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Review article

EFFECT OF INTERCROPPING ON RESOURCES USE, WEED MANAGEMENT AND FORAGE QUALITY

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ABSTRACT

Intercropping cereal and grain legume crops helps maintain and improve soil fertility, because crops such as cowpea, mung bean, soybean and groundnuts accumulate from 80 to 350 kg nitrogen ha^{-1}. 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. Intercropping can conserve soil water by providing shade, reducing wind speed and increasing infiltration with mulch layers and improved soil structure. Enhanced productivity of multispecies agroecosystems (intercropping) compared with that of monospecific agro ecosystems (each of the component species being grown alone) may be explained by two major processes that result in improved resource use: complementarity and facilitation.

INTRODUCTION

In intensive agricultural systems, crop diversity is reduced to one or very few species that are generally genetically homogeneous, the planting layout is uniform and symmetrical and external inputs are often supplied in large quantities. Such systems have clearly negative impacts on soil and water quality and on biodiversity conservation [56]. Species in the same field [88], is the practical application of basic ecological principles. Its potential mechanisms and effects consist of competition (niche differentiation, resource use sharing, weed control), diversity (pest and disease control), facilitation (physical support, excretion of N and allellochemicals, modification of the rhizosphere) and associated diversity (habitats for natural predators, litter diversity enhances soil microbial diversity) [39]. Intercropping cereal and grain legume crops helps maintain and improve soil fertility, because crops such as cowpea, mung bean, soybean and groundnuts accumulate from 80 to 350 kg nitrogen (N) ha^{-1} [70]. The greatest intercrop advantages are attained when the species that are mixed differ markedly either morphologically, phenologically or physiologically [5]. Intercropping systems are diverse and include mixed cropping, row cropping, patch cropping, relay cropping and alley cropping [29]. Because of the physiological and morphological heterogeneity that characterize mixed communities, mechanization of some cropping operations, like pesticide and fertilizer application, and harvesting is difficult in intercropped systems. Consequently, crop associations, except for relay cropping, are not common in industrialized countries. In contrast, small-holding subsistence farmers in the tropics have traditionally intercropped their lands to minimize risks associated with monocultures, and to assure stable income and nutrition [29]. The crops are not necessarily sown at the same time, and harvest time may also differ. However, the crops must co-occur for a significant period of their growth [65]. Intercrops can be combinations of annuals, perennials or a mixture of the two (or more) species (breed, type) [6].

Resources use in intercropping

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 [2, 5, 15, 61, 88, 42, 49, 50, 38, 40, 92, 77, 24, 66, 47, 61]. Currently, there is renewed interest in intercropping [9, 26, 40] because resources may be used more efficiently than in the corresponding monoculture [86, 88].

