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Intercropping as a multiple advantage cropping system: Review

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Abstract
The objective of this review paper is to organize relevant literature on the multiple advantages of intercropping system using the results of researches undertaken in different parts of the world. Accordingly, relevant materials including journal articles reviews and short communications were used to organize the review entitled “intercropping as a multiple advantage cropping system”. The review material can assist researchers who are interested to conduct their research in intercropping and its potential advantages. In addition it helps the practitioners to have a clear understanding on multiple advantages of intercropping in resource use efficiencies including light, nutrient and spaces to increase their productivity and cropping efficiency. Contrary to other cropping systems such as mono-cropping, intercropping boosts crop competition and optimizes resource usage on a certain farming area and makes efficient use of resources essential for growth including water, solar energy, and soil nutrients. Soils in sub-Saharan Africa lack available nitrogen and the legume component in the intercropping system can provide a consistent source of nitrogen to the soil through biological nitrogen fixation. Intercropping in tropical agricultural systems and elsewhere has received more attention and researches suggest that it can offer production improvements over solitary crops without increasing external inputs. Due to better use of available resources, better productivity and climate resilience, intercropping could be recommended as the best cropping strategy.

Keywords: Intercropping, light use efficiency, water use efficiency, nutrient use efficiency, interloping efficiency

Introduction

Background: The objective of this review paper is to unify the multiple advantages of intercropping. Intercropping, or the combined cultivation of two or more crop species on the same field is a crop diversification method that enables lowering inputs while attaining better crop yields than anticipated based on the solo crop yields of the constituent species (Li *et al.*, 2020; Tamburini *et al.*, 2020; Vandermeer, 1992) [43, 82, 85]. Intercropping presents a compelling possibility for the sustainable intensification of agriculture because it contributes to resource efficiency and crop species diversification (Martin-Guay *et al.*, 2018) [58]. The main purpose of intercropping is to increase the output on a particular plot of land by effectively using resources that would not otherwise be used by a single crop. For crop systems to be more sustainable, high N use efficiency is crucial to reducing N fertilizer input and N losses to the environment (Cassman *et al.*, 2002) [7].

Materials and Methods

This review paper was organized using data and information that are adopted from secondary sources like journal articles, reviews and short communications. By collecting necessary information from different sources, the review paper was compiled and arranged for better understanding and clarification.

Review findings

Crop morphopysiology under intercropping

The intercropping of maize (*Zea mays* L.) and soybeans (Glycine max L. Merr) is the primary

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planting method for the production of cereals and legumes (Rahman *et al*., 2017) [72]. Morphophysiological alterations such stem elongation, increased lodging, decreased chlorophyll a/b ratio and leaf size, improved soybean photosynthetic efficiency, and higher specific leaf weight were reported (Iqbal *et al*., 2019) [34]. In another study it was indicated that row spacing and soybean sowing density have a significant impact on the intraspecific and interspecific competition of plants for soil resources, particularly water and nutrients, and they also cause morphological changes in plants, particularly their height, branch length, and number of pods, which are the primary yield-determining factors (Soares *et al*., 2015; Souza *et al*., 2017) [79, 80]. The study on the chlorophyll fluorescence parameter (Fv/Fm) indicated a similar level in normal light and under shading conditions (Hussain *et al*., 2019) [33], in contrary to this, a study on soybean plants grown in pots and subjected to various levels of shading revealed a decrease in the Fv/Fm parameter as a result of shading compared to the control (Khalid *et al*., 2019) [39]. It has been indicated that the severe maize shading that occurred under maize soy bean intercropping system, soybean plants are growing vegetative from germination to maturity and as a result their seedling height increased and they became more vulnerable to lodging as the intensity of the shade increased (Wolff and Coltman, 1990; Yang *et al*., 2018) [90, 91]. The modification in the leaf surface and changing the leaf area index (LAI), light absorption and canopy photosynthesis and sowing density can affect yield (Rahman *et al*., 2011; Souza *et al*., 2017) [71, 80].

Resource use under intercropping

Intercropping has become known as a crop production technique that could be beneficial (Okpara *et al*., 2004) [69]. The main purpose of intercropping is to increase the output on a particular plot of land by effectively using resources that would not otherwise be used by a single crop. Many studies have shown the benefits of intercropping in increasing the effectiveness of resource utilization (Ma *et al*., 2017; Martin-Guay *et al*., 2018) [51, 58]. Contrary to other cropping systems such as mono-cropping, intercropping boosts crop competition and optimizes resource usage on a certain farming area and makes efficient use of resources essential for growth, including water, solar energy, and soil nutrients (Chang *et al*., 2020; Mousavi and Eskandari, 2011) [9, 63]. The nutritional needs, rooting capacity, height, canopy structure, and complementary utilization of growth resources of crops under intercropping regularly differ (Lithourgidis *et al*., 2011) [46]. When grown together rather than separately, component crops use the available resources differently especially when they have different growth and maturity periods that increases their demand for resources at various times and increase their productivity (Fukai and Trenbath, 1993; Maitra *et al*., 2019) [26, 54]. Intercropping is a more effective technique in poorer soil and environmental conditions due to increased nutrient resource uptake and use efficiency and minimal input cultivation (Knörzer *et al*., 2009) [40]. In most of the intercropping systems in tropical regions, corn has generally been recognized as the best component crop (John and Mini, 2006) [36].

