A Review on the Comparative Advantage of Intercropping Systems

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Abstract
Mono-cropping style production has significant problems and that there exists a sufficient justification for studying intercropping approaches. Consequently, researchers have proposed general categories of benefits and utilities of intercropping. Benefits of intercropping are crop yield, productivity of various plant constituents, economic return, yield stability, social benefits, pest control, and fertilizer use efficiency. The most important advantage of intercropping systems includes both tall and short plant components for their potential complementarity in sunlight utilization for crop production. Because of these advantages intercropping is practiced in many parts of the world. Furthermore, because of some favorable exudates from the component legumes, greater land-use efficiency, greater yield stability and increased competitive ability towards weed, intercropping is advantageous over mono-cropping. This review summarizes the most important aspects of intercropping system comparative to mono-cropping system. The objectives of this review are therefore, (1) to assess the available literatures on the intercropping systems so as to indicate the system as an optional cropping system where it is required accordingly, (2) to show the scientific justifications on the advantages and disadvantages of the system in an attempt to provide the comparative advantages over the mono-cropping system for selection and its influence on food security and the economy of a country especially where there is no a problem of labor, and (3) to indicate as the system can allow more efficient uses of on farm resources like water in order to enable sustainable crop production for a nation.
Keywords: competition, complementarity, intercropping, mono-cropping

Introduction

Intercropping is the growing of two or more crops simultaneously on the same field such that the period of overlap is long enough to include the vegetative stage (Gomez and Gomez, 1983). Intercropping, double cropping and other mixed cropping practices that allow more efficient uses of on farm resources are among the agricultural practices associated with sustainable crop production (NRC, 1993; Tolera, 2003).

Intercropping provides year-round ground cover, or at least for a longer period than monocultures, in order to protect the soil from desiccation and erosion. By growing more than one crop at a time in the same field, farmers maximize water use efficiency, maintain soil fertility, and minimize soil erosion, which are the serious drawbacks of mono-cropping (Hoshikawa, 1991). It also reduces seasonal work peaks as a result of the different planting and harvesting times of intercropping crops. Moreover, it could serve to increase output per unit area, particularly with low levels of external inputs since a mix of species makes better use of available nutrients and water in the soil (Kotschi *et al.,* 1986).

Numerous researchers cover the theory and mechanisms of yield stability in intercropping. Willey (1979a) clearly and evidently proposed that intercropping gives higher yields in a given season and greater stability of yields in different seasons compared with sole cropping. Moreover, Mead and Willey (1980) stated in detail that in intercropping systems, yields are more stable. Its relation to yield stability is the notion of risk, in terms of either productivity or income or both. Beets (1982) thought that crop insurance was a major principle of intercropping in that if environmental factors change, some of the intercrop does well when others do poorly. He thought that for intercropping to be risk advantageous, the components of the crop association needed to have different environmental requirements or contrasting habits. Clawson (1985) concluded that traditional farmers cultivate a great variety of crops in order to maximize harvest security. This included intra species diversity such as different colors of maize with different maturation times. Wolfe (1985) reported that grain mixtures can generally provide a better guarantee of high yield than a priori choice of a single best variety, largely due to the unpredictability of the growing season.

For most polyculturaliest, either first or third world, a production goal is income; just as productivity is determined by environment of ecological and technical factors; income is governed by a wide array of psychological, cultural, input, costs and market factors (Geno and Geno, 2001); polyculturaliests, seeking both subsistence and market income make clear and repeated choices to avoid risk and income variability.

Besides the benefit of yield and income, intercropping can be seen to produce social benefits to both the land-holder and the surrounding community (Geno and Geno, 2001). Bradfield (1986) noted that updating traditional intercropping practices (as opposed to promoting monocultures) offers the potential of scale specific technologies that favor the small farmer. Addressing the question of equity, Willey (1981) found that the advantages of multiple cropping, that the benefits are achieved not by means of costly inputs but by the simple suitability of growing crops together. Thus intercropping offers a very genuine way in which the poorer or smaller farmer can benefit at least as much as the better return one. Similarly, Jodha (1981) noted that research reveals its potential for greater employment. Because intercropping is often a system used on small farms, any breakthrough in intercropping technology will help poor farmers more than the rich, thus better serving equity goals.

