

# Overview of the advantages and limitations of maize-soybean intercropping in sustainable agriculture and future prospects: A review

Deborah Joy Blessing<sup>1</sup>, Yan Gu<sup>1\*</sup>, Manjun Cao<sup>1</sup>, Yue Cui<sup>1</sup>, Xiaowen Wang<sup>1</sup>, and Bismark Asante-Badu<sup>2</sup>

<sup>1</sup>Jilin Agricultural University, College of Agronomy, 2888 Xincheng Street, Changchun 130118, China.

\*Corresponding author (guyan810831@163.com).

<sup>2</sup>Jilin Agricultural University, College of Resources and Environmental Sciences, 2888 Xincheng Street, Changchun 130118, China.

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## ABSTRACT

Intercropping has benefited the global agricultural sector in several ways. It is a critical farming practice for long-term productivity, agro-ecological improvement, land management, and land use. It is a well-known method to increase soil health and crop productivity. The impact of intercropping on the yield and production of maize (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) has been investigated at the leaf, stem, and root level. However, there is limited information about how to determine the best planting density for maize-soybean intercropping (MSI). The benefits and drawbacks of MSI are discussed in this review. Intercropping maize and soybean improves resource use, lodging resistance, and pest and weed control according to the existing research. Furthermore, soybean has low light use efficiency (LUE) and radiation use efficiency (RUE) due to the deep shade created by the maize canopy. As a result, more research is required to discover the optimal planting density to improve light and radiation efficiency.

**Key words:** Agricultural sustainability, future prospect, maize-soybean intercropping, soil erosion.

## INTRODUCTION

Intercropping is an agricultural technique used to grow two or more different crops in alternate rows on a given plot of farmland at the same time during their growing season or in a growing period (Lithourgidis et al., 2011; Mousavi and Eskandari, 2011; Federer, 2012). A tall crop is often intercropped with a short crop in this farming system (Oseni, 2010; Undie et al., 2012), such as intercropping a legume and cereal (Undie et al., 2012).

Intercropping in China, dates back over 10 centuries and is usually known as an antiquated and outdated farming system (Lithourgidis et al., 2011). Studies promote this ancient cropping system as a substitute for more sustainable agriculture with low input and stabilized yield (Knörzer et al., 2009; Ren et al., 2017). However, there is a high and growing demand of the food supply due to the exponentially increasing world population (Tilman et al., 2011; Elferink and Schierhorn, 2016; Lulie, 2017); it was predicted by the United Nations on 13 June 2013 that the population would increase by 33% from 7.2 billion to 9.6 billion by 2050 (UN, 2013). As a result, there is an urgent need for increased, long-term food production (Xu et al., 2020). This cultivation strategy has proven to be beneficial in several ways, including maintaining a rapidly growing population (Bybee-Finley and Ryan, 2018; Zaeem et al., 2019).

Unlike other cropping systems, intercropping increases crop competitiveness and improves resource use on a given area of farmland (Chang et al., 2020). These crops frequently vary in nutritional requirements, rooting ability, height, canopy structure, and the complimentary use of intercrop growth resources (Lithourgidis et al., 2011). There is also decreased disease transmission, which increases crop yields (He et al., 2011; Kebebew et al., 2014; Bybee-Finley and Ryan, 2018; Iqbal et al., 2019). The ecological and biological benefits of intercropping are well documented.

Intercropping systems provide 15% to 20% of the world food supply (Lithourgidis et al., 2011). It was reported by Xu et al. (2020) that intercropping has been dubbed as the “new green revolution” because it is able to increase land efficiency by using information on how species complement one another and provide a way to achieve sustainable agricultural intensification. It has become the best cropping system for maize (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.), and it also plays a critical role in contributing to modern and sustainable agriculture.

Intercropping is an effective and sustainable cropping system for maize (cereal) and soybean (legume). It has often been known to be much more effective compared with monocropping even when practiced with scarce resources (Ouda et al., 2007; Ren et al., 2017). This also produces high yielding maize components such as yield per plant, weight, 1000 kernel weight, and leaf area (He et al., 2011). Intercropping legumes with maize improves the soil by fixing N and other minerals and converting them from inorganic to organic forms that are accessible for crop absorption. This completely or largely substitutes N fertilization and leads to saving resources (Li et al., 2013). In a low input and high-risk context, the maize-soybean intercropping (MSI) system offers significant benefits to small landholder farmers (Kebebew et al., 2014; Iqbal et al., 2019).