Light use under intercropping

To use the most of the solar energy that falls on the soil during the early phases of growth, enough LAI is required. LAI and the spatial distribution of leaf area determine how much radiation is absorbed by crop canopies (Watiki *et al*., 1993) [87]. The component crops have different PAR interception and nutrient uptake rates. The maximum solar radiation is typically used at a specific LAI, and in short-duration crops, this time period is typically quite short (Egli, 2011) [19]. Better energy use is made possible through multiple cropping (Beets, 2019) [5]. Reports indicated that relay intercropping technique could boost grain productivity, make efficient use of heat and light sources, and raise the land equivalent ratio up to 2.2 (Du *et al*., 2018; Yang *et al*., 2017) [18, 93]. For example, Corn grown alone utilize only 75 percent of the available light while, corn intercropped with mung bean absorb 95 percent of the light that strikes it (Sumit and Kler, 2000) [81]. In narrow-wide row planting patterns, the canopy lighting environment was enhanced, and RUE dramatically increased with narrow and wider row combinations in maize (Liu *et al*., 2012) [47]. In another study, when corn and soybeans are intercropped, corn is the dominant crop because it absorbs more sunlight (Liu *et al*., 2017) [48]. Within the canopies of soybean plants, the microclimate environment is altered, including the amount of light and its spectral characteristics (Yang *et al*., 2014) [92].

It was reported that in the typical intercropping system of maize and peanut including tall and low association and a population structure like an umbrella, which is advantageous for increasing the rate at which light energy is transmitted and intercepted by the combined population (Awal *et al*., 2006; Maddonni *et al*., 2001) [2, 52]. The composition of the chloroplasts and the photosynthetic properties of the intercropped maize and peanut were altered compared to sole cropping and the utilization of weak light in the peanut and strong light in the maize was observed. Lodging is one of the most enduring barriers in the maize soybean intercropping system and poses a serious threat to the growth and sustainability of agriculture (Raza *et al*., 2020) [73]. In contrary to this, it was reported that for some crops that are particularly prone to lodging, intercropping can improve lodging resistance (Assefa and Ledin, 2001; Lulie, 2017) [1, 50].

Nitrogen use under intercropping

In intercropping settings, increased nutrient uptake can take place both spatially and temporally. While the growing root mass can boost nutrient uptake in terms of space, crops in an intercropping system benefit in terms of timing when the peak nutrient demands are at different times (Bitew *et al*., 2021) [6]. Higher N-uptake in the intercrop has been found, compared to mono-cropping, in species with differing rooting and uptake patterns, such as those grown in cereal-legume intercropping systems (Zhao *et al*., 2022) [101]. It has been reported that intercropping reduces the amount of nitrate leaching (Whitmore and Schröder, 2007) [88]. Through biological N fixation, the addition of grain legumes to pasture intercrops can make intercropping systems more sustainable sources of nitrogen (Crews and Peoples, 2004) [16].

Maize-soybean relay intercropping system promote efficient use of crop and soil nutrients, regulate the nitrogen cycle of soil, and significantly increase the rate of nitrogen fertilizer utilization (Fu *et al*., 2019) [25]. Recent research has revealed that the nitrogen uptake of grain was 8.5% lower in monoculture soybean than in intercropping soybean and maize soybean intercropping soybean had a 105.15% higher nitrogen use efficiency than monoculture maize and wheat-maize soybean relay intercropping had a higher total nitrogen accumulation than monocultures (Yong *et al*., 2015) [97]. In contrast to soybean, which depends on air nitrification, there is less competition with maize for soil nitrogen, allowing it to use more of it for growth (Fan *et al*., 2018) [21]. Soybean is a regenerative crop that can restore soil nutrients (Zaeem *et al*., 2019) [99].

According to Fu *et al*. (2019) [25], maize soybean intercropping outperformed maize mono-cropping in terms of the N uptake of maize grain. A change in the makeup of the microbial community caused the plant P absorption in maize-soybean intercropping to increase (He *et al*., 2013) [32].

