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Review article

Annual intercrops: an alternative pathway for sustainable agriculture

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Abstract

Intercropping, the agricultural practice of cultivating two or more crops in the same space at the same time, is an old and commonly used cropping practice which aims to match efficiently crop demands to the available growth resources and labor. The most common advantage of intercropping is the production of greater yield on a given piece of land by making more efficient use of the available growth resources using a mixture of crops of different rooting ability, canopy structure, height, and nutrient requirements based on the complementary utilization of growth resources by the component crops. Moreover, intercropping improves soil fertility through biological nitrogen fixation with the use of legumes, increases soil conservation through greater ground cover than sole cropping, and provides better lodging resistance for crops susceptible to lodging than when grown in monoculture. Intercrops often reduce pest incidence and improve forage quality by increasing crude protein yield of forage. Intercropping provides insurance against crop failure or against unstable market prices for a given commodity, especially in areas subject to extreme weather conditions such as frost, drought, and flood. Thus, it offers greater financial stability than sole cropping, which makes the system particularly suitable for labor-intensive small farms. Besides, intercropping allows lower inputs through reduced fertilizer and pesticide requirements, thus minimizing environmental impacts of agriculture. However, intercropping has some disadvantages such as the selection of the appropriate crop species and the appropriate sowing densities, including extra work in preparing and planting the seed mixture and also extra work during crop management practices, including harvest. The selection of an appropriate intercropping system for each case is quite complex as the success of intercropping systems depend much on the interactions between the component species, the available management practices, and the environmental conditions. Plant breeding can contribute determinedly to increase of productivity of intercropping systems by investigating and exploiting the genetic variability to intercrop adaptation. This paper provides an overall view and evaluation of annual intercropping, summarizing its main advantages supported by a number of key examples from the literature which point out its great value in the context of sustainable agriculture.

Keywords: Agrobiodiversity, crop mixtures, monocultures, intercropping, sustainable agriculture.

Introduction

Self-sustaining, low-input, and energy-efficient agricultural systems in the context of sustainable agriculture have always been in the centre of attention of many farmers, researchers, and policy makers worldwide (Altieri et al., 1983; Altieri, 1999). However, most practices of modern agriculture, e.g. mechanization, monocultures, improved crop varieties, and heavy use of agrochemicals for fertilization and pest management, led to a simplification of the components of agricultural systems and to a loss of biodiversity. Restoring on-farm biodiversity through diversified farming systems that mimic nature is considered to be a key strategy for sustainable agriculture (Jackson et al., 2007; Scherr and McNeely, 2008). On-farm biodiversity, if correctly assembled in time and space, can lead to agroecosystems capable of maintaining their own soil fertility, regulating natural protection against pests, and sustaining productivity (Thrupp, 2002; Scherr and McNeely, 2008). Biodiversity in agroecosystems can be enhanced in time through crop rotations and sequences in space through cover crops, intercropping, and agroforestry (Altieri, 1999; Malézieux et al., 2009). While modern agriculture has brought vast increases in productivity to the world's farming systems, it is widely recognized that much of this may have come at the price of sustainability (Tilman et al., 2002; Lichtfouse et al., 2009). This is because modern farming systems imply the simplification of the structure of the environment over vast areas, replacing natural plant diversity with only a limited number of cultivated plants in extensive areas of arable monocultures (Vandermeer et al., 1998). By contrast, on-farm biodiversity is familiar to traditional farmers mainly in developing countries, where traditional farming systems are characterized by their great degree of genetic diversity in the form of mixed cropping and agroforestry patterns, based on numerous varieties of domesticated crop species as well as their wild relatives (Altieri, 1999). These farming systems offer a means of promoting diversity of diet and income, stability of production, reduced insect and disease incidence, efficient use of labor, intensification of production with limited resources, and also maximization of returns under low levels of technology (Anil et al., 1998; Malézieux et al., 2009). Intercropping, also referred to as mixed cropping or polyculture, is the agricultural practice of cultivating two or more crops in the same space at the same time (Andrews and Kassam, 1976; Ofori and Stern, 1987; Anil et al., 1998). The component crops of an intercropping system do not necessarily have to be sown at the same time nor they have to be harvested at the same time, but they should be grown simultaneously for a great part of their growth periods. In intercropping, there is normally one main crop and one or more added crop(s), with the main crop being of primary importance for economic or food production reasons. The two or more crops in an intercrop normally are from different species and different plant families, or less commonly they may be simply different varieties or cultivars of the same crop, such as mixing two or more kinds of wheat seed in the same field. The most common advantage of intercropping is to produce a greater yield on a given piece of land by achieving more efficient use of the available growth resources that would otherwise not be utilized by each single crop grown alone. There are many different kinds of species that can be used for intercropping such as annuals, e.g. cereals and legumes, perennials, including shrubs and trees, or a mixture of the two (annuals and perennials). In the case of shrubs and trees the term mostly used is agroforestry. The objective of this paper was to provide an overall view and evaluation of annual intercropping, summarizing its main advantages supported by a number of key examples from the published literature which point out its great value in the context of sustainable agriculture. The paper focuses exclusively on annual intercropping and not on agroforestry.