Despite these benefits of MSI, the synergetic effects of this system on the soil, stem, leaf, and root of the maize plant are still unknown. There are several shortcomings of this system that should be addressed, such as the incompatibility with mechanization (planting and harvesting), microclimate conducive to the outbreak of pathogenic (fungal) diseases, high maintenance cost (Okigbo and Greenland, 1976; Gebru, 2015), low light use efficiency (LUE), radiation use efficiency (RUE), and low relative soybean yields (Iqbal et al., 2019).

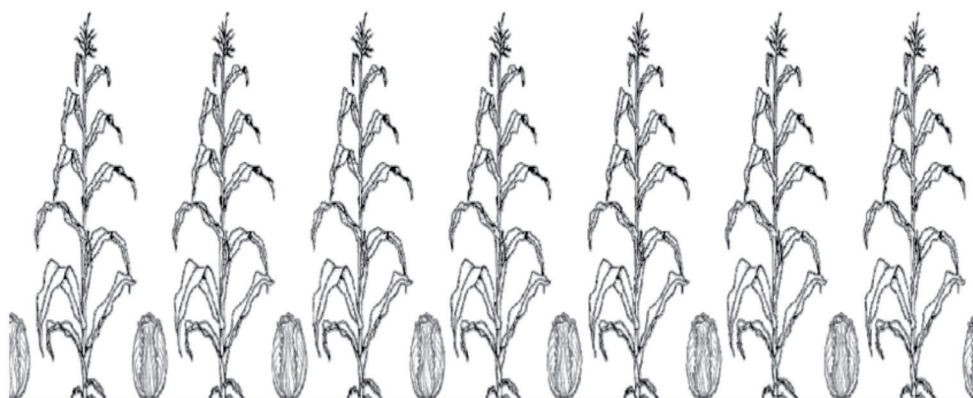
One of the objectives of this study was to describe in detail the types of intercropping systems and the various advantages they provide for soil nutrient fixation and plant development. Another objective was to discuss the important limitations related to maize-soybean intercropping (MSI) that hinder good agronomic practices and try to provide future possibilities. This paper provides a critical and intensive review of studies to assist agronomists in future research to enhance agricultural yield and also save resources.

## TYPES OF INTERCROPPING

### Row intercropping

More than one crop is simultaneously cultivated in this intercropping system; one or more crops are sown in fixed rows and a crop or other crops can be immediately cultivated in the rows or randomly with the first crop (Mousavi and Eskandari, 2011; Maitra et al., 2019) (Figure 1). Ram and Meena (2014) conducted a field experiment in the dry region of Rajasthan to test alternative pearl millet and mung bean row ratios. The treatments included 1 pearl millet, 1 mung bean, and 10 pearl millet with mung bean treatments in rows at various ratios. These treatments with 1:7, 2:6, and 1:3 row ratio, respectively, outperformed the individual and other intercropping treatments for pearl millet equivalent yield, land equivalent ratio (LER), aggressiveness, net returns, benefit-cost ratio, and nutrient uptake. Hooda et al. (2004) and Kuri et al. (2012) also reported that intercropping pearl millet with green gram produced the highest net return and benefit-cost ratio over an individual pearl millet crop.

Figure 1. Illustration of traditional maize and cabbage intercropping (Feike et al., 2012).



### Mixed intercropping

This type of intercropping involves growing multiple crops all at once with no definite row layout (Figure 2). This method of intercropping is widespread in labor-intensive subsistence farming and is suitable for grass-legume intercropping in pastures (Ofori and Stern, 1987; Maitra et al., 2019). Studies using totally mixed intercropping have been reported to raise farmer income, improve diversity and ecosystem functions, alter soil biota, protect and improve soil quality, match feed preferences and cultural expectations, and increase variety and ecosystem functions (Finn et al., 2013; Duchene et al., 2017; Bi et al., 2019). In addition, mixed intercropping has been linked to various ecological benefits such as enhanced resource use in total niche space (niche differentiation), positive interspecific interactions, diversification effects, and collection effects (Bi et al., 2019).