Water use efficiency under Intercropping

The use of intercropping systems could encourage the complete utilization of farmland water by plant roots, enhance water storage in the root zone, decrease inter-row evaporation and manage excessive transpiration, and produce a unique microclimate beneficial to the growth and development of plants (Feng-yun *et al*., 2012) [24]. The water use of intercropping is higher than that of monoculture throughout the entire growth period but, the difference is less than the weighted mean value of the comparable water uses in sole cropping (Morris and Garrity, 1993) [62]. The basis for niche difference in time and space use is provided by crops with diverse resource demand characteristics, which also encourage the effective use of related resources (Yin *et al*., 2020) [95]. It was hypothesized that the differing root distributions from the intercropping of the two crops exploration of the soil profile could account for the variations in water uptake (Willey, 1990) [89]. In additive series designs, intercrops have higher water usage efficiency values than solitary crops (Kanton and Dennett, 2004) [37]. Intercropping's water use can be varied by spatial arrangement of intercrop strips. For instance, maize-pea strip intercropping (4:4 model, four rows of maize and four rows of pea) decreased water consumption by 10.2-13.7 percent compared to sole cropping, in contrary, maize-pea strip intercropping (2:4 model, two rows of maize and four rows of pea) increased water consumption by 12.5-19.8% compared to sole cropping (Mao *et al*., 2012) [57].

Taking appropriate management techniques to limit soil evaporation is crucial since it contributes significantly to the overall amount of water consumed by agricultural systems (Yin *et al*., 2019) [96]. It was reported that the longer growth period of intercropping, soil evaporation during the entire growth period was higher than that of sole cropping (Wang *et al*., 2015) [86]. However, daily soil evaporation during intercropping was lower than that of sole cropping, demonstrating that intercropping has a significant advantage over sole cropping in improving crop water availability (Fan *et al*., 2013; Yin *et al*., 2019) [22, 96]. When produced in water-limited locations and during dry seasons, cereal-legume intercropping, particularly that of maize-soybean has been recognized as more productive than their respective mono-crops for their potential to save water (Mao *et al*., 2012; Ouda *et al*., 2007) [57].

Table 1: Researches on improved water use efficiency (WUE) with intercropping compared to the corresponding sole cropping

Country	Cropping system	References
Argentina	Maize soybean-intercropping	(Coll *et al*., 2012) [15]
Brazil	Maize-cowpea intercropping	(De Barros *et al*., 2007) [17]
China	Maize-soybean intercropping	(Ren *et al*., 2017) [75]
China	Maize-wheat intercropping	(Yin *et al*., 2019) [96]
China	Maize-pea intercropping	(Mao *et al*., 2012) [57]
Canada	Wheat-bean intercropping	(Chapagain and Riseman, 2015) [12]
Egypt	Maize-soybean intercropping	(Kubota *et al*., 2015) [41]
India	Maize-soybean intercropping	(Raza *et al*., 2021) [74]
Kenya	Maize-cowpea intercropping	(Miriti *et al*., 2012) [60]
Pakistan	Maize-soybean strip intercropping	(Raza *et al*., 2021) [74]

Intercropping for soil fertility and soil health

The promotion of soil health and quality, yield, fertilizer use effectiveness, and long-term agricultural output can be accomplished successfully and attractively by intercropping (Fu *et al*., 2019; Zaeem *et al*., 2019) [25, 99]. It was reported the soil fertility and crop productivity can be improved by introducing a legume component through intercropping with cereal crops with the least amount of external inputs and recently, efforts are going in this direction (Bedoussac *et al*., 2015; Meena and Lal, 2018) [3, 59]. As the soils in sub-Saharan Africa are lacks accessible nitrogen and the legume can provide a consistent source of nitrogen to the soil through biological nitrogen fixation, cereal -legume intercropping is crucial in maintaining soil fertility and output (Layek *et al*., 2018) [42]. When maize and cowpeas are grown together, soil N, P, and K concentrations are said to be higher than when maize is grown alone (Mugwe *et al*., 2011) [65]. Along with boosting the intake of N through grain, the intercropping of maize and soybeans enhanced the nutrients that are readily available in the soil (Chalka and Nepalia, 2006) [8]. Pulses are well-known for their capacity to restore soil fertility (Bedoussac *et al*., 2015; Ghosh and K. Ghosh, 2004) [3, 27]. Pulses have a number of distinctive traits, including deep roots, the capacity to fix nitrogen, the capacity to shed their leaves, and the ability to mobilize insoluble soil nutrients (Ofori and Stern, 1987) [68]. Pulses can halt the continuous cereal-cereal system's trend of diminishing production by enhancing the chemical, biological, and physical conditions in the soil (Savci, 2012) [77]. Cereal-legume intercropping have emerged as a suitable substitute for improving soil health, protecting natural resources, and ensuring the sustainability of agriculture (Maitra *et al*., 2021) [53].

