well known, but technically we still do not have the information necessary to begin immediate implementation. With the present focus in agriculture aimed at maximizing single crop yields, there is a lack of acceptance of the idea that yields need to be thought of more on a long-term, diversified basis. Agricultural research has not yet accepted the challenge that an integrated focus to forest and farm management requires.

Socioeconomic Implications of Multiple Cropping Systems: Perspectives for the Future

In all of the aspects of multiple cropping systems that this review has considered—yield, resource use, pest and disease control, weeds, use of space and time, types of planting systems—much of the evidence indicates that generally there are more advantages than disadvantages of a biological, physical, or agronomic nature. But we need to consider the social and economic implications of the possible more widespread use of multiple cropping systems in present day agriculture.

As was seen in table 4, the types of advantages derived from multiple cropping are many and varied. With a greater diversity of crops,

Table 8.—Classification and Examples of Agroforestry Technologies

Combined agrosllvicultural systems (trees with crops):

1. Agrosilviculture—establishment of trees, intercropped with agricultural crops during initial stages of tree growth, until tree canopies close and force the elimination of the crops. Production available in early stages of tree development, and cultivation activities simultaneously benefit both crops and trees.
2. Forest trees of commercial value in crop systems. Maintain trees in crop areas, either planted or natural, at low densities that do not interfere, yet provide value in the future.
3. Fruit trees in crop systems. A system that allows fruit production and grain or vegetable production simultaneously.
4. Trees that serve as shade for certain crops or improve the soil through nitrogen fixation, organic matter incorporation, mulch, and microclimate modification.
5. Trees used as hedgerows, fence lines, or windbreaks around cropping areas, where management is intimately linked with the needs of the crops.
6. Trees around rivers, lakes, or artificial reservoirs or tanks, integrated with fish or waterfowl management, providing shade, food, and roosting.

Combined forestry and grazing systems (trees with grasses):

1. Grazing or forage production takes place within forestry plantations, aiding in avoiding weed or brush build up, lowering fire risk.
2. Grazing or forage production in young natural forests, with same advantages as above.
3. Forest trees of commercial value in pastures, either planted or natural, at densities that do not interfere with the pasture species.
4. Timber trees in pasture, either planted or natural, with the capacity to fix nitrogen and improve soil, thus lowering the need to fertilize and provide commercial value.
5. Trees in pastures that provide shade for the animals and aid in improving the soil through nitrogen fixation and nutrient extraction from deeper soil levels.
6. Trees, either in or around pastures, or in forests, that produce foliage of forage value for animal consumption. Can allow the reduction of feed supplement for animals.
7. Fruit trees in pastures, allowing for commercial production of both fruits and animals.
8. Trees around pastures as hedgerows, fence lines, or windbreaks.

Simultaneous combinations of forestry with crops and grazing:

1. Forest plantations planted with crops and grasses, permitting the management of grazing animals, either free to wander or enclosed in specific areas. Especially adapted to smaller animals, such as ducks or pigs. Requires close control of activities and use of specific crops.
2. Trees associated with crops and grazing, either planted or natural, in densities that will not adversely influence the crops. Trees scattered in and around cropping areas can be periodically pruned and used as forage for animals, with the timber harvestable at some later date.
3. Hedgerows or living fence lines around rural communities, serving as shade, windbreak, property divisions, forage, fruits, timber, and firewood. In this sense, the system is truly multiple use.

SOURCE: Combe and Budowski, 1979 (15)

a farmer is less affected by market fluctuations and is able to shift from one crop to another depending on price and demand, At the same time, the harvest is spread out over a longer period of time. Less dependence on outside energy sources has obvious advantages, especially in areas where capital is limited. Labor, instead of being concentrated in certain periods of the year, can be more evenly distributed, an important consideration in relation to the migrant farm worker problem. In times of higher unemployment, multiple cropping systems can offer more and steadier work.

Most of the economic disadvantages are derived from our lack of experience and knowledge with multiple cropping systems. Reported lower yields, complexity of management activities, higher labor demands, and the difficulty in mechanizing such systems are all important factors that discourage modern farmers from participating in multiple cropping practices.

An important aspect of this resistance comes from the emphasis on large profits that governs so much of modern agriculture today. Maximum profits in the short term, rather than concern with maintaining constant income in the long term, governs the decisionmaking process on most American farms today, But with the incredible rise in farm costs, a new focus is necessary. All of these increases cannot be passed onto the consumer. Many of the advantages of multiple cropping systems definitely need to be stressed more for use on farms today. Smaller farms, with a greater diversity of products and activities, can function quite profitably because they are less dependent on high-cost energy inputs. Lower costs mean food can be produced at a lower price, the benefits being transferred to the general population,

Smaller farms would require more farmers, To a certain extent multiple cropping systems mean a return to the land, with the incentives necessary to keep the farmers there. The great diversity of activities in multiple cropping systems would promote an increase in interdisciplinary activities in their investigation, installation, management, and use in agriculture. This stimulation of interchange and collaboration can, in the long term, lead to greater social cohesion, Rural regions might once again take on the social importance they enjoyed in the past. The problems of lack of trained personnel, and social, political, and economic restrictions on multiple cropping systems, all can be overcome by thorough and conscientious programs of research aimed at determining the proper methods, varieties, and practices necessary.

The belief that multiple cropping is only suitable for marginal or underdeveloped regions ignores the fact that just a relatively short time ago, such systems were the most common type of agriculture. Only recently have they been replaced by monoculture systems dependent on the use of massive quantities of inexpensive high energy inputs. For the moment, this time has passed and we need to learn from the past to reshape agriculture for the future. This will be a great challenge for agricultural research.

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