Features of Intercropping System

A yield advantage of intercropping can be indicated by using different methods, among which Land Equivalent Ratio (LER) is the most commonly used to indicate the biological efficiency and yield per unit area of land as compared to mono-cropping system; an LER greater than 1.0 implies that for that particular crop combination, intercropping yielded more than growing the same number of stands of each crop as sole crops. An LER of less than 1.0 implies that intercropping was less beneficial than sole cropping (Onwueme and Sinha, 1991). In a study that was conducted in the field at Kenya Agriculture Research Institute Njoro, Kenya, in both years (2004 and 2006) of the study, land equivalent ratio was >1 in all the intercropping systems (tomato/maize, tomato/kale and tomato/onion) (Ramkat *et al*., 2008).

Resource use efficiency in intercropping

Increased crop production (over-yielding) often observed in intercrops compared to sole crops has been attributed to enhanced resource use (Szumigalski and Van-Acker, 2008). Francis (1986) and Sivakumar (1993) also reported that efficient and complete use of growth resources such as solar energy, soil nutrients and water is one of the advantages of intercropping system over sole crops. Intercrops are most productive when their component crops differ greatly in growth duration so that their maximum requirement for growth resources occur at different times (Fukai and Trenbath, 1993). Baker (1975) and Anitha *et al*. (2001) reported that to have yield advantages in intercropping system, there should be minimum of 25 percent difference in duration of crops. For high intercrop productivity, plants of the early maturing component should grow with little interference from the late maturing crop. The latter may be affected by the associated crop, but a long time period for further growth after the harvest of the first crop should ensure good recovery and full use of available resources (Fukai and Trenbath, 1993). Intercropping allows effective utilization of growth resources through crop intensification both in space and time dimensions. The conventional ways of intensifying crop production are vertical and horizontal expansions. Intercropping offers two additional dimensions, time and space (Francis, 1986a). The intensification of land and resource use in space dimension is an important aspect of intercropping. For example, enhanced and efficient use of light is possible with two or more species that occupy the same land during a significant part of the growing season and have different pattern of foliage display. Different rooting patterns can explore a greater total soil volume because of the roots being at different depths (Francis, 1986a). These differences in foliage display and rooting patterns create the space dimension of intercropping.

Another important feature is a difference in time of maturity and hence in nutrient demand among different species in intercropping which will create the time dimension of the system. The difference in time dimension will lead to efficient utilization of resources by lessening competition among the intercrop components (Trenbath, 1986). Intercropping crop species with similar growth duration produces an advantage in the utilization of space only, whereas the association of crops with different growth durations results in a gain in total yields through better utilization of two dimensions, space and time (Liebman, 1995). The ability of intercrops to intensify resource use both in space and time dimension makes greater total use of available growth resources than mono cropping (Francis, 1986a). Intercropping increased the amount of solar radiation intercepted due to faster canopy cover, which lead to efficient utilization of light resources (Ramakrishna and Ong, 1994). Keating and Carberry (1993) also stated that intercropping offers the advantage of efficient interception and utilization of solar radiation than mono cropping. Improved productivity per unit incident radiation could be achieved by the adoption of an intercropping system that either increase the interception of solar radiation and/or had greater radiation use efficiency. Minimizing the proportion of radiation energy reaching the ground is a simple means of promoting efficient utilization of incident solar radiation (Ramakrishna and Ong, 1994). Advantages from intercropping of short and long duration species is due to enhanced radiation capture over time. Improved utilization of radiation energy resulted in more efficient production of biomass or increased proportion of biomass partitioned to yield.

Nutrient use efficiency of the individual crops in an intercrop is mostly lower than their respective sole crops. However, the cumulative nutrient use efficiency of an intercropping system was in most cases higher than either of the sole crops (Chowdhury and Rosario, 1994). Solar radiation, water and some nutrients would be wasted during early growth stages of long-term crops, but they can be utilized by an associated crop growing between the rows (Midmore, 1993). They reported that in maize/mung bean intercropping the nutrient absorption by both maize and mung bean was reduced due to intercropping, mung bean being more affected than maize.

Similarly, higher land equivalent ratio over unity was largely done to a higher total uptake of nutrients by the component crops in the mixture than the sole crops. Chowdhury and Rosario (1994) also reported greater efficiency of intercrops than that of the sole crops in converting absorbed nutrients to seeds/grains also contributed to the yield advantage. Morris and Garrity (1993) reported that on average intercrops took up 43% more phosphorus and 35% more potassium than the sole crops. The larger and longer duration of functional root systems under intercrops than either sole crop were postulated by researchers for the greater capture of non-mobile nutrients like phosphorus and potassium. Enlarged root systems provided an expanded root surface area to which non-mobile nutrients diffused (Morris and Garrity, 1993).