Nutrient use efficiency under intercropping

The ability of rhizobacteria to fix nitrogen (N) in the soil, which allows for more fixed N to stay in the upper soil layers and be available to plants, is one way that intercropping with legumes can specifically improve soil fertility (Chapagain and Riseman, 2014; Hauggaard-Nielsen *et al*., 2009) [11, 30]. Intercropping helps crops to use more of the available nutrients (Bedoussac and Justes, 2010) [4], including macro- and micronutrients (Neugschwandtner and Kaul, 2016) [67]. As a result, nutrient utilization efficiency can be increased and the main crops' fertilizer needs can be decreased in comparison to stands of conventional, non-intercropped crops (Ghosh *et al*., 2006; Salehi *et al*., 2018) [28, 76].

Intercropping in crop microclimate

In farming, the microclimate, which includes the temperature, relative humidity (RH), and light intensity, has a significant role in the development and production of crops (Shamshiri *et al*., 2018) [78]. Intercropping alters the microenvironment, especially in terms of temperature, RH, and light intensity (He *et al*., 2011) [31]. Relative humidity, which was determined to be on the decline and the number of hours per day with relative humidity below 92% in intercropping was reduced, according to earlier studies (Gómez-Rodrıguez *et al*., 2003; Zhu and Li, 2007) [29, 102]. Additionally, intercropping can enhance the quantity of light that is absorbed by crops per unit planting area, which will increase agricultural yield and radiation use efficiency (Monteith, 1977; Tsubo and Walker, 2002) [61, 83]. In the tropics, where capital can be a major barrier to agricultural production, microclimate modifications requiring high inputs, like the use of artificial shade materials, are not practical (Jaya *et al*., 2001) [35]; however, microclimate modification using inexpensive and straightforward methods, like intercropping, may be both acceptable and affordable. Due to its broad adaptability to a variety of climates, maize is one of the row crops frequently used for intercropping to give shade to understory crops. Additional details has been provided on the microclimate advantages of intercropping: microclimate within canopy can decrease temperature extremes; lower temperatures and less air movement result in less evaporation and higher relative humidity than open areas (Farrell and Altieri, 1995) [23].

Intercropping for crop productivity and intercropping efficiency

The primary goal of intercropping is to increase overall productivity per unit of time and space, in addition to the wise and equitable use of land resources and farming inputs like labor (Esmaeili *et al*., 2011) [20]. Intercropping systems provide clear advantages over solitary crops in terms of productivity per unit area (Li *et al*., 2013; Mucheru-Muna *et al*., 2010) [44, 64]. Intercropping in tropical agricultural systems and elsewhere has received more attention and researches suggest that it can offer production improvements over solitary crops without increasing external inputs due to better use of available resources (Chowdhury and Rosario, 1992; Kermah *et al*., 2017; Liang *et al*., 2020; Upadhyay *et al*., 1990; Zhang and Li, 2003) [14, 38, 45, 84, 100]. Both additive and replacement series of intercropping system were reported to exhibit yield advantages (Maitra *et al*., 2020; Manasa *et al*., 2018) [55]. Reports indicate the benefits of cereal-legume intercropping systems for boosting productivity (Chapagain *et al*., 2018; Yin *et al*., 2017) [94, 10].

The complementarity of resources between the various crops in the intercrops was one explanation for the surplus yield achieved through intercropping (Nassary *et al*., 2019) [66]. It was demonstrated that even with a minimal amount of soil N treatment using maize soybean intercropping, a maximum maize yield could be obtained (Chen *et al*., 2017) [13]. In another study it was reported that the sum of the relative yields is frequently larger than one, each species' yield when grown in an intercropping system is typically lower than that of a single crop (Martin-Guay *et al*., 2018; Yu *et al*., 2015) [58, 98]. It was reported that the intercropping method for maize and soybeans is widely used in many parts of China, and farmers there are achieving a land equivalent ratio of 1.3 to 1.4, which is far higher than other relay-intercropping systems globally (Liu *et al*., 2018) [49].

Conclusion

This review focused on the advantages of intercropping, which is a cropping method that has several advantages in light use efficiency, nutrient use efficiency and better productivity as compared to mono-cropping system. Intercropping is the growing of two or more crops simultaneously on the same land and are a cropping system with multiple advantages. Intercropping alters the microenvironment, especially in terms of temperature, RH, and light intensity. Intercropping in tropical agricultural systems has received more attention and researches suggest that it can offer production improvements and climate resilient production system. It provides clear advantages over solitary crops in terms of productivity per unit area and intercropping efficiency. Based on the findings of different researches, it could be concluded that intercropping is more advantageous in tropical areas than mono-cropping systems.

Conflict of interest

No conflict of interest

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