Beneficial effects of intercropping on nutrient uptake, such as phosphorus (P), have been verified in many previous studies. For example, interspecific increases occurred in faba bean/maize intercropping systems both in no P and P fertilized fields [49, 50, 54]; white lupin increased P uptake of intercropped wheat [22, 32]; pigeon pea (Cajanus cajan) stimulated P uptake of associated sorghum [1]. Resource use efficiency is not likely to be much affected in intercropping systems with component crops that differ in growing period, since competition between component crops is weak [31]. The most important growth resources used by crops are light, water, and nutrients [12]. Aboveground parts of plants compete for light, belowground for water and nutrients [57]. Intercropping can conserve soil water by providing shade, reducing wind speed and increasing infiltration with mulch layers and improved soil structure [79, 91]. The location of the different root systems in an intercropping system affects water uptake and the ability of each crop to compete for water resources [71]. 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 [35]. Willey and Roberts [87] suggested that, light is the most important factor when temporal use of resources was achieved due to better distribution of leaf area over time. Yield advantage of more than 20 per cent was achieved in sunflower and radish intercropping system but peak light interception values were not higher than those of the sole crops [47]. Singh [74] observed that paired rows of sorghum with two rows of intercrops (groundnut, cowpea and soybean) yielded more as compared to other planting geometry. This was attributed to better plant growth and more number of pods per plant of intercrops as a result of penetration of more sun light. Trenbath [80] reported that an "ideal" leaf arrangement could be approached by a mixture of a tall erect leaved genotype and a short, prostrate-leaved genotype. Therefore, a mixed crop better exploits the potential of light [56, 78]. 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 [59, 60, 81]. Numerous studies have been performed on competition for resources (radiation, water and minerals) in intercropping systems [89]. However, although competition for light and water are now quite well understood [10], several gaps remain in our knowledge of the interactions between associated species for soil mineral resources. This is a consequence of the experimental and theoretical difficulties to study these phenomena [68, 69]. Singh and Agrawal [72] in a field experiment consisting intercropping of pearl millet with pigeonpea and castor reported that the N and P uptake by pearl millet was significantly influenced by cropping systems. The N and P uptake was maximum with sole pearl millet as compared to intercropping with pigeonpea and castor. Water is the most limiting factor for plant production and water is the medium that transports all other soil-based resources [56]. Plants grown in mixed crops are different in root morphological and physiological plasticity: length density, surface, depth, root systems interpenetration [40].The components of the intercrops may be complementary in a spatial sense by exploiting different layers of the soil with their root systems [12, 52]. In Danish and German experiments the accumulation of phosphorous (P), potassium (K) and sulphur (S) was 20% higher in the intercrop (50:50 – a relative proportion of grain legume and spring cereals seeds) than in the respective sole crops [39]. The fractions of the incoming PAR which are absorbed by canopies of component crops in intercrop systems mainly depend on leaf area index and canopy structure [46, 76]. Although the principles are understood, Willey [89] noted that it is a challenge to determine light capture by component crops in intercrops. Measurement is difficult, especially over a whole growing season, but several modeling approaches are available to estimate light interception in heterogeneous canopies. Wilkerson et al [90] describes an empirical approach based on a competitive factor and an 'area of influence'. The productivity of each species depends of its ability to take up soil resources, potentially in competition with other components in the association. The competition for resources depends on the discrepancies and overlapping which exist between the activity cycles of the species being associated [89]. It also results fromthe distribution of root systems and their possible overlapping [44, 72]. Sillon et al [71] pointed out the importance of defining the uptake zones of each species in order to better describe the behaviour of the system. Such a definition has already been proposed for the exploitation of water resources and its modelling [17] but it still needs to be evaluated for nitrogen.

Provide nitrogen

The legume can provide N to the non-legume directly through mycorrizal links, root exudates, or decay of roots and nodules; or indirectly during a spring period, where the legume fixes atmospheric dinitrogen (N2), and thereby reducing competition for soil NO3 with the non-legume [6, 20].

In mixed stands, the risk of N losses through leaching is substantially reduced in comparison to sole cropped pea [64]. Urbatzka et al [82] suggest that when pea was cultivated in mixture with cereals, the N utilization effect was higher than in pea pure stands and the N preceding crop effect of pea decreased.

Microbiological and chemical properties in the rhizosphere

Intercropping has significant effects on microbiological and chemical properties in the rhizosphere, which may contribute to the yield enhancement by intercropping [75]. Another explanation is that P efficient species may increase P mobilization in the rhizosphere by acidification. This may then increase P availability for less P efficient crops [1, 22, 51]. Wang et al [85] reported that intercropping had a variable effect on the microbial community structure (assessed by fatty acid methylester analysis and ribosomal intergenic spacer amplification) in the rhizosphere of intercropped wheat and Brassicas (two canolas and one mustard) between alkaline and acidic soils. In the acidic soil, intercropping changed the microbial community structure in the rhizosphere of wheat, and reduced rhizosphere P availability and wheat growth; in the alkaline soil, however, intercropping had no effect on the microbial community structure in the rhizosphere of wheat, or on rhizosphere P availability and wheat growth. Li et al [51] demonstrated that intercropping can affect the microbial community structure (studied by phospholipid fatty acid analysis) in the rhizosphere of intercropped maize and legumes (faba bean and white lupin (*Lupinus albus*) grown in an acidic soil, but the effect was plant species-specific under different P level and form (as $KH2PO4$ or $FePO4$) supply conditions; changes of rhizosphere microbial community structure were only exhibited in faba bean, not in maize or white lupin. Another potential indirect effect in the rhizospheres of intercropped species is enhanced nutrient mineralization due to the priming effect. The priming effect is defined as the change in soil organic matter (SOM) decomposition rates, resulting from the addition of fresh organic matter [11]. Thus, it can occur in the rhizosphere via root turnover and rhizodeposition [19]. Fontaine et al [28] suggested that microorganisms use the energy from this fresh material to decompose SOM in order to release organic N when inorganic Nis limiting. P limitation has never been proven to provoke a priming effect, but it may be likely in ecosystems that are primarily P limited, such as in the tropics. A positive priming effect (stimulation of SOM mineralization) should lead to the recycling of organic N and P and may ultimately enhance plant growth [45].