Interactions in intercropping

Competition and complementarities are the two most important interactions in intercropping. Willey (1979a) suggested three broad categories of competitive relationships in intercropping: 1) when the actual yield of each species is less than expected, termed mutual inhibition, 2) where the yield of each species is greater than expected (mutualism); and 3) the most common situation, where one species yields less than expected and the other more; termed compensation. Complementarity is a key feature of intercrops and natural vegetation. According to Willey (1979a), yield advantage in multiple cropping occurs when component crops differ in their use of growth resources in such a way that when they are grown in combination they are better able to complement each other and so make better overall use of resources than when grown separately in terms of competition. The component crops are not competing for exactly the same resources (in space or time) and intercrop competition is less than intracrop competition.

Temporal and spatial complementarities can be differentiated from one another (Willey 1979a). In temporal complementarities, growth patterns differ in time (typically at least 30-40 days maturity difference); crops use water at different times, particularly where the system is moisture limited. It involves a time displacement that results in the capture of more resources by the intercrop rather than a change in the efficiency of utilization. Spatial complementarity is the combined leaf canopy or root system of an intercrop that makes better use of available resources when grown together, such as total light interception, water and nutrient uptake because component crops exploit different soil layers or canopy heights in intercropping. Component crops differ in their nutrient requirements, the form of nutrients which they can readily exploit and their ability to extract them from the soil. One crop exploits a greater volume of soil. Where the total quantities of resource captured is relatively similar, the efficiency of utilization of the resources captured is increased in intercrops compared to the sole crops.

Willey (1979a) concluded that the greater the difference in maturity and growth factor demands of the crop components either because of genetic difference or manipulation of planting dates, the more opportunity for greater total exploitation of growth factors and subsequent over-yielding. In another report, Willey (1979b) concluded that better use of growth resources as a result of complementary effects between component crops is the major sources of yield advantage.

Physiological complementarity can occur in polycultures composed of species that use C_4 and C_3 photosynthetic pathways (Geno and Geno, 2001), and this is illustrated by the earlier North Carolina example of maize, a C_4 type plant that is better adapted to high light environments. Of course, the most common example of physiological complementarity is fixation of nitrogen by legume components, meaning that soil nitrogen is available for neighboring non-legumes. Vandermeer (1989) reported on a 1985 experiment that demonstrated not only the direct transfer of nitrogen from soybean to maize, but also that the transfer was mediated through Vesicular Arbuscular Mycorrhiza (VAM) fungi associated with their roots. He also reported in a 1982 study that phosphorous was actually transferred from one species to another through mycorrizal connections. Resource partitioning in plants may change when they are grown in polycultures where greater percentages of total dry matter and nutrients are allocated to harvestable portions of crops. In this case, each unit of captured energy and nutrients results in a greater benefit to the farmer in polycultures than monocultures. For example, in arid Africa, pigeon pea grown in monoculture produces 19% of its total above ground weight as edible seed, but 32% when grown in mixtures with sorghum. Indeed, African researchers have found that increases in allocation ratios for sorghum, millet, and groundnut that occurred when they grew in polycultures were most marked under drought conditions (Willey 1985). These phenomena are likely explained by the typical stress response of many plants to divert resources to reproduction as a response to competitive or environmental pressure.

Plants compete in all dimensions of the environment, for space for light interception to rooting depth for water and nutrient uptake. Competition often occurs along with complementarity (Geno and Geno, 2001). Interspecies competition is an interaction between two species that reduces the fitness of one or both of them; and the interspecies interactions, including above and belowground competition and facilitation, play an important role in determining the structure and dynamics of plant communities in agriculture (Aerts, 1999).