### Relay intercropping

This involves planting one or more crops within an established crop in such a way that the final stage of the first crop corresponds with the initial growth stage of the other crop(s) (Leihner, 1983) (Figure 3). In other words, a second crop is planted after the first has attained reproductive maturity or is close to maturity but is not yet ready for harvest (Mousavi and Eskandari, 2011; Maitra et al., 2019).

Figure 2. Illustration of mixed intercropping of different plants on a plot of land.

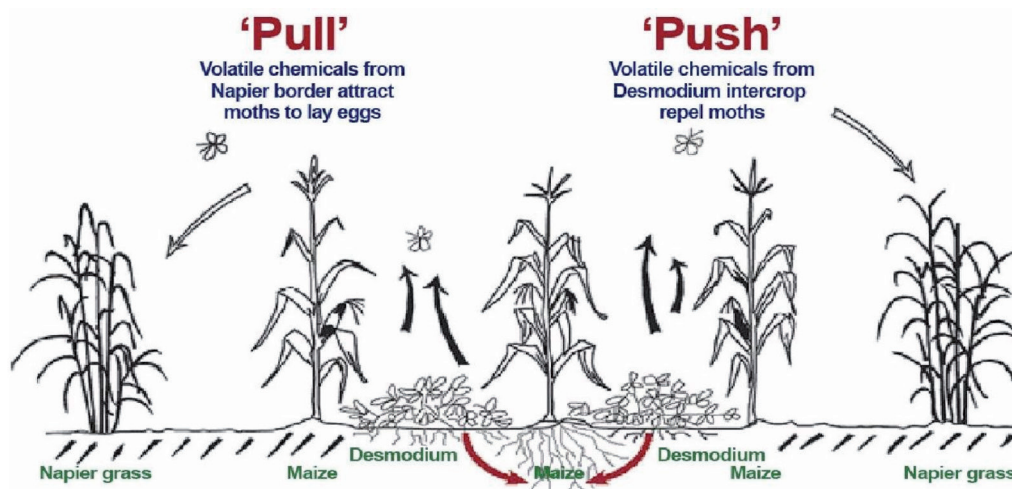
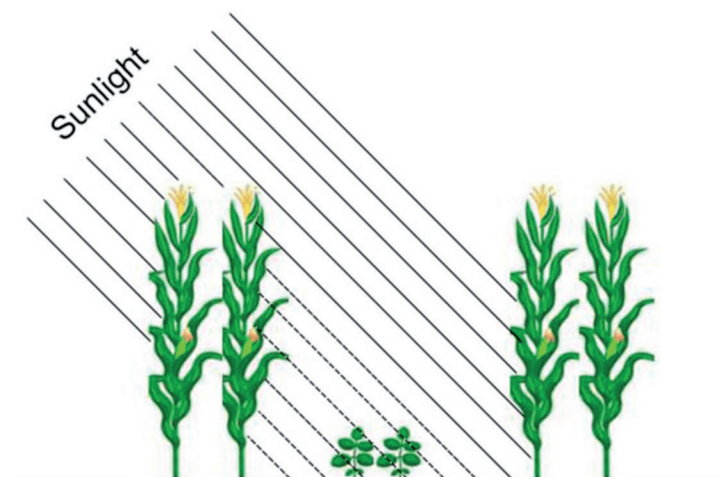


Figure 3. Schematic depiction of a maize-soybean relay intercropping system (Raza et al., 2019a).



According to Echarte et al. (2011), in leguminous and cereal crops, relay intercropping is suggested because it has an overall economic profitability, reduces insects, weeds, and pests, is environmentally beneficial, and has high yields. Soybean is normally the late planted crop in a maize-soybean relay intercropping system (Echarte et al., 2011). Chen et al. (2017) indicated that the LER frequently ranges from 1.7 to 1.8 when both crops are planted at their optimal planting density. This intercropping method is well known because the intercrops do not intensively compete throughout their co-growth period, which enables a more balanced use of land, light, and water (Wu et al., 2017; Feng et al., 2019; Raza et al., 2019b).