Intercropping worldwide

Traditional agriculture, as practiced through the centuries all around the world, has always included different forms of intercropping. In fact, many crops have been grown in association with one another for hundred years and crop mixtures probably represent some of the first farming systems practiced (Plucknett and Smith, 1986). Various types of intercropping were known and presumably employed in ancient Greece about 300 B.C. Theophrastus, among the greatest early Greek philosophers and natural scientists, notes that wheat, barley, and certain pulses could be planted at various times during the growing season often integrated with vines and olives, indicating knowledge of the use of intercropping (Papanastasis et al., 2004). Today, intercropping is commonly used in many tropical parts of the world particularly by small-scale traditional farmers (Altieri, 1991). Traditional multiple cropping systems are estimated to still provide as much as 15-20% of the world's food supply (Altieri, 1999). In Latin America, farmers grow 70-90% of their beans with maize, potatoes, and other crops, whereas maize is intercropped on 60% of the maize-growing areas of the region (Francis, 1986). Other quantitative evaluations suggest that 89% of cowpeas in Africa are intercropped, 90% of beans in Colombia are intercropped, and the total percentage of cropped land actually devoted to intercropping varies from a low 17% for India to a high of 94% in Malawi (Vandermeer, 1989). In the tropical regions, intercropping is mostly associated with food grain production, whereas in the temperate regions it is receiving much attention as a means of efficient forage production (Anil et al., 1998; Lithourgidis et al., 2006). Although intensive monocropping is much easier for large-scale farmers, who plant and harvest one crop on the same piece of land using machinery and inorganic fertilizers, small-scale farmers, who often do not have readily access to markets and grow enough food only to sustain themselves and their families, recognize that intercropping is one good way of ensuring their livelihood. Intercropping is a common practice in many areas of Africa as a part of traditional farming systems commonly implemented in the area due to declining land sizes and food security needs (Dakora, 1996). It is mostly practiced on small farms with limited production capacity due to lack of capital to acquire inputs. Features of an intercropping system can differ largely with soil conditions, local climate, economic situation, and preferences of the local community. Several crop species have been identified as suitable or unsuitable for intercropping. Local varieties, which have been selected over the years for this purpose, are used for intercropping. However, in the mechanized agricultural sector of Europe, North America, and some parts of Asia, intercropping is far less widespread. This is because modern agriculture has shifted the emphasis to a more market-related economy and this has tended to favour intensive monocropping systems (Horwith, 1985). Although agricultural research originally focused on sole cropping and ignored the potential of intercropping, there has been a gradual recognition of the value of this kind of cropping system. In fact, despite its advantages, the agricultural intensification in terms of plant breeding, mechanization, fertilizer and pesticide use experienced during the last 50 years has led to elimination of intercropping from many farming systems. However, intercropping has been shown to produce higher and more stable yields in a wide range of crop combinations, while the system is characterized by minimal use of inputs such as fertilizers and pesticides, emphasizing the production of healthy, safe, and high quality food in the context of environmentally sound production. For organic sector, intercropping is considered an effective means of self-regulation and resilience of the organic agroecosystems to meet environmental perturbations in the organic culture practice (Lammerts van Bueren et al., 2002). Organic farmers have practically no chemical tools to confront environmental fluctuations since according to the principles of organic agriculture and the European Union regulation 2092/91 agrochemicals are not allowed. Nowadays, organic farmers still depend mainly on modern varieties developed from conventional breeding programs (Murphy et al., 2007; Vlachostergios and Roupakias, 2008; Vlachostergios et al., 2010), but the majority of these varieties cannot face up efficiently problems as pest and fungus pathogens, weed competitiveness, or resource exploitation under organic farming systems (Wolfe et al., 2008; Lammerts van Bueren et al., 2003). On the contrary, intercropping offers effective weed suppression, pest and disease control, and use of soil resources under organic farming systems (Bulson et al., 1997; Theunissen, 1997; Jensen et al., 2005). The last decades, several organic farmers are experimenting and gradually adapt intercropping systems in order to benefit from the advantages of intercropping (Entz et al., 2001).

Types of intercropping (spatial and temporal patterns)

Several types of intercropping, all of which vary the temporal and spatial mixture to some degree, have been described (Andrews and Kassam, 1976). The degree of spatial and temporal overlap in the component crops can vary somewhat, but both requirements must be met for a cropping system to be an intercrop. Thus, there are several different modes of

Fig 1. Row intercropping, where two plant species are cultivated in separate alternate rows (corn with climbing bean)

intercropping, ranging from regular arrangements of the component crops to cases where the different the component crops are intermingled. In mixed intercropping, the plants are totally mixed in the available space without arrangement in distinct rows, whereas in alternate-row intercropping, two or more plant species are cultivated in separate alternate rows (Fig. 1). Another option is that of within-row intercropping, where the component crops are planted simultaneously within the same row in varying seeding ratios (Fig. 2). With strip intercropping, several rows of a plant species are alternated with several rows of another plant species (Fig. 3). Intercropping also uses the practice of sowing a fast-growing crop with a slow-growing crop, so that the first crop is harvested before the second crop starts to mature. This practice requires some kind of temporal separation, e.g. different planting dates of the component crops so that the differential influence of weather and in particular temperature on component crop growth can be modified (Midmore, 1993). Further temporal separation is found in relay intercropping, where the second crop is sown during the growth, often near the onset of reproductive development or fruiting of the first crop, so that the first crop is harvested to make room for the full development of the second crop (Andrews and Kassam, 1976).

Advantages of intercropping

Efficient resource utilization and yield advantage

The main advantage of intercropping is the more efficient utilization of the available resources and the increased productivity compared with each sole crop of the mixture (Willey, 1979; Jannasch and Martin, 1999; Li et al., 1999; Hauggaard-Nielsen and Jensen, 2001; Hauggaard-Nielsen et al., 2001b; Zhang and Li, 2003; Szumigalski and Van Acker, 2006; Andersen et al., 2007; Dhima et al., 2007; Ofosu-Anim and Limbani, 2007; Muoneke et al., 2007; Agegnehu et al., 2008; Carrubba et al., 2008; Launay et al., 2009; Mucheru-Muna et al., 2010). An alternative to yield for assessing the advantages of intercropping is to use units such as monetary units or nutritional values which may be equally applied to component crops (Willey, 1985). Yield advantage occurs because growth resources such as light, water, and nutrients are more completely absorbed and converted to crop biomass by the intercrop over time and space as a result of differences in competitive ability for growth resources between the component crops, which exploit the variation of the mixed crops in characteristics such as rates of canopy development, final canopy size (width and height), photosynthetic adaptation of canopies to irradiance conditions, and rooting depth (Midmore, 1993; Morris and Garrity, 1993; Tsubo et al., 2001). Regularly intercropped pigeonpea or cowpea can help to maintain maize yield to some extent when maize is grown without mineral fertilizer on sandy soils in sub-humid zones of Zimbabwe (Waddington et al., 2007). Intercropping maize with cowpea has been reported to increase light interception in the intercrops, reduce water evaporation, and improve conservation of the soil moisture compared with maize alone (Ghanbari et al., 2010). This yield advantage occurs when the component crops do not compete for the same ecological niches and the interspecific competition for a given resource is weaker than the intraspecific competition. Normally, complementary use of resources occurs when the component species of an intercrop use qualitatively different resources or they use the same resources at different places or at different times (Tofinga et al., 1993). In ecological terms, resource complementarity minimizes the niche overlap and the competition between crop species, and permits crops to capture a greater range and quantity of resources than the sole crops. Improved resource use gives in most cases a significant yield advantage, increases the uptake of other nutrients such as P, K, and micronutrients, and provides better rooting ability and better ground cover as well as higher water use efficiency (Midmore, 1993; Morris and Garrity, 1993). Thus, selection of crops that differ in competitive ability in time or space is essential for an efficient intercropping system as well as decisions on when to plant, at what density, and in what arrangement. Although in this way cropping management decisions specify the design of intercropping systems, intercrop performance is governed largely by the availability of and the competition for the environmental resources. Research has shown that intercrops are most productive when component crops differ greatly in growth duration (Wien and Smithson, 1981; Smith and Francis, 1986; Fukai and Trenbath, 1993; Keating and Carberry, 1993). For example, when a long-duration pigeonpea cultivar was grown in mixture with three cereal crops of different growth durations, i.e. setaria, pearl millet, and sorghum, the Land Equivalent Ratio was highest with the quick-maturing setaria and lowest with the slow-maturing sorghum (Rao and Willey, 1980). It must be noted here that Land Equivalent Ratio shows the efficiency of intercropping for using the environmental resources compared with monocropping with the value of unity to be the critical value. When the Land Equivalent Ratio is greater than one (unity) the intercropping favours the growth and yield of the species, whereas when the Land Equivalent Ratio is lower than one the intercropping negatively affects the growth and yield of the plants grown in mixtures (Willey, 1979; Willey and Rao, 1980). Asynchrony in resource demand ensures that the late-maturing crop can recover from possible damage caused by a quick-maturing crop component and the available resources, e.g. radiation capture over time, are used thoroughly until the end of the growing season (Keating and Carberry, 1993). By contrast, when the component crops have similar growth durations their peak requirements for growth resources normally occur about the same time and the competition for

Fig 2. Mixed intercropping within rows, where the component crops are planted simultaneously within the same row (corn with climbing bean)

the limiting growth resources is intense (Fukai and Trenbath, 1993). Intercropping advantages are not as large or as obvious as those with crops of differing growth cycles and may vary from substantial (Rao and Willey, 1980) to low (Rao, 1986), or to negative (Cenpukdee and Fukai, 1992a, 1992b).

Insurance against crop failure

One important reason for which intercropping is popular in the developing world is that it is more stable than monocropping (Horwith, 1985). Data from 94 experiments on mixed cropping sorghum/pigeonpea showed that for a particular 'disaster' level quoted, sole pigeonpea crop would fail one year in five, sole sorghum crop would fail one year in eight, but intercropping would fail only one year in thirty-six (Rao and Willey, 1980). The stability under intercropping can be attributed to the partial restoration of diversity that is lost under monocropping. From this point of view, intercropping provides high insurance against crop failure, especially in areas subject to extreme weather conditions such as frost, drought, flood, and overall provides greater financial stability for farmers, making the system particularly suitable for labor-intensive small farms. Thus, if a single crop may often fail because of adverse conditions such as frost, drought, flood, or even pest attack, farmers reduce their risk for total crop failure by growing more than one crop in their field (Clawson, 1985). Consequently, intercropping is much less risky than monocropping considering that if one crop of a mixture fails, the component crop(s) may still be harvested. Moreover, farmers may be better able to cope with seasonal price variability of commodities which often can destabilize their income. For example, if the market price may be more favourable for one crop than for others, farmers may be able to benefit from good prices and may suffer less due to poor prices for particular crops, if they grow several crops. Intercropping maize with beans reduced nutrient decline and raised household incomes compared with monocropping of either of the two crops in the Mbeere District of Eastern Kenya (Onduru and Du Preez, 2007). During the past two decades, yield increases from intercropping have been reported in several studies in semi-arid environments. On the basis of these studies, intercropping has been advocated to increase crop yield and improve yield stability in environments where water stress occurs. Combinations involving crops with slightly differing growth duration, e.g. millet and sorghum or mixtures of early- and late-maturing cultivars of the same species are used in areas with growing seasons of variable-length to exploit the occasional favourable season yet insure against total failure in unfavourable seasons (Rao, 1986). On average, late-maturing cultivars of groundnut and sorghum gave higher dry pod and grain yield, respectively, when intercropped with early-maturing cultivars of the associated crops (Tefera and Tana, 2002). If the growing season is long, the late-maturing type takes advantage of the abundant resources, whereas if the growing season is short, the early-maturing type can provide a reasonable yield. Differing growing seasons may thus lead to reversals of success in such intercrops, giving more stable yield in intercropping when measured over a run of seasons.

Soil conservation

Intercropping with legumes is an excellent practice for controlling soil erosion and sustaining crop production (El-Swaify et al., 1988). Where rainfall amount is excessive, cropping management systems that leave the soil bare for great part of the season may permit excessive soil erosion and runoff, eventually resulting in infertile soils with poor characteristics for crop production. Moreover, deep roots penetrate far into the soil breaking up hardpans and use moisture and nutrients from deeper down in the soil. Shallow roots bind the soil at the surface and thereby help to reduce erosion. Also, shallow roots help to aerate the soil. Reduced runoff and soil loss were observed in intercrops of legumes with cassava (El-Swaify et al., 1988). In another experiment it was observed that although soil erosion was greater with forage legume intercropping than with cassava sole cropping in the first cropping period, once they were well established and uniformly distributed, the undersown legumes controlled soil erosion effectively (Leihner et al., 1996). Similarly, sorghum-cowpea intercropping reduced runoff by 20-30% compared with sorghum sole crop and by 45-55% compared with cowpea monoculture (Zougmore et al., 2000). Moreover, soil loss was reduced with intercropping by more than 50% compared with sorghum and cowpea monocultures.

Improvement of soil fertility

Legumes enrich soil by fixing the atmospheric nitrogen changing it from an inorganic form to forms that are available for uptake by plants. Biological fixation of atmospheric nitrogen can replace nitrogen fertilization wholly or in part. When nitrogen fertilizer is limited, biological nitrogen fixation is the major source of nitrogen in legume-cereal mixed cropping systems (Fujita et al., 1992). Moreover, because inorganic fertilizers have contributed to environmental damage such as nitrate pollution, legumes grown in intercropping are regarded as an alternative and sustainable way of introducing N into lower input agroecosystems (Fustec et al., 2010). In addition, the green parts and roots of the legume component can decompose and release nitrogen into the soil where it may be made available to subsequent crops. In particular, under low soil N conditions the advantages of legumes in an intercrop are greater (Lunnan, 1989). The benefits of a legume intercrop with respect to nitrogen are direct transfer of nitrogen from

Fig 3. Strip intercropping, where several rows of a plant species are alternated with several rows of another plant species (one broomcorn row with two bush bean rows)

the legume to the cereal during the current intercrop and residual effects when the fixed nitrogen becomes available on the sequential crops after the senescence of the legume and the decomposition of residues. The direct transfer of nitrogen to companion crops occurs mainly by excretion of nitrogen from the legume nodules, representing an immediate source of nitrogen to the cereal. Thus, the use of legumes in mixtures contributes some nitrogen to the cereal component and some residual nitrogen to the following crops (Adu-Gyamfi et al., 2007). The main pathway of conservation of other nutrients is through the return and decomposition of crop residues (Rahman et al., 2009). Crop residues represent a major resource of fertilization for the small-scale farmer and manipulation of the fate of the nutrient released by the decomposition of crop residue is thus a main target for improving nutrient use efficiency of cropping systems. This is because minerals from the soil become available for development of aboveground biomass through the roots of legumes in intercropping. Transfer of other nutrients, such as P, might occur through mycorrhizal bridges (Newman, 1988).