As already mentioned, intercropping has some benefits in terms of a better use of the available resources (land, light, water and nutrients), and a reduction in crop disorders. It is assumed that the same mechanisms favoring increased water uptake are involved: greater root concentrations or complementary exploration of the soil profile. Intercropping of plants with different rooting patterns permits greater exploitation of a larger volume of soil and improves access to relatively immobile nutrients. As a result, intercropped plants tend to absorb more nutrients than those in monocultures (Horwith, 1985). In the case of tomato/maize intercropping, tomato may absorb nutrients and water from deeper soil profiles than maize as it has deeper rooted system, whereas maize could be satisfied from the shallower soil zones as its root system is fibrous type. Lorenz and Maynard (1988) grouped cauliflower, corn, lettuce, potato, radish and spinach in shallow rooted (45-60 cm), eggplant, pea and turnip in moderately deep (90-120 cm) and only tomato into deep rooted (more than 120 cm).

Plant population in intercropping

Plant population is the number of plants per unit area, and it would be useful to know optimum or critical population densities to avoid population as limiting factor for crop yield. Establishing of the plant population ensures that the crop produced is of acceptable quality (Balasubramaniyan and Palaniappan, 2001). The authors further stated that plant population depends on type and growth habit of crops, soil fertility, rainfall and other growth requirements. There is negative effect of very high population density particularly in branching crops due to competition for sun light under dense situation (Balasubramaniyan and Palaniappan, 2001).

According to Willey (1979b), intercropping gives a yield advantage when the total plant density is higher than that of either of the sole crops. Tilahun (2002) also reported yield increment as total population of maize and faba bean were increased from 75% and 25% to 100% and 75% of maize and faba bean recommended sole population, respectively. Willey (1979b) and Natarajan (1990) showed through example as the proportion of component population and total populations of intercrops in relation to the sole crops should be expressed in relative terms; for example, if they are taken as 100 each, a simple intercropping system having half of the sole crop optimum of each component are considered to have 50:50 component population and total population pressure as 100.

In terms of total population pressure, two broad classes of intercropping systems can be distinguished (Geno and Geno, 2001). One is substitutive or replacement series of intercropping in which proportional populations are related to sole crop of the series and whatever the population is added the two proportions must always add up to 100%. The second is additive or superimposed intercropping in which one component crop is added to the other so that the final plant population is generally more than either crops sown sole. Substitutive intercropping generally consists of crops from the same phenological group and the yield gain in such mixture is from a simple response to reduced population because of complementary in space and to some extent to time or both. The challenge comes in knowing how much to be substituted to optimize the yield (Sullivan, 2003). Additive refers to a situation where the component crops are plastic enough to take advantage of their lower plant population in intercrop and when specific objectives of the farmers is a particular proportion of the product which consists of crops from different phenological groups (Cannell, 1983).

While combinations of some crops are grown in association at full stands it could be impractical to plant them together (Geno and Geno, 2001). So, staggering by delaying early planting and growth of the dominant crop in mixture or by synchronizing harvest of the dominant crop at critical development stage of dominated (understorey) will permit planting of full crop stand of component crops. Both systems are subjected to confounding effects of environmental and genetic factors that influence the onset or release of competition, particularly for the light (Midmore *et al*., 1988), but this does not inevitably lead to yield advantage over simultaneous sowing (Ofori and Stem, 1987).

The other option is reduction of component population. Pal *et al.* (1993) in sorghum or maize and soybean intercropping, recommended sorghum or maize to be planted at optimum population of sorghum or maize and the soybean to be planted at 1/3 of its optimum population for maximum productivity and land use efficiency. Densities may vary in intercropped fields depending on growth habit and competitiveness of intercropped plants. There will be a competition for space and resources between crops and the spacing of the crops will be a variable which will affect the yields. Basically there are two different designs: the substitutive and the additive. In the additive design seeding rates for each crop is kept, as they are in monoculture, while in the substitutive design the seeding rate of each crop in the mixture is adjusted below its full rate; the rationale is that if full rates of each crop were planted, neither would yield well because of intense overcrowding. By reducing the seeding rates of each, the crops have a chance to yield well within the mixture. The challenge comes in knowing how much to reduce the seeding rates. That is why designing of different treatment combination required to reach on the better ones based on their yield returns.

Many vegetation and yield variables are potentially influenced by the competition of the plant with a second crop in an intercrop system and by competition with other plants of the same species in monocrop systems, and this influence may be affected by changes in plant population density (Fortin *et al*., 1994). The structure of plant vegetation and its geometric elements combined with the total amount of leaf area determine the distribution of light within the canopy (Geno and Geno, 2001). Zahara (1970) stated that production of sunburn and sunscald cull fruits of tomato was increased with the increase in space between plants. Therefore, intercropping optimum population of tomato with maize will be essential to maximize both quality and quantity of the yield of both component crops per unit area of land.

The benefits of intercropping

Modification of microclimate

The emphasis of much previous work on intercropping temperate crops in the tropics was mainly on soil microclimate characterization and not on within-canopy microclimate. In the tropics, where capital can be one of the major constraints in agricultural production, microclimate modifications that require high inputs such as the use of synthetic shade materials are not feasible (Jaya *et al*., 2001); microclimate modification by cheap and simple means, such as intercropping might be acceptable as well as affordable. Maize is one of the row crops often selected for intercropping to provide shelter to understory crops because of its wide adaptation over a range of climates.

Light interception and radiation use efficiency

Willey (1979a) thought that light was the most important factor and noted that it was different from other growth resources in that it is only instantaneously available and thus must be instantaneously intercepted to be of benefit while other resources are typically pools awaiting plant exploitation. It has been suggested that light transmission through the canopy is affected by row orientation in addition to plant population density (Jaya *et al.,* 2001). They further showed that maize planted at medium density (7.1 plant m^{-2}) with N-S orientation reduced within-canopy maximum temperatures at 40 cm above the ground by 1.2^{o}C. The temperature reduction was associated with a reduction of irradiance up to 70%; the reduction, especially in temperature, was highly sensitive to row orientation and plant density and at some combinations resulted in increased temperature. For cauliflower-maize intercropping in the lowland tropics, a plant density of 7 plants m^{-2} at N-S orientation was found to be promising with an irradiance of above 300 Wm^{-2} at midday about 5 weeks after sowing (Jaya *et al.,* 2001). It was also indicated that this must be coordinated with the development of the cauliflower so that curd initiation takes place at this time; early growth of the cauliflowers will take place in higher irradiances to ensure sufficient carbohydrate supply.

Kinet and Peet (1997) showed that the light factor can be both positive and negative on the growth of tomato. High light intensity tends to accelerate flowering in many cultivars of tomato, whereas low light intensity limits vegetative growth and may also delay flowering. Tomatoes grown in protective structures often are provided with supplemental light when intensity is low and day lengths are short but in the tropical lowlands rather there is a high intensity; so intercropping can maintain yield potential of tomato by reducing the extreme light condition and fluctuation of temperatures that affect yield in the hot dry season periods.

Light interception and light use efficiency are powerful concepts for characterizing the resource capture and use efficiency of cropping systems, including intercrops. Improved productivity can result from either greater interception of solar radiation, higher light use efficiency, or a combination of the two (Willey, 1990). Light interception as a result of mixing two species and growing them together instead of alone is sometimes increased, either as a result of a lengthening of the period of soil coverage (temporal advantage), or as a result of a more complete soil cover (spatial advantage) (Keating and Carberry, 1993). When total crop densities are higher in intercrops, they can intercept more light especially early in the growing season. Intercrops composed of non-synchronous patterns of canopy development and different maturation times can display a greater amount of leaf area over the course of the growing season and intercept more total light energy than monocultures. Carandang (1980) thought that intercrops allow maximum utilization of sunlight by increasing light interception by 30-40%.

Temperature dynamics

There have been many studies on the effects of adverse temperatures on reproductive development of tomato at both low and high temperatures. The critical period appears to be 3-6 and 12-14 days before anthesis (Kinet and Peet, 1997) for low temperature and 9 days before anthesis for high temperature effects. Low temperatures reduce pollen production, shed, viability and tube growth (Fernandez-Munoz *et al*., 1995). Kinet and Peet (1997) concluded that at high temperatures, flower formation, pollen grain and ovule formation, style elongation, pollen germination, fertilization and seed formation are all adversely affected. High temperature may also reduce sources strength of susceptible plants. Export of assimilated carbon from a tomato leaf was reduced under high temperature regimes (Kinet and Peet, 1997). The degree of injury to the fruit depends on irradiance, spectral quality, temperature and treatment duration (Adegoroye and Jolliffe, 1983). If temperatures are over 30 ^{0}C, but under 40 ^{0}C, the area straps yellow (Grierson and Kader, 1986) because temperature above 30 ^{0}C prevents lycopen formation (Kinet and Peet, 1997). This condition will be controlled by intercropping as the practice modifies the climate within the canopy.

Typical causes of poor fruit set in the field or greenhouse are too high or too low temperature or humidity; low light and winds. For example, (Kinet and Peet, 1997) showed that day temperature over 32 ^{0}C and night temperature over 21 ^{0}C reduce fruit set. Temperature has profound effects on many growth and development processes in tomato, including leaf growth, photosynthesis and respiration, fruit development and fruit quality (Braden and Smith, 2004). Low temperatures during the seedling phase slow down growth and development (Kinet and Peet, 1997). Therefore, as intercropping modifies the extreme temperatures both in air and in soil, it can be used to improve yield of tomato during the off season cultivation. Farrell and Altieri (1995) elaborated on the microclimate benefits of intercropping characteristics: microclimate within canopy can moderates temperature extremes, lower temperatures and reduced air movement leads to less evaporation and increased relative humidity versus open sites.

Canopy and relative humidity

Intercropping composed of different patterns of canopy development and different maturation times can display a greater amount of leaf area over the course of the growing season and intercept more total light energy than monocultures. Where polycultures produce earlier or later canopy, evaporation of soil moisture is reduced, weeds suffer from light and moisture competition, and there is decreased rain impact erosion through canopy filtering and greater root structures. Wilson and Ludlow (1991) reported soil temperatures up to 10 ^{0}C cooler on forage under tree plantations in the tropics, assisting seedling survival, soil-water relations and possibly affecting the rate of litter breakdown and nitrogen mineralization.

Soil moisture and nutrient use

Another important reason for intercropping is the improvement and maintenance of soil fertility. This is reached when a cereal crop (such as maize or sorghum) or a tuber crop (such as cassava) is grown in association with a pulse (beans, peas, *etc.*) (Geno and Geno, 2001). They also reported that deep-rooting pulse crops, such as pigeon pea, also take up nutrients from deeper soil layers; thereby recycle nutrients leached from the surface. Legumes also grow well in soils low in phosphate (Geno and Geno, 2001); after the intercrop is harvested, decaying roots and fallen leaves provide nitrogen and other nutrients for the next crop. This residual effect of the pulse crop on the next crop is largest when the remains of the pulse are left on the field and ploughed under after harvest. However, when a large amount of nitrogen is removed in the grain harvest, more nitrogen is removed from the field than fixed by the pulse crop (Geno and Geno, 2001). Thus soil depletion can still occur in a grain-pulse intercrop when the nutrients taken up by the crops are not replaced with manure or fertilizers (Giller, 2001). In intercropping, nitrogen fixation by the legume is not enough to maintain soil fertility. A basal fertilizer is generally needed for both the cereal and the legume. Fertilizers are more efficiently used in an intercropping system, due to the increased amount of humus and the different rooting systems of the crops, as well as differences in the amount of nutrients taken up.

Experimental evidence showed that plant interactions below ground are normally more intense than those above ground and competition may limit uptake. According to Snaydon and Harris (1981) nutrients often occur in specific zones of the soil due to particular environmental conditions (*i.e.* leaching), management practices (*i.e.* surface applied phosphates), or nutrient solubility. Parallel to these differences, and often partially in response to them, there are differences in root distribution patterns between plants and throughout the soil profile. The authors, further indicated as roots can also use soil resources differently: In the way that the nutrient requirement is satisfied (legumes use N, non-legumes use NO^-_3 or NH^+_4). Different species may differ in their requirement for a resource. There are fourfold difference between species for calcium concentration, twofold for potassium and phosphate and threefold difference for nitrogen concentration.

Water use efficiency is also another importance of intercropping system. Dunn *et al*. (1999) suggested greater water resource capture was essential to solving environmental water leakage. They reported that Lucerne in rotation with wheat crops helped through summer uptake from a rooting depth double that of wheat. However, they caution that too much water use too quickly can jeopardize persistence and note the case of blue gum plantations in south Western Australia where loss of growth rate midterm in the rotation and ultimate death of the plantation is common, due to the need for carryover of soil water to maintain root infrastructure.

Pest management

Yield advantage of intercropping is also common to reduce pests of crops. For example, insect and diseases are less when tomato was intercropped with maize (Pino *et al.,* 1994). High densities of *Frankliniella occidentals* occur on capsicum but not in tomato, *Myzus persiceae* also found in larger numbers on capsicum but was only in dry colonies on tomato when sweet pepper was intercropped with tomato (Nihoul *et al.,* 1994). Tomato had an autotoxic effect. The aqueous extract significantly inhibited the growth of cucumber, radish, lettuce (Zhou *et al*., 1997). Tomato intercropped in Chinese chive or along with or without inoculation of *Pseudomonas* *solanacearum*. Chinese chive had on detrimental effect on the growth and suppressed the occurrence of bacterial wilt of tomato (Yu, 1999). Intercropping tomato with cowpea significantly reduced bacterial wilt compared with tomato alone (Michal *et al*., 1997). Heavy infestation of *Semisia tabaci* and *Aphis gossypii* was recorded when tomato was intercropped with maize (Plana *et al.,* 1995). Significantly reduced incidence of diamond back moth (*Plutella xylostella*) was observed when cauliflowers were planted 30 days after the tomato (Kandoria *et al.,* 1999). Greatest infestation (5.6%) of tomato fruit borer, (*Helicoverpa armigera*) was recorded when intercropped with snap beans. It was, however, lowest (3.4%) when intercropped with radishes. Total tomato fruit borer infestation ranged from 17.0 percent in radishes as an intercrop to 28.2 percent where snap beans were intercropped (Patil *et al*., 1997).

Gomez-Rodriguez *et al.,* (2003) evaluated the effect of marigold intercropped with tomato (*Lycopersicon esculentum* Mill.) on *Alternaria solani* conidia germination, on conidial density and tomato leaf damage, as well as microclimatic changes, compared to tomato intercropped with pigweed (*Amaranthus hypochondriacus* L.) and mono-cropped tomato. They found that intercropping with marigold induced a significant reduction in tomato early blight caused by *A. solani*, by means of three different mechanisms. One was the allelopathic effect of marigold on *A. solani* conidia germination; while pigweed did not have any of this inhibitory effect in conidia germination. The second way was by altering the microclimatic conditions around the canopy, particularly by reducing the number of hours per day with relative humidity ≥ 92%, thus diminishing conidial development. The third mechanism was to provide a physical barrier against conidia spreading. When intercropped with tomato, pigweed plants worked also as a physical barrier and promoted reductions in the maximum relative humidity surrounding the canopy, but to a lesser extent than marigold. Therefore, tomato intercropping is a common practice in different countries of the world for different purposes that all contribute to the yield increment either directly or indirectly as discussed above.

Like other pests, weeds become a problem when they increase in number or size to the detriment of the crop. Of several advantages that intercropping systems can have, over monoculture systems, its weed growth reduction is the most important. Liebman and Dyck (1993) indicated that weed population density and biomass production may be markedly reduced using intercropping (spatial diversification). Intercrops may demonstrate weed control advantages over sole crops in two ways. First, greater crop yield and less weed growth may be achieved if intercrops are more effective than sole crops in usurping resources from weeds or by suppressing weed growth through alleopathy. Alternatively, intercrops may provide yield advantages without suppressing weed growth if intercrops use resources that are not exploitable by weeds or convert resources to harvestable material more efficiently than sole crops (Geno and Geno, 2001).

Alleopathic interactions can occur between weeds, between weeds and crops, or between crops. Alleopathy is different from other interspecies competition in that the detrimental effect is not through direct competition for nutrients or space but is exerted through release of a chemical by one component. Many crops produce alleopathic chemicals. Barnes and Putnam (1983) reported that for pea growing in temperate climates, rye grain is often used as a fallow season green manure crop, largely for cover and organic matter benefits. Spring planted living rye reduced weed biomass by 94% over plots without rye. Residues of fall planted, spring killed rye reduced weed biomass over bare ground controls. In greenhouse studies, rye root leachates reduced tomato dry weight by 25-30%, further indicating the alleopathic properties of rye and its utility as an alleopathic cover crop, tilled or chemically killed. In this case, the rye residues appear to suppress total weed growth, but not weed germination, or the growth and yield of the peas.

Einhellig and Leather's (1988) study of cultivated sunflower, a known alleopathic crop, found no differences in weed biomass between plots with and without herbicide applications (Geno and Geno, 2001). Not only can crop affect other crops and weeds by alleopathic chemicals, but they can be autotoxic as in tomato, pigeon pea, lucerne and red clover. Many of these interactions can occur with plant residues as well as during the life of the plant.

Unlike intercrop principles that seem to apply more to traditional gardens than modern farming, alleopathy has immediate application even in industrial monocultures as per the sunflower example above (Geno and Geno, 2001). For example, oats are known to be alleopathic. Lanini *et al*. (1992) found that during lucerne stand establishment, an oat companion crop, seeded either in rows or broadcast together, helped fight weeds and increased first-cut forage yield without negative impacts on lucerne production (at appropriate density). It proved economical and an effective alternative to chemical weed control in seedling lucerne. Oat replaces weeds in the first cutting and total forage yields were increased. Similarly, Cheema *et al*. (2000) reported in the utility of a practice of spraying an alleopathic water extract of mature sorghum and as surface or incorporated mulch on weed control in irrigated wheat in India. Weed control was 35-50% higher and yield increased 10-21%. The most effective treatment of two foliar sprays at 30 and 60 days from planting produced an incredible marginal rate of return of 535%.

Intercrops can have a range of effects on weeds beyond alleopathy. Liebman (1995) catalogued numerous mechanisms that resulted in fewer weeds, higher yield, fertility enhancement and favorable environmental impact. This is through elimination of herbicides or hand weeding, earlier and fuller canopy, erosion protection from heavy rain or running water or through a general theory of greater preventative use of resources that are then not available for weed growth. In a study of intercropped wheat and beans in England, Bulson (1994) found that while both intercrops, either spring or winter cropped, produced higher yields and suppressed weeds, total removal of weeds did not significantly increase the yield of either intercrops or sole crops.

Accordance to the study result of Girma *et al.* (2005), under Melkassa Agricultural Research Center, Ethiopia, the Orobanche (parasitic weed) shoot count was significantly reduced for tomato/maize and tomato/common bean intercropping plots as trap cropped than the check (sole tomato) plot and tomato yield was increased as a result of reduction of Orobanche shoot count; and they recommended that potential trap crops may be the cheapest means of controlling Orobanche parasitic weeds in tomato production; and also concluded that optimum control of parasitic weeds by means of trap crops is by far the most economical method to be practiced by small-scale commercial farmers of vegetable growers in the Central Rift Valley of Ethiopia.

Therefore, as many researchers indicated, the main objective of intercropping has been to increase maximize use of resources such as space, light and nutrients (Ndakidemi, 2006), as well as to improve crop quality and quantity (Mpairwe *et al*., 2002). Other benefits include water quality control through minimal use of inorganic nitrogen fertilizers that pollute the environment (Crew and Peoples, 2004). The current trend in global agriculture is to search for highly productive, sustainable and environmentally friendly cropping systems (Crew and Peoples, 2004). This has resulted into renewed interest in cropping systems research (Vandermeer, 1989).

Disadvantages in intercropping

There are, however, some disadvantages in intercropping systems. These includes yield reduction of the main crop, loss of productivity during drought periods, and high labor inputs in regions where labor is scarce and expensive (Gliessman, 1985). It is well documented that in most cases the main crop in an intercropping system will not reach as high a yield as in a monoculture, because there is competition among intercropped plants for light, soil nutrients and water (Willey, 1979b). This yield reduction may be economically significant if the main crop has a high market price than the other intercropped plants.

Another disadvantage that is likely to be occurring is the higher cost of maintenance, in particular, weeding, which may have to be done by hand. This is not a serious problem in countries where excess farm labor is cheap, for example, Ethiopia; but for countries lacking such a labor force, intercropping will result in increased costs. Furthermore, harvesting of one crop may cause damage to the other (Gliessman, 1985). Finally, the intercropped canopy cover may result in a microclimate with a higher relative humidity conducive to disease outbreak, especially of fungal pathogens (Gliessman, 1985).

Conclusions

As a general conclusion, through intercropping, farmers can achieve the full production of the main crop and also an additional yield (bonus) associated with an increased plant population of the second component. Hence, intercropping can increase incomes obtained by smallholder farmers in areas where labor is not shortage, like sub Saharan Africa, through reduction of economic risk and market fluctuation resulting from growing a single crop which is more prone to natural hazards and helping the farmers in better utilization of land by having more than one crop produced per unit area. Though all intercrops produced higher productivity, the farmers could better use the appropriate population of component crops in intercropping systems in order to maximize yield of both crops as well as total productivity.

It is, therefore, important to support intercropping systems with appropriate agronomic practices such as timely irrigation, pest protection and the likes to sustain the cropping system in the sub Saharan Africa in particular and in the countries where labor is not problem for proper management in general even though sometimes sole cropping may became more productive.

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