### Strip intercropping

This cropping system consists of cultivating two or more crops in separate strips that are wide enough to allow autonomous cultivation but narrow enough to allow crop convenience (Leihner, 1983; Maitra et al., 2019) (Figure 4). A maize-soybean strip intercropping model has been developed and used over time. Strip intercropping allows maize and soybean to grow in close proximity in thin strips. The primary focus of this planting method is based on three important strategies: increased row spacing, reduced inter-plant spacing, and optimal cultivar screening. This intercropping method is considered excellent for mechanical cultivation and crop harvesting; it also contributes to the appropriate competitiveness of two intercropped species (Iqbal et al., 2019) (Figure 5). Resource use (as evidenced in group water use efficiency), weed, pest, and disease management, increased yield, economic benefits, and improved soil fertility and N acquisition are some of the advantages of maize-soybean strip intercropping (Iqbal et al., 2019). The high RUE and LER are two main variables that make strip intercropping attractive in different parts of the world (Wang et al., 2015; Yang et al., 2015b; Liu et al., 2017b).

Figure 4. Schematic depiction of maize-soybean strip intercropping at different distances (Raza et al., 2019b).

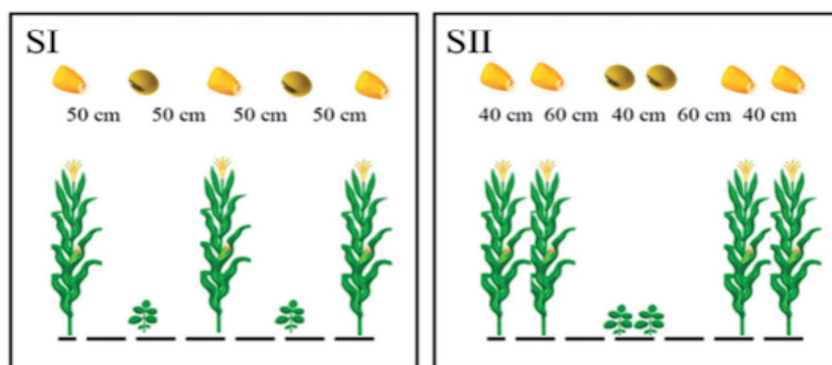
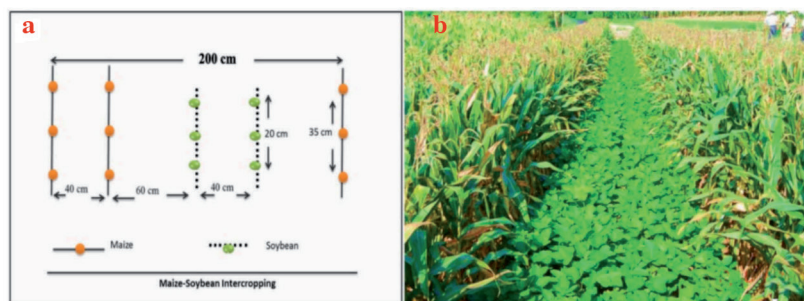


Figure 5. Illustration of the advantages of maize-soybean intercropping (based on Iqbal et al., 2019).



1. Resource use
  - Improve field microclimate
  - High light interception
2. Weed, pest, and disease control
  - Suppress pest incidence
  - Less weed infestation
3. Improve soil fertility and N acquisition
  - Long-term N immobilization of N
  - Reduces N application
4. Yield and economic benefits
  - Maximum land use efficiency
  - Maximum net income

In a study by Liu et al. (2017b), the intercepted photosynthetically active radiation (PAR) and RUE in maize and soybean were evaluated as compared with monocropping under various intercropping systems, including different strip intercropping configurations (SI1, SI2, and SI3 based on the extended row crop radiation transmission model) and row intercropping configurations (row intercropping based on the horizontally homogeneous leaf area model). The PAR and RUE intercepted intercropping systems were found to be higher than monocropping systems. In addition, PAR intercepted by soybean in strip intercropping was 1.35 times higher than in row intercropping, and SI2 (0.4 m maize row spacing and 1.6 m distance between maize strips) was suggested as the best by researchers.

## ADVANTAGES OF MAIZE AND SOYBEAN INTERCROPPING

### Increased soil fertility through nutrient acquisition

Intercropping two crop species, notably cereal (maize) and legume (soybean) crops, can provide significant advantages to the soil (Bybee-Finley and Ryan, 2018). In a study conducted by Zaeem et al. (2019), it was found that intercropping silage maize with forage soybean is a good way to increase forage production and also improve soil health in cool weather. The ability of legumes to fix atmospheric N in the soil (Phiri et al., 2013) provides a cheaper soil fertility option. Intercropping non-N-fixing (maize) and N-fixing (soybean) crops has been reported to increase yield and productivity over monocropping (Seran and Brintha, 2009; Thayamini and Brintha, 2010). Soybean fixes N in the atmosphere rather than competing with maize for soil N in the absence of N fertilizer (Thayamini and Brintha, 2010). Habineza et al. (2018) investigated the influence of MSI on soil fertility using three soybean varieties (hybrid SB19, local var. GAZELLE, and hybrid TGX1990-5F). These researchers observed that the hybrid TGX1990-5F had more nodules per plant, fixed more N, and had higher levels of other nutrients (organic C, K, and P). After harvest, TGX1990-5F was in the middle at both locations and rainy seasons, compared with other varieties. After harvesting, soil pH was sufficiently moderate to support the next crop. Given that TGX1990-5F can lower the cost of N fertilization by naturally fixing N, it was suggested that small-scale farmers use it for intercropping with maize (Habineza et al., 2018). Furthermore, soybean straw (decayed roots and fallen leaf debris) is ploughed back into the soil after the intercrop is harvested to deliver N and other nutrients to prepare for the next crop (Lulie, 2017).

### Effects of pests, disease, and weed management on intercropping

Pests, disease, and weeds stifle productivity in MSI, causing high larval density at an early stage, particularly in maize monocropping. This is evidenced by its tunneled stem and broken cobs, thus reducing maize yield. Therefore, pesticides and herbicides have been used, but they have produced harmful effects on the environment and human health (Paoletti and Pimentel, 2000). Research aimed at reducing the impact of weeds, pests, and illnesses has gained momentum (Ramert et al., 2002; Mousavi and Eskandari, 2011; Iqbal et al., 2019).

The population of beneficial insects has also expanded, which keeps pest populations under control and reduces the need for dangerous chemicals (Maitra et al., 2019). Intercropping two other crops on the same piece of land alters the condition and environmental quality of the host plant, which affects the ability of the insect pest to identify and recognize it (Lulie, 2017; Maitra et al., 2019).

In a study conducted by Chabi-Olaye et al. (2005), it was observed that high larval density (21.3% to 48.1%) reduced plant development in a maize monocrop compared with a maize intercrop. Maize monocrops had more tunneled stems and damaged cobs, which resulted in lower maize yields. Intercropping is known to be more effective than monocropping to suppress weeds, although its efficiency varies according to its ability to invade weed resources or suppress weed development through allelopathy (Girjesh and Patil, 1991; Mousavi and Eskandari, 2011). According to Lulie (2017), intercropping provides superior weed management than monocropping due to a more competitive effect on weeds over time and area. When compared to monocrops, weed density and DM were lower in maize-legume intercrops (Bilalis et al., 2010). This was attributed to the fact that weeds had less access to light.

Gao et al. (2014) also indicated that intercropping significantly lowered disease incidence and the severity index of soybean red crown rot. It was further detected that when soybean was cultivated in close proximity to maize (Intercropping System Control 2 [ISC2], 5 cm apart), disease severity was considerably reduced (Gao et al., 2014). Intercropping with maize can significantly minimize or even eliminate the occurrence and development of red crown rot in soybean growth when the intercropping planting distance is taken into account.

### **Intercropping enhances maize lodging resistance**

According to Raza et al. (2020), lodging is one of the most persistent constraints in the MSI system, and poses a severe danger to agricultural development and sustainability. Several of the negative effects of lodging in maize include mechanical damage, disease infections, and decreased plant height that reduces light interception effectiveness and results in harvest loss (Lulie, 2017). However, when lodging resistance is enhanced in intercropping, not only does it improve harvestable yield or crop quality but also harvest efficiency (Lulie, 2017). Maize, which is prone to lodging when intercropped with legumes such as soybean, has been found to increase lodging resistance when sown at the correct time and density (Raza et al., 2020).

### **Intercropping efficiency in resource use and productivity**

The higher uptake and use efficiency of nutrient resources and low input cultivation makes intercropping a more efficient system under poorer soil and environmental conditions (Knörzer et al., 2009). In a study of intercropping complementarity of separate wheat, canola, and field pea crops and intercrop combinations, Szumigalski and Van Acker (2008) evaluated the effects on LERs, canopy light interception, soil moisture, water use, and water use efficiency with/without in-crop herbicides at two field sites in Manitoba, Canada. Surplus yield by intercropping was attributed in part to the complementarity of resources between different crops among the intercrops. Intercropping also benefits the efficient use of the resources responsible for growth such as water, solar energy, and soil nutrients (Mousavi and Eskandari, 2011). Component crops used available natural resources differently when intercropped than when grown separately (Mousavi and Eskandari, 2011; Lulie, 2017), especially when they had different growth and maturity periods, which caused them to have higher demand for resources at different times and be more productive (Fukai and Trenbath, 1993; Maitra et al., 2019).

### **Intercropping for erosion control**

Intercropping protects the soil from desiccation and erosion by supplying year-round or at least longer-term ground cover than monocropping (Gebu, 2015). Shallow roots bind the soil at the surface in MSI, which improves air quality and decreases soil erosion (Lulie, 2017). Rain can clog surface pores, which prevents water from penetrating the soil and increases surface erosion. These legumes are used as cover crops in intercropping to keep rain from hitting the bare soil, which prevents soil compaction (Thayamini and Brintha, 2010; Maitra et al., 2020). Tall crops, such as maize, also act as wind barriers for smaller leguminous crops, such as soybean, by reducing wind speed and preventing saltation and wind erosion (Thayamini and Brintha, 2010; Gebu, 2015; Maitra et al., 2020). Five treatments (only maize, maize intercropped with bean, maize intercropped with cowpea, and maize intercropped with bean and cowpea) were examined for runoff and soil loss in a maize-based intercropping research study (Kariaga, 2004). Maize intercropped with cowpea obtained the lowest runoff in the cropped plot, indicating that cowpea is better at concealing the soil surface and, when intercropped with maize, provides better soil depletion protection. It also demonstrated that maize-legume intercropping is beneficial to control soil erosion.

### **Increased yield and land equivalent ratio (LER)**

Maize-soybean intercropping is conducted entirely with the aim of increasing yield, particularly for small farmers and in countries with short growing seasons. The LER, area time equivalent ratio, and aggressiveness are some of the most common methods to calculate intercropping yield and efficiency. Gebu (2015) mentions that the LER is the most widely used indicator of biological efficiency and yield per capita output. Whenever  $LER > 1$ , intercropping is more profitable than monocropping, and when  $LER < 1$ , intercropping is much less beneficial. Intercropping maize and soybean is beneficial for the LER (Jinchi et al., 2005; Gao et al., 2010; Yang et al., 2015a; Ren et al., 2017). Under the supervision of the East-West Center in Hawaii, a study was conducted at 14 locations over a 3-yr period to verify the effectiveness of a maize-soybean intercrop with the respective individual crops at various N fertilization levels (Ahmed and Rao, 1982). At all the studied locations and across all N levels,  $LER > 1$ . It was also determined that the maximum LER values were recorded at a 0% N level. Gao et al. (2010) reported that the LER of the maize-soybean strip intercropping system was 1.19 in 2007 and 1.31 in 2008 ( $LER > 1$ ), indicating that the maize-soybean strip intercropping system has significantly higher land use efficiency and biological efficiency. A study with the intercropping of sunflower and soybean by Nawar et al. (2020) also showed that intercropping increases LER.

## LIMITATIONS OF MAIZE-SOYBEAN INTERCROPPING

Intercropping has several drawbacks, including a restriction in the use of machinery for seeding, weeding, and harvesting. It is difficult to manage individual crops in intercropping, for example, fertilizer management and herbicide use to contain weeds. Intercropping also needs more labor per unit area, and it can decrease the production of each crop if not effectively managed (Aye and Howeler, 2012).

Mechanization procedures during planting and harvesting are typically problematic for MSI. Maize is typically harvested first, which damages soybean and hinders harvesting in general (Okigbo and Greenland, 1976; Gebru, 2015). Low soybean yield, which is mostly due to a reduction in intercepted PAR, is commonly cited as a major constraint for MSI (Echarte et al., 2011; Undie et al., 2012). The maize canopy cover in intercropping can create a microclimate with higher relative humidity, which is unfavorable for soybean growth and could even promote outbreaks of pathogenic fungal diseases. However, over the long term, choosing an appropriate ratio for maximum intercrop yield is somewhat more challenging. For example, maintenance costs during weeding for MSI are typically substantial, especially in countries with labor shortages (Gebru, 2015).

## EFFECT OF INTERCROPPING ON MAIZE AND SOYBEAN PLANTS, SOIL, AND ROOTS

### Effect on plants

Regarding the performance of maize functioning and the plant as a whole, MSI has increased plant height, stem, chlorophyll content, fodder production, and grain yield (Ren et al., 2017; Zaeem et al., 2019).

On the contrary, MSI using different spatial patterns frequently results in different shade and light environments above the soybean canopy, which directly affects soybean leaf structure (anatomic) and photosynthetic fluorescence properties (Fan et al., 2017). The light environment of the lower soybean plant is affected by the deficiency in the quantity and quality of light caused by shade from the taller maize plant. This could result in variations in internode length, plant height, leaf diameter, and branching in the soybean crop, and growth variations in LUE, growth rate, harvest index (Liu et al., 2017a), and grain yield (Ren et al., 2017). A study by Nawar et al. (2020), in which sunflower was intercropped with soybean, showed that the shading effect caused by the development of the sunflower canopy resulted in an unfavorable growth environment around the soybean plants, which enhanced some hormonal activity and led to more node formation and stem elongation. Stem elongation was reported as one of the mechanisms used by plants to increase their ability to capture more solar radiation. On the long run, this decreases the stem diameter of soybean and reduces its ability to resist lodging. Liu et al. (2017a) found that poor light intensity caused soybean growth to slow down, resulting in smaller leaf size and stem circumference and leading to decreased soybean production in MSI. These soybean-related restrictions are obviously linked to maize canopy development (Chui and Shibles, 1984; Liu et al., 2017a). In addition, maize shade affects the stem circumference of soybean and lowers its lodging susceptibility (Liu et al., 2016; Raza et al., 2019a; Cheng et al., 2020). Low PAR and the ratio of red light to far red light, which decreased because of the maize canopy, also produce soybean stem vining in maize-soybean relay strip intercropping. This results in a long, thin stem with less lodging resistance (Liu et al., 2015; Hussain et al., 2019).

### Effect on soil

Intercropping is a successful and attractive method to promote soil health and quality, yield, fertilizer use efficiency, and long-term agricultural production (Fu et al., 2019; Zaeem et al., 2019). The soil nutrient balance and active microbial communities can be used to analyze data concerning soil health. An experiment conducted in the cool environment of the boreal ecosystem (Zaeem et al., 2019) discovered that silage maize planted with forage soybean were suitable to increase forage cultivation. When cultivated on Podzols in a cool temperature boreal habitat, this is accomplished through enhancing active biological processes, rhizosphere soil acid phosphatase activity, and accessible P.

Zaeem et al. (2019) found that rhizosphere soil acid phosphatase activity was significantly ( $p < 0.05$ ) higher, especially in the intercropping treatment compared with monocropping; this implies that intercropped maize planted on Podzols can use organic P more efficiently than monocropped maize.

Fu et al. (2019) revealed that the N uptake of maize grain was superior in MSI than in maize monocropping. Moreover, Chen et al. (2017) stated that a maximum maize yield can be achieved even with limited soil N treatment with MSI. This is because maize is less competitive for soil N, allowing it to use more soil N for growth, