Reviews

Increasing Sustainability by Intercropping

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Summary. Plant interactions are both competitive and cooperative. Farmers use intercropping to the mutual advantage of both main and secondary crops in a multiple-crop-production system. A vegetable crop has a competitive advantage over a younger secondary cover crop interseeded before vegetable maturity. Non-legume intercropped cover crops can use soil N, while a legume intercrop can increase N in agricultural systems by biological N fixation. Intercropping also may be more efficient than monocropping in exploiting limited resources. Relay-planting main crop and intercrop components so that resource demands (nutrients, water, sunlight, etc.) occur during different periods of the growing season can be an effective means of minimizing interspecific competition. Intercropping systems often exhibit less crop damage associated with insect and plant pathogen attacks, and they provide weed control.

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Natural ecosystems exhibit the capacity for both competition and cooperation (Odum, 1971). The ability of different plant species to cooperate to mutual advantage is often the result of physical changes in plant structures or manipulation of the surrounding environment. This principle of *mutualism* can be applied to plant interactions in an agricultural system. *Intercropping* is the growing of two or more crops *simultaneously* on the same field (Andrews and Kassam, 1976; Sanchez, 1976). The practice of relay *intercropping* involves planting a second crop after an initial crop has reached maturity, but before it is ready for harvest. One application of relay intercropping is to divide crops into two categories: the main component is the crop of primary importance and has the desired yields; the second crop, or secondary component, provides added economic and/or environmental benefits (Willey, 1979a). Figure 1 shows a conceptual model of the crop components when summer annual legumes are intercropped in a strip-tilled broccoli (*Brassica oleracea* var. *italica*) production system (Coolman, 1989). Such summer annual legumes may be relay-intercropped into a stand of maturing broccoli to achieve an economic yield in the broccoli component. The legume provides benefits of biological N fixation, weed control, and soil conservation.

A summer annual legume sown immediately following broccoli trans-

planting usually has a favorable environment for germination. The area between the rows receives sunlight throughout the day, while the broccoli transplants reduce evaporative demand in the soil surface due to reduction of wind currents. As the legume germinates and begins to grow, the broccoli foliage enlarges and gradually shades the soil between the broccoli rows. Eventually, the broccoli suppresses the legume's growth through shading and dominates resource (nutrients, water, sunlight, etc.) use in the field.

Following broccoli harvest, the previously suppressed legume enters the steep upward portion of its growth curve and dominates the field throughout the remainder of the summer. The result is a complete stand of legumes capable of fixing N and retaining in the soil additional plant nutrients for future crops. Relay intercropping thus results in a mutually beneficial relationship between the broccoli and legume components.

The effects of intercropping on plant interactions

Intercropping has been an agricultural practice for thousands of years (Kass, 1978). Intercropping was used commonly in the United States until the 1940s, when energy-intensive, modern agriculture developed in response to the development of power machinery, fertilizers, and chemical pesticides (Horwith, 1985). In less-developed countries, the majority of farmers still practice intercropping because of a lack of access to either credit, inputs, or machinery.

Ofori and Stern (1987) suggest that growing two or more crops simultaneously is more efficient than monocropping for exploitation of limited resources. One major concern regarding intercropping systems on infertile soils is the accelerated depletion of mineral nutrients when both crops are harvested. Intercropping often results in accelerated harvesting of soil resources as a short-term gain for farmers with limited resources. This concern is reduced if nurse crops are not harvested from the system, but instead their capacity to capture and recycle nutrients for use by the following primary crop is used to the farmer's advantage. The advantages and disadvantages of intercropping systems, the competitive constraints, and the management techniques that can be used

Fig. 1. Conceptual representation of broccoli-legume intercropping system prior to broccoli harvest.

to facilitate mutually beneficial plant interactions are reviewed below.

Below-ground interactions

Little is known about root interaction in intercropping systems. Trenbath (1974) considered yield advantages in mixtures of oat varieties to be the result of differential root growth. Another view is that differences in rooting patterns are the result of mutual avoidance of root systems (Baldwin et al., 1972; Raper and Barber, 1970). Differences in root systems, particularly rooting depth, lateral root spread, and root density, have been found to affect competition for water (Babalola, 1980; Haynes, 1980). Haynes concluded that proper management of root systems can minimize root competition for water.

Wiley (1979a) counters that root avoidance also should occur in monocultural cropping systems. He concludes that increased exploration of the soil matrix by roots in intercropping systems does not have a direct advantage over monocultures. However, relay intercropping has the advantage of separating rooting systems

in time. As plants begin to mature, the uptake of both nutrients and water declines. A second crop planted during this period may be an effective way of avoiding interspecific root competition (Sanchez, 1976).

Competition for water and nutrients under relay intercropping affects the suppressed crop component in two ways (Baldwin and Tinker, 1972). First, the roots of suppressed plants are less-developed at the interface with roots of the dominant crop. Second, suppressed crops are likely to show an increased root : shoot ratio. Shallow-rooted primary crops of an intercropping system may force companion crops to develop deeper rooting systems that explore the soil matrix more extensively than their monoculture counterparts (Fisher, 1976; IRRI, 1972). Such root avoidance may assist in developing root systems that use soil to a greater depth (Trenbath, 1974).

Above-ground interactions

Light, water, mineral nutrients, oxygen, and carbon dioxide are all required for plant growth (Trenbath, 1976). Competition occurs when two

plants vie for the same nutritional and water requirements in the same space—one of the plants usually receives less than it requires. Overlapping in space and time, the growth of two or more crops often results in decreased yields of both crops due to competition for limited essential resources (Dalal, 1977; Wahua and Miller, 1978; Wanki et al., 1982). Any development of intercropping systems must evaluate the effects of competition on crop yields.

Crop protection

Intercropping systems often exhibit less crop damage associated with insect and plant pathogen attacks, although the results are quite variable. Previous research has shown a reduction of insect damage in intercropped systems compared to monocultures (Kass, 1978; Nickel, 1973; Perrin, 1977). Francis and Sanders (1978) reported lower attacks of fall armyworm (*Spodoptera frugiperda*) in a corn-bean intercrop than in a corn (*Zea mays*) monoculture. Vandermeer (1989), however, conducted a similar experiment using identical cropping patterns in Nicaragua and failed to detect any differences in insect pests under both rain-fed and irrigated conditions. Evidence also exists that intercropping reduces both nematode and disease attack (Castillo et al., 1976; Egunjobi, 1984). Many mechanisms for reduced insect, nematode, and disease problems associated with intercropping have been proposed (Aiyer, 1949; Root, 1973; Trenbath, 1976). Unfortunately, while each suggest a mechanism of control for a particular situation, no single explanation is universal.

Intercropping with a cover crop often provides weed control in the cropping system. One proposed mechanism of weed control is competition of the secondary crop with weed species. Vandermeer (1989) reported that a recent review by Liebman (1986) found that 20 of 23 intercropping systems involving cover crops suppressed weed growth significantly.

Individual intercropping systems show more variable weed control effects. For example, a maize-cowpea intercrop in Nigeria had no suppressive effect on weeds early in the season, but controlled weed growth effectively later in the cropping season (Ayeni et al., 1984). On the other hand, a maize-cassava system at the same location did

not suppress weed growth (Unamma and Ene, 1983). Again, while reviews of research on intercropping and weed control are impressive, individual cropping systems respond differently and, therefore, must be evaluated on their own merit based on site-specific conditions and the crops used.

Nutrients

Intercropping with legumes may have either beneficial or detrimental effects because interspecific competition, the nitrogen-fixing capacity of the legumes, planting times, and soil fertility levels can affect nutrient accrual (Sanchez, 1976). Numerous experiments have demonstrated a yield advantage of legume and non-legume mixtures over monocultural counterparts (Agboola and Fayemi, 1972; Kurtz et al., 1952; Trenbath, 1976; Willey, 1979b). One interpretation of this advantage is that the non legume component uses soil N, while the legume component uses N from the atmosphere (Hall, 1974; Snaydon and Harris, 1979). Sanchez (1976) suggested that legume-cereal intercroppings can be beneficial when the cropping system is managed to minimize interspecific competition. Relay intercropping of shade-tolerant legume species between rows of a main crop may be one method of minimizing interspecific competition. Legumes must be planted early enough in the growing season to accumulate appreciable amounts of N from the atmosphere to be effective N contributors (Coolman, 1988; Eaglesham et al., 1982). Nitrogen contributions in relay-cropping systems tend to be site-specific, being affected by crop components, planting dates, and timing of N release from legume residues (Sanchez, 1976).

Most intercropping systems exhibit competition for N between crop components (Ofori and Stern, 1987). Legume-cereal intercropping systems have less N competition when legumes are fixing N actively (Trenbath, 1976). If N fixation is inhibited, the legume behaves like other crop species and competes for soil N actively (Ofori and Stern, 1987). Wahua (1983) found that management of crop growth stages played an important role in N competition. He concluded that, when corn and sorghum (*Sorghum* spp.) had simultaneous maximum N demands, yields of both crops were reduced dras-

tically. Ofori and Stern (1987) suggested that intercropping non-legumes with legumes increased the N fixation of the legume component. Their results suggested that non-legume components had a competitive advantage for soil N that forced legume components to maximize their biological N-fixing capabilities. They contend that legumes generally take a subordinate role in legume-cereal intercroppings.

Relay-intercropping systems

One way to reduce competition for limited water and mineral nutrients is to plant crops at different times of the growing season in a relay-intercropping system (Andrews and Kassam, 1976). Vegetable crop components planted first must have a competitive advantage over younger secondary cover crop components. This results in a reduced growth pattern for the crop planted later in the season. Willey (1979a) suggested that the main way to achieve complementarity, or cooperation, between crop components is to develop crop growth patterns so that each crop exerts its major demands on resource use at different times in the growing season. Competition, therefore, can be controlled through adjusting the time when each crop has reached its maximum demand for water and nutrients. Baker and Yusuf (1976) compared yield increases in cereal mixtures to differences in date of maturity, and estimated that no advantage could be gained unless the temporal difference in cereal maturity exceeded 30 to 40 days.

In addition, dominant and suppressed crops can develop under differentially planted intercropping systems (Huxley and Maingu, 1978). This relationship actually may be used to an advantage in intercropping systems that use legumes as a nurse crop for N fixation (Gliessman, 1985). Interseeding legumes with indeterminate growth patterns into a main crop may suppress legume growth initially, but also may exhibit a greater ability to contribute N to the system. Indeterminate legume species have a longer growing season and tend to partition less total N to reproductive activities than legumes with determinate growth patterns (Eaglesham et al., 1982). These results suggest that proper sowing time of indeterminate legumes into transplanted vegetable crops may be one

way to develop beneficial plant interactions in intercropping systems.

Conclusions

The adoption of intercropping systems has a number of potential advantages and disadvantages that are often site- and crop-specific. Intercropping can be a more-efficient means of exploiting the resources required for plant growth. Relay-planting crop components so that resource demands occur during different periods of the growing season can be an effective means of minimizing interspecific competition. Yet, little is known about root interactions in individual intercropping systems, which makes it difficult to predict yields, use of resources, or biological interactions for a given system. The effect of intercropping on insect, nematode, disease, and weed problems is site-specific and difficult to predict and, therefore, must be evaluated for each new intercropping combination.

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