Negative effects of intercropping

Negative effects of intercropping have also been reported [16]. For example, in a field trial conducted on maize (Zea mays)/wheat (*Triticum aestivum*) intercropping, maize growth decreased in rows adjacent to wheat and the root system of maize was restricted during the early stage when intercropped with wheat [52, 53, 92]. This suggests that the beneficial effects of intercropping only occur between crop species with contrasting nutrient requirements e.g. cereal legume. If so, this may imply that the intercropping of crop species with equal nutrient utilization efficiencies (e.g. cereal and legume intercropping) may cause direct competition for nutrients and therefore produce negative effects on both P uptake and yield. Results from previous similar intercropping experiments, conducted on both alkaline and neutral soils, were highly variable [50, 53, 54, 85].

Complementarity and facilitation

Enhanced productivity of multispecies agroecosystems (intercropping) compared with that of monospecific agroecosystems (each of the component species being grown alone) may be explained by two major processes that result in improved resource use: complementarity and facilitation [30]. Geno and Geno [33] concluded that interspecific competition and facilitation occurs at the same time. Van der Meer [84] noted that both competition and facilitation take place in many intercropping systems, and that it is possible to obtain the net result of land equivalent ratio (LER), an indicator of intercropping advantage, >1 where the complementary facilitation is contributing more to the interaction than the competitive interference. Experimentally, these processes can be difficult to tease apart [55]. Species may use a given resource differently in time, in space, and in forms [30]. A well-known example is the complementarity of N use between cereals and N2-fixing legumes, where both species compete for the same pool of soil N, while only the legume can substantially access the additional pool of atmospheric N2 through symbiotic fixation. Facilitation occurs when one species enhances the growth or survival of another [14]. Hereafter, we use facilitation to mean positive interactions by which a species can modify the biotic/ abiotic environment of its roots (rhizosphere), ultimately benefitting the intercropped species by increasing nutrient availability [14].

Weed management

Many authors like Amanullah et al [4] and Banik et al [7] indicated the limiting effect of intercropping on the number and biomass of weeds. Weed suppression, the reduction of weed growth by crop interference, has been referred as one determinant of yield advantage of intercropping, being a viable alternative to reduce the reliance of weed management on herbicide use [2, 7]. There are two possible reasons for the reduction of weeds biomass in intercropping systems. Some intercrop species release allopathic compounds which limit the occurrence of weeds [67], intercropping also encourages efficient utilization of the environmental resources [26]; thus, the growth of weeds is decreased, depending on the availability of environmental resources. Hence, recent studies have addressed intercropping as an option for an integrated weed management, particularly in farming systems with low external inputs [3, 37]. If the crops grown together differ in the way they utilize environmental resources, they can complement each other and make better combined use of resources than when they are grown separately [37]. Weed suppression in intercropping through more efficient use of environmental resourcesm by component crops has also been reported [17]. Is well known that the weeds interfere with crops causing serious effects through either competition for light, water, nutrients and space and/or allelopathy [25]. Lawson *et al* [48] reported that in maize-legume intercropping legume crops are generally suppressed by weeds and shade effect by the corresponding maize crop which cause difference in photosynthetic efficiency of the two intercropped crops. Crop yield losses due to weeds depend on the cultivar grown, species and number of weeds per area, competition period, and crop development stage. Besides reducing crops yield, weeds can reduce grain quality, cause irregular maturation and harvesting difficulties, as well as act as hosts for pests and pathogens [7, 71]. Maize legume intercropping is advocated because of its beneficial effect on yield increase of maize [18], control of weeds and control legume root parasite infections [27] which ultimately may improve the farmers income and soil fertility.

Forage quality

In addition, weeds can deplete nutrients from soils [3]. The weed-control cultural practices evaluated in the past have again become interesting [7] and are being currently studied, such as intercropping [37]. In order to improve forage quality, intercropped maize and annual legumes have been assessed, reporting not only similar total dry matter yield but also an increase in crude protein (CP) concentration from 19 to 27 g kg^{-1} [34, 41] and in CP yields per hectare (13.0 to 37.8%) [34, 43] when compared to monocropped corn. As for fiber concentration, Javanmard *et al* [43] found reductions of 124 to 146 g kg^{-1} in NDF values and of 75 to 77 g kg^{-1} in acid detergent fiber (ADF) values in corn-soybean intercropping as compared to monocropped corn [23, 63].

MATHERIALS AND METHODS

This paper is a review of the literature search on ISI, Scopus and the Information Center of Jahad and MAGIRAN, SID is also abundant. Search library collection of books, reports, proceedings of the Congress was also performed. All efforts have been made to review articles and abstracts related to internal and external validity.

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