Improvement of forage quality

Combining the growth of cereal forages with other crops capable of increasing the protein content of the ration has great nutritional and financial value. Combinations of cereals with legumes are seen as one way of achieving this goal. Intercropping cereals with legumes and other fodder crops to provide forage for ensiling offers one method for increasing home-grown protein sources. Most patterns of intercropping corn with soybean produced more forage than sole crops compared at the same yield ratio of corn-soybean as in the intercrop harvested mixture (Putnam et al., 1986). Moreover, increases in crude protein content by 11-51% were recorded for the various intercrop treatments over corn sole crop. Intercropping field beans with wheat improved forage dry matter and percentage of dry matter compared with bean sole crop and also enhanced crude protein, neutral detergent fibre content, and water-soluble carbohydrates compared with beans and wheat sole crops (Ghanbari-Bonjar and Lee, 2002; Lithourgidis and Dordas, 2010). Forage yield and quality can be enhanced by intercropping barley or oat with pea (Carr et al., 2004). Also, barley intercrops with Austrian winter pea (*Pisum sativum* ssp. *arvense*) resulted in values of Land Equivalent Ratio ranging from 1.05 to 1.24 on a biomass basis and from 1.05 to 1.26 on a protein basis indicating a production advantage of intercropping (Chen et al., 2004). Intercropping corn with legumes was far more effective than corn monocrop to produce higher dry matter yield and roughage for silage with better quality (Geren et al., 2008). Common vetch intercrops with barley or winter wheat produced higher dry matter than sole common vetch and the intercrop of common vetch with barley at a seeding ratio 65:35 gave higher forage quality than other intercrops tested (Lithourgidis et al., 2007). Also, intercropping common bean with corn in two row-replacements improved silage yield and protein content of forage compared with sole crops (Lithourgidis et al., 2008). The crude protein yield, dry matter yield, and ash content of maize forage increased by intercropping with legumes compared with maize monoculture (Javanmard et al., 2009). Furthermore, intercropping legumes with maize significantly reduced neutral detergent fibre and acid detergent fibre content, increasing digestibility of the forage. It is evident from the above that intercrops of maize with legumes can substantially increase forage quantity and quality and decrease the requirements for protein supplements compared with maize sole crops (Javanmard et al., 2009). Maize and cowpea intercrops gave higher total forage dry matter digestibility than maize or cowpea sole crops and led to increased forage quality (crude protein and dry matter digestibility concentration) than maize monoculture and higher water-soluble carbohydrate concentrations than sole cowpea (Dahmardeh et al., 2009).

Lodging resistance to prone crops

Intercropping can provide better lodging resistance for some crops highly susceptible to lodging (Assefa and Ledin, 2001) (Fig. 4). Lodging, which is commonly observed in some crops, frequently can reduce plant growth severely. Some of the damage is often attributable to subsequent disease infections and mechanical damage, whereas loss of plant height reduces efficiency of light interception (Fig. 5). The ability of forage crops to remain standing is particularly important because lodged forage crops may not be able to photosynthesize and translocate nutrients and water efficiently, which can result in loss of yield. In addition, lodged crops may slow harvest operations or may cause harvest loss. Improved standability commonly results in increased harvestable yield, improved crop quality, and increased efficiency of harvest. Lodging-prone plants, e.g. those that are prone to tip over in the wind or heavy rain, may be given structural support by their companion crop (Trenbath, 1976). Delicate or light sensitive plants may be given shade or protection and thus wasted space can be utilized. The introduction of legumes intercropped with non-legumes has drawn considerable interest because not only is there the ability to improve cash returns by increasing land use efficiency, but the inclusion of component crops such as canola or mustard as an intercrop will also greatly improve lodging resistance of grain legumes, thereby increasing yield, product quality, and harvest efficiency (Waterer et al., 1994). This is because legumes are sensitive to shading, resulting in thinner stems and easier to lodging. Lodging of pea in mixed stands with oat was prevented to some extent because oat provided support to pea and also acted as a wind barrier

Fig 4. Lodging resistance for susceptible crops through intercropping: a) barley with common vetch, b) corn with climbing bean, and c) wheat with lathyrus

(Rauber et al., 2001). Similarly, Cowell et al. (1989) observed advantageous impacts like this in mixed stands of lentil (*Lens culinaris*) and flax (*Linum usitatissimum*).

Reduction of pest and disease incidence

An important aspect of intercropping systems is their ability to reduce the incidence of pests and diseases. However, this is a very complex aspect and both beneficial and detrimental effects have been observed. Indeed, components of intercrops are often less damaged by various pest and disease organisms than when grown as sole crops, but the effectiveness of this escape from attack often varies unpredictably (Trenbath, 1993). A review of 150 published field studies in which 198 herbivore species were studied showed that 53% of the pest species were less abundant in the intercrop, 18% were more abundant in the intercrop, 9% showed no significant difference, and 20% showed a variable response (Risch, 1983). Crops grown simultaneously enhance the abundance of predators and parasites, which in turn prevent the build-up of pests, thus minimizing the need of using expensive and dangerous chemical insecticides. Mixed crop species can also delay the onset of diseases by reducing the spread of disease carrying spores and by modifying environmental conditions so that they are less favourable to the spread of certain pathogens. The worsening of most insect problems has been associated with the expansion of monocultures at the expense of the natural vegetation, thereby decreasing local habitat diversity. Results from 209 studies involving 287 pest species were analyzed (Andow, 1991). Compared with monocultures, the population of pest insects was lower in 52% of the studies, i.e. 149 species and higher in 15% of the studies, i.e. 44 species. Of the 149 pest species with lower populations in intercrops, 60% were monophagous and 28% polyphagous. The population of natural enemies of pests was higher in the intercrop in 53% of the studies and lower in 9%. Thus, the simplification of cropping systems can affect the abundance and efficiency of the natural enemies, which depend on habitat complexity for resources. Compared with a monoculture, adding more plant species to a cropping system can affect herbivores in two ways. Firstly, the environment of the host plants, e.g. neighbouring plants and microclimatic conditions, is altered and secondly, the host plant quality, e.g. morphology and chemical content, is altered (Langer et al., 2007). However, the simultaneous effect on both the environment and the quality may complicate comparisons between systems as several mechanisms can affect herbivorous insects (Bukovinszky et al., 2004). Changes in environment and host plant quality lead to direct effects on the host plant searching behaviour of herbivorous insects as well as indirect effects on their developmental rates and on interactions with natural enemies. Mixed cropping of cowpeas with maize reduced significantly the population density and activity of legume flower bud thrips (*Megalurothrips sjostedti*) compared with sole cowpea crop (Kyamanywa and Ampofo, 1988). Similar results were also reported with intercrops of beans, cowpea, and maize, where the reduced pest incidence was attributed to the increased populations of natural enemies favoured by intercropping (Kyamanywa and Tukahirwa, 1988). Black aphid (*Aphis fabae*) infestation of beans was greatly reduced when beans intercropped with older and taller maize plants which interfered with aphid colonization and only small proportions of beans were infested by the aphid (Ogenga-Latigo et al., 1993). There was significantly lower population of insects on the cowpea crop when grown in mixture with maize at

Fig 5. Loss of plant height in intercrop of oat with common vetch which results in reduction efficiency of light interception

specific ratios than in monoculture (Olufemi et al., 2001). Intercropping maize with soybean, groundnut, and common beans reduced significantly termite attack and the consequent loss in grain yield of maize compared with maize monoculture, whereas it increased the nesting of predatory ants in maize fields. Also, soybean and groundnut were more effective in suppressing termite attack than common beans, suggesting the necessity to identify suitable legumes for each intercropping situation (Sekamatte et al., 2003). *Orobanche crenata* infection on faba bean and pea was reduced when these host crops were intercropped with oat than when grown alone. Moreover, the number of *O. crenata* plants per host plant decreased as the proportion of oats increased in the intercrops (Fernandez-Aparicio et al., 2007). Intercropping upland rice with groundnut at low and medium populations of groundnut resulted in lower green stink bug (*Nezara viridula*) and stem borer (*Chilo zacconius*) infestations in rice compared with rice monoculture (Epidi et al., 2008). This demonstrates that careful selection of crop combination and plant population could lead to reduced pest incidence in upland rice. Also, intercropping cowpea with cotton proved the best in suppressing the population of thrips and whiteflies, produced high yield, and was at par with the intercrops of cotton with marigold and cotton with sorghum Chikte et al., 2008). Intercropping sugar bean between the sugarcane rows reduced nematode infestation when compared with a standard aldicarb (nematicide) monocrop treatment and an untreated control (Berry et al., 2009). Turnip root fly (*Delia floralis*) oviposition was found to be lower in a clover-cabbage intercrop compared with the monocultures and the reduction in the number of *D. floralis* pupae in intercropping could be explained by a disruption in the oviposition behaviour caused by the presence of clover because predation or parasitization rates did not differ between cultivation systems (Björkman et al., 2010). Intercropping has been shown to be an effective disease management tool. Also, variety mixtures provides functional diversity that limits pathogen and pest expansion due to differential adaptation, i.e. adaptation within races to specific host genotypic backgrounds, which may prevent the rapid evolution of complex pathotypes in mixtures (Finckh et al., 2000). According to Trenbath (1993) three principles are proposed to explain yield of intercrops. The productivity of an attacked crop component may be increased several-fold through intercropping. The influence of attack on the Land Equivalent Ratio is positive where escape occurs, especially if two or more components each escape from their own specific attacker. Use of symptomless carriers of disease can lead to low Land Equivalent Ratio values. Several examples have demonstrated that intercropping can reduce considerably the incidence of various diseases by reducing the spread of carrying spores through modification of environmental conditions so that they become less favourable for the spread of certain pathogens. For example, intercropping potato with maize or haricot beans has been reported to reduce the incidence and the rate of bacterial wilt (*Pseudomonas solanacearum*) development in potato crop (Autrique and Potts, 1987). A mixture of wheat and black medic (*Medicago lupulina*) reduced the incidence of take-all disease (*Gaeumannomyces graminis*) of wheat, a soilborne pathogen (Lennartsson, 1988). Mixtures of winter rye with winter wheat and spring barley with oats reduced the incidence of leaf fungal diseases (Vilich-Meller, 1992). Both mixed intercropping and row intercropping bean with maize significantly decreased incidence and severity levels of bacterial blight and rust compared with sole cropping (Fininsa, 1996). In the same study, common bacterial blight incidence levels were reduced in mixed cropping by an average of 23% and 5% than with sole cropping and row intercropping, respectively, whereas intercropping reduced rust incidence levels by an average of 51% and 25% relative to sole cropping and row intercropping, respectively. It was also observed that when pea was intercropped with barley, the level of ascochyta blight (*Ascochyta pisi*) was reduced and also net blotch (*Pyrenophora teres*), brown rust (*Puccinia recondita*), and powdery mildew (*Blumeria graminis*), in order of incidence, on barley during the period between flag leaf emergence and heading were reduced in every intercrop treatment compared with barley monocrop (Kinane and Lyngkjær, 2002). Dual mixtures of grain legumes such as pea, faba bean, and lupin with barley reduced the disease incidence compared with the corresponding sole crops, with a general disease reduction in the range of 20–40% (Hauggaard-Nielsen et al., 2008). It was also observed that for one disease in particular, i.e. brown spot on lupin, the disease reduction was almost 80% in the intercrops. By contrast, there was no stable effect of intercropping on bacterial blight (caused by *Xanthomonas axonopodis* pv. *vignicola*) reduction on cowpea, though intercropping cowpea with maize or cassava in alternate rows reduced bacterial blight in some cases (Sikirou and Wydra, 2008). Climbing genotypes of common beans most susceptible to angular leaf spot (*Phaeoisariopsis griseola*) had less diseased pods in the bean intercrop with maize than in the monocrop and also anthracnose (*Colletotrichum lindemuthianum*) on pods of a susceptible bean cultivar was less intense in the intercrop with maize than in the sole crop (Vieira et al., 2009). Ascochyta blight (*Mycosphaerella pinodes*) severity on pea was substantially reduced in pea-cereal intercrop compared to the pea monocrop when the epidemic was moderate to severe and the disease reduction was partially explained by a modification of the microclimate within the canopy of the intercrop, in particular, a reduction in leaf wetness duration during and after flowering (Schoeny et al., 2010). Weed control is an important aspect in intercropping because chemical control is difficult once the

Fig 6. Weed infestations by *Papaver rhoeas* and *Sinapis arvensis* in intercrop of soft wheat with common vetch without any weed control treatment

crops have emerged. This is also because normally in intercropping a dicotyledonous crop species is combined with a monocotyledonous crop species and therefore the use of herbicides is problematic (Fig. 6). In general, intercrops may show 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 (Olorunmaiye, 2010) or suppressing the growth of weeds through allelopathy. Alternatively, intercrops may provide yield advantages without suppressing the growth of weeds below levels observed in sole crops if intercrops use resources that are not exploitable by weeds or convert resources into harvestable materials more efficiently than sole crops.Intercropping may often result in reduced weed density and growth compared with sole crops (Liebman and Dyck, 1993). Intercrops that are effective at suppressing weeds capture a greater share of available resources than sole crops and can be more effective in pre-empting resources by weeds and suppressing weed growth. Intercrops of sorghum with fodder cowpea intercepted more light, captured greater quantities of macronutrients N, P, and K, produced higher crop yields, and contained lower weed densities and less weed dry matter compared with sole-cropped sorghum (Abraham and Singh, 1984). Similarly, intercropping cassava with maize with nitrogen-fertilizer application gave the highest leaf area index and light interception and hence the best weed control, highest N, P and K uptake, total yields and Land Equivalent Ratio, whereas intercropping with no nitrogen application made a slight improvement in leaf area index, light interception, and weed control over cassava sole crop (Olasantan et al., 1994). Intercropping leek and celery in a row-by-row replacement design considerably shortened the critical period for weed control in the intercrop compared with the leek pure stand. Also, the relative soil cover of weeds that emerged at the end of the critical period in the intercrop was reduced by 41% (Baumann et al., 2000). Pea intercrops with barley instead of sole crop had greater competitive ability towards weeds and appeared as a promising practice of protein production in cropping systems with high weed pressures (Hauggaard-Nielsen et al., 2001a). Similarly, intercrop treatments such as wheat-canola and wheat-canola-pea tended to provide greater weed suppression compared with each component crop grown alone, indicating some kind of synergism among crops within intercrops with regard to weed suppression (Szumigalski and Van Acker, 2005). Deferred seeding of blackgram (*Phaseolus mungo*) in rice after one weeding was the most remunerative intercropping combination and also it was very effective for weed smothering among non-weeded intercrops (Midya et al., 2005). A significant reduction in weed density and biomass for the wheat/chickpea intercrops over both monocrops of wheat or chickpea was found (Banik et al., 2006). Mixed cropping peas with false flax in additive arrangements had a great suppressive effect on weed coverage, i.e. 63% in 2003 and 52% in 2004, compared with sole pea (Saucke and Ackermann, 2006). Intercropping single and double rows of sorghum, soybean, and sesame with cotton was effective in inhibiting purple nutsedge density (70-96%) and dry matter production (71-97%) (Iqbal et al., 2007). However, intercropping of four winter cereals with common vetch did not show any significant competitive advantage against sterile oat (Vasilakoglou et al., 2008). On conventionally managed land, mixtures of wheat and oats and mixtures of wheat and barley at a seeding ratio 25:75 showed high yield potential than the monocrops, whereas barley mixtures also exhibited weed suppressive capabilities (Kaut et al., 2008). Farmers reported that intercropping maize with improved varieties of horsegram (*Macrotyloma uniflorum*) reduced labour since less weeding was required and, in most cases, did not have a yield-reducing impact on their maize crop or on the availability of fodder (Witcombe et al., 2008). Recently, it was reported that intercropping maize with legumes considerably reduced weed density in the intercrop compared with maize pure stand due to decrease in the available light for weeds in the maize-legume intercrops, which led to a reduction of weed density and weed dry matter compared the with sole crops (Bilalis et al., 2010). Similarly, finger millet (*Eleusine coracana*) intercropped with greenleaf desmodium (*Desmodium intortum*) reduced *Striga hermonthica* counts in the intercrops than in the monocrops (Midega et al., 2010).

Promotion of biodiversity

Intercropping is one way of introducing more biodiversity into agroecosystems and results from intercropping studies indicate that increased crop diversity may increase the number of ecosystem services provided. Higher species richness may be associated with nutrient cycling characteristics that often can regulate soil fertility (Russell, 2002), limit nutrient leaching losses (Hauggaard-Nielsen et al., 2003), and significantly reduce the negative impacts of pests (Bannon and Cooke, 1998; Boudreau and Mundt, 1992 Fininsa, 1996) also including that of weeds (Hauggaard-Nielsen et al., 2001a; Liebman and Dyck, 1993). Intercropping of compatible plants promotes biodiversity by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment. Stable natural systems are typically diverse, containing numerous different kinds of plant species, arthropods, mammals, birds, and microorganisms. As a result, in stable systems, serious pest outbreaks are rare because natural pest control can automatically bring populations back into balance (Altieri, 1994). Therefore, on-farm biodiversity can lead to agroecosystems capable of maintaining their own soil fertility, regulating natural protection against pests, and sustaining productivity (Thrupp, 2002; Scherr and McNeely, 2008). From this point of view, crop mixtures which increase farmscape biodiversity can make crop ecosystems more stable and thereby reduce pest problems. Increasing the complexity of the crop environment through intercropping also limits the places where pests can find optimal foraging or reproductive conditions.

Disadvantages of intercropping

Depending on crops mixed, competition for light, water and nutrients, or allelopathic effects that may occur between mixed crops may reduce yields (Cenpukdee and Fukai, 1992a, 1992b; Carruthers et al., 2000; Santalla et al., 2001; Yadav and Yadav, 2001; Olowe and Adeyemo, 2009). Selection of appropriate crops, planting rates, and changes in the spatial arrangement of the crops can reduce competition. A serious disadvantage in intercropping is thought to be difficult with practical management, especially where there is a high degree of mechanization or when the component crops have different requirements for fertilizers, herbicides, and pesticides. Additional cost for separation of mixed grains and lack of marketing of mixed grains, problems at harvest due to lodging, and grain loss at harvest also can be serious drawbacks of intercropping. Mechanization is a major problem in intercropping. Machinery used for sowing, weeding, fertilizing, and harvesting are made for big uniform fields. Harvesting remains a great problem, but it may be more easily overcome where the intercrops are harvested for forage or grazed. In the developing countries, the work needed in the field is mainly done by hand with simple tools because intercropping is very labour intensive. In these countries, however, where manual labour is plentiful and cheap, it is not necessary to invest in expensive machinery especially for intercropping. From this point of view intercropping has no disadvantages, but for intercropping on a large scale basis, mechanization is generally believed to be impossible or inefficient (Vandermeer, 1989).

Crop combinations in intercropping

Careful planning is required when selecting the component crops of a mixture, taking into account the environmental conditions of an area and the available crops or varieties. For example, faba bean yielded more in a maize/faba bean intercrop, but not in a wheat/faba bean intercrop (Fan et al., 2006). Moreover, total biomass, grain yield, and N acquisition of faba bean increased considerably when intercropped with maize, but the values decreased when faba bean intercropped with wheat, irrespective of nitrogen fertilizer application, indicating that the legume could gain or lose productivity in an intercrop situation depending on the companion crop. Similarly, significant yield and monetary advantage was found in the case of intercrops of groundnut with maize than intercrops of groundnuts with sorghum or pearl millet (*Pennisetum glaucum*) (Ghosh, 2004). It is particularly important not to have crops competing with each other for physical space, nutrients, water, or sunlight. Examples of intercropping strategies are planting a deep-rooted crop with a shallow-rooted crop, or planting a tall crop with a short crop that requires only partial shade. Component crops differ with geographical location and are determined by the length of growing season and the adaptation of crops to particular environments. Maize seems to dominate as one of the cereal component of intercrops, often combined with various legumes. The combination of cereals with legumes in mixed cropping offers particular scope for developing energy-efficient and sustainable agriculture due to the nitrogen fixation capability of the legume and the provision of protein in the form of either grain or forage. There are many different types of species that can be used for intercropping: annuals, e.g. cereals and legumes, perennials including trees, or a mixture of the two. In the latter case the term that is used mostly is agroforestry. In areas with annual rainfall of less than 600 mm and rather short growing seasons such as northern Nigeria, early-maturing and drought-tolerant crops such as millet and sorghum often dominate. In areas with annual rainfall greater than 600 mm cereals such as wheat, barley, oat, and rye, and legumes such as pea, lupins, and common vetch of ranged maturity are often used. In tropical and subtropical regions, the cereals primarily used are maize, sorghum, millet, but less rice, whereas the legume crop is normally cowpea, groundnut, soybean, chickpea, bean, and pigeonpea. In these systems early- and slow-maturing crops are used that are combined to ensure efficient utilization of the growing season length. In temperate regions such as Southern Europe with warm climates, intercrop combinations consist of wheat, oats, rye, or barley as the cereal component and field bean, vetch, lupin, or soybean as the legume component (Malézieux et al., 2009; Lithourgidis and Dordas, 2010). In areas with high rainfall in the West Africa, maize and cowpea are used, whereas in South and Central America maize with different types of beans are mainly used. In India, short-duration sorghum and millet are grown with pigeonpea that matures 90 days later than the cereal. In Asia, rice and other cereals with legumes are grown in high rainfall areas. It is not clear which species are the best for intercropping since there are conflicting reports depending on the environment. Some of the most common crop mixtures are those of winter cereals with a legume. One of the most common cereals that are used in temperate regions is barley (*Hordeum vulgare* L.) which was found to produce higher quality forage than oat, triticale, and wheat (Thompson et al., 1992; Qamar et al., 1999). On the other hand, another study showed the most suitable cereal for intercropping with common vetch is oat (*Avena sativa* L.) (Thomson et al., 1990). However, it was also proposed that wheat (*Triticum aestivum* L.) is the most suitable cereal for intercropping (Roberts et al., 1989). Legumes are mostly preferable to non-legumes because they supply their own N and have higher protein content, but in production agriculture where N is not limited or where legumes do not perform well, non-legumes or mixtures of legumes and non-legumes may be more advantageous. When choosing the appropriate forage to be grown, farmers should consider the need for roughage and protein, the costs of N fertilizer for crops, protein for animal feed stuff, and the rotational role of the crop (Papastylianou, 1990). Also, crop morphology and the duration of life cycle have been used to distinguish crop combinations crops of similar height and growth duration such as barley and oats of similar morphology and different growth duration e.g. 6-month sorghum and 3-month millet annual or biennial crop with those of longer growth duration such as millet and cassava or soybean and sugarcane, annual crops of cereals and legumes such as sorghum and pigeonpea and cowpea.

Breeding for intercropping

Plant breeding can contribute determinedly to increase of productivity of intercropping systems by investigating and exploiting the genetic variability to intercrop adaptation. A number of studies indicated major differences in cultivar performance under different agronomic systems such as intercropping (Sharma and Mehta, 1988; Vandermeer, 1989; O'Leary and Smith, 1999; Yadav and Yadav, 2001). Selection for system yield under intercropping revealed some adaptation to the intercrop environment that differed from selection for crop yield under monoculture (O'Leary and Smith, 2004). Therefore, the evaluation of the genetic material developed for monoculture may be insufficient to identify suitable genotypes for intercropping (Francis and Smith, 1985). According to Francis et al. (1976), Willey (1979), and Smith and Francis (1986) the significance of genotype by cropping system interaction is the crucial point when evaluating different cultivars for their performance under different cropping systems to decide whether separate selection programs should be applied under different cropping systems such as monoculture or intercropping. Thus, a significant genotype by cropping system interaction is considered a strong evidence that selection and evaluation of different varieties for each system is needed (Atuahene-Amankwa et al., 2004; Santalla et al., 2001; Tefera and Tana, 2002; Gebeyehu et al., 2006). Sharma et al. (1993) studied the effect of cropping system on combining ability and gene action in soybean and observed low genotypic correlations for yield and its components across and within cropping systems that justify the selection of different parents and crosses for sole and intercropped soybeans. However, some reports about positive correlations between yields in sole crop and intercrop (Holland and Brummer, 1999) raised the question of the indirect selection in another cropping system (such as monoculture) that could also lead to varieties that satisfy the demands of intercropping. Arguing this aspect, Galwey et al. (1986) mentioned that correlation between characters in sole crop and intercrop gives only their relationship, whereas the breeder is interested in identifying cultivars which depart from the trend. Besides, even when the correlation between sole-crop and intercrop yields is positive, there may be significant departure from the trend which can be exploited by plant breeding (Davis and Wooley, 1993). Plant characters that are considered to be useful in monoculture may not be so under intercropping and there is a need to clarify the plant traits that promote intercropping advantage. According to Davis and Woolley (1993) the traits required for intercropping are those which enhance the complementary effect between species and minimize the intercrop competition. Therefore, the selection criteria must take into account not only the influence of a particular trait on the target crop yield, but its potential effect on the component crop. Selection criteria in breeding for monoculture are usually different from those for intercropping. Pea-lodging, for example, is a desirable character for pea monoculture, but it is of minor importance when pea is intercropped with barley because barley contributes to an improved standing ability of pea (Karpenstein-Machan and Stuelpnagel, 2000). Analogous observations were reported by several researchers (Clark and Francis, 1985; Nelson and Robichaux, 1997; Yadan and Yadav, 2001; Osiru and Ezumah, 1994) who are in agreement that different plant characters are appropriate for cultivars intended for use in intercrop than those intended for use in sole crop. However, to develop the appropriate genotype for intercropping, three categories of genetic traits are needed: traits not interacting with the cropping systems, traits specific to intercrops, and traits related with socioeconomic and quality aspects (Baudoin et al., 1997). In practice, breeding for intercropping is a complicated process due to interactions between crops, varietal traits, agronomic practices, and its value for the money invested. From this point of view, the challenge for breeders is to sort through the numerous selection criteria, focus on a limited number of clearly defined characters associated with heritable genetic gain, and adopt the most effective and economic breeding scheme. An intercropping system targeted for breeding must be of major significance, cover a large area, and be sufficiently unique to justify a separate breeding program (Davis and Wooley, 1993). Also, it should be mentioned that because a distance between on-station and on-farm yield performance has been observed and because possible modifications in culture practice probably would be needed (Baudoin et. al., 1997), the breeding program of intercrop adapted varieties must be followed by an on-farm adaptation program. In any case, success in breeding for intercropping passes through the exploitation of the available genetic diversity with simultaneous understanding of the complex interactions among the component crops and their physical and biological environment.

Overall evaluation and future of intercropping

There seems to be a prejudice among some researchers that intercropping is only for peasant farming and has no place in modern agriculture. However, in many areas of the world, traditional farmers developed or inherited complex farming systems in the form of polycultures that were well adapted to the local conditions and helped them to sustainably manage harsh environments and to meet their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science (Denevan, 1995). In most multiple cropping systems by smallholders, productivity in terms of harvestable products per unit area is higher than under sole cropping with the same level of management and yield advantages can range from 20% to 60% due to reduction of pest incidence and more efficient use of nutrients, water, and solar radiation. These microcosms of traditional agriculture offer promising models for other areas as they promote biodiversity, thrive without agrochemicals, and sustain year-round yields (Altieri, 1999).Intercropping has been an important production practice in many parts of the world and it continues to be an important farming practice in developing countries (Clawson, 1985). Despite its potential and multiple advantages, mainstream agronomic research has largely focused on monocrop systems, with little interest in ecological interactions between species in intercropping systems (Malezieux et al., 2009). Thus, although intercropping has been used traditionally for thousands of years and is widespread in many parts of the world, it is still poorly understood from an agronomic perspective and research in this area is far less advanced than comparable work in monoculture. This is due in part to the wide use of pure crop cultures in the developed world, in part to the relative lack of resources in the developing world, but not least to the complexity of the problems involved. Thus, more research is needed to better understand how intercrops function and to develop intercropping systems that are compatible with current farming systems. It has been emphasized already that for an intercrop combination to be biologically advantageous, the mixture components need to be chosen with care. Unfortunately, the interactions among the plants, animals, and microorganisms are so subtle and specific to particular locations that present knowledge only provides a rough guide as to what new combinations of crops and varieties should be tried. Consequently, if the possible advantages of mixed cropping are to be exploited, local experimentation will be needed using a range of possible components and a series of seasons. However, in real life, it is usually not the biological but the economic advantage which decides which cropping systems are actually used. Intercropping often involves staggered plantings and selective harvesting and thus it tends to be labour intensive. If it is soundly practiced, it requires less pesticides and fertilizers, and therefore can be a low-polluting method of farming. Where there is rural unemployment, where capital is in short supply, and where production must be sustainable without expensive fossil fuels and pollution control intercropping is a possible solution. In traditional systems, intercropping systems evolved through many centuries of trial and error. Obviously, to have persisted, these systems had to have merit biologically, environmentally, economically, and sociologically. However, to gain acceptance, any agricultural practice must provide advantages over other available options in the eyes of practitioners. Many of the impediments to adoption of new practices of diversification are mainly sociological and financial rather than technological. In the absence of crops specifically developed to suit intercropping situations, all experimental work involved varieties that had been developed for monoculture. As a result, the trend had been to adapt, with some modifications, monoculture practices to intercropping situations. This may serve as a guide and indication of what to look for in future intercropping work. Better understanding of intercropping systems should lead to the increased adoption rates of these systems in the agricultural sector. Intercropping has great potential to be more beneficial to agriculture in the future and thus receive more attention because of its more efficient use of environmental and other resources than monocrop systems. Obviously, the biggest obstacle in adopting intercropping systems is to conceptualize planting, cultivation, fertilization, spraying, and harvesting of more than one crop in the same field. Agronomic recommendations do not apply in each case as each intercrop combination seems to be a particular case. Furthermore, given the numerous intercrop combinations possible and the different climatic and soil conditions involved in each particular case, generalization to agronomic recommendations may not be possible as often they can be proven invalid. However, for research efforts to be most effective, scientists need to be aware of the client, i.e. the farmer, and the practices, problems, and constraints faced by the farmer. Once the potential benefits of the intercropping are realized and the will develops, mechanization could be developed for these potentially beneficial systems, but probably it will take a long time before mechanized intercropping systems will rival the current monoculture systems. Considering the multiple advantages that can occur from intercropping, particularly in the seek of sustainable agricultural systems, and the environmental problems with current farming systems, it seems reasonable to continue research on the possibilities of growing more than one crop in a field at the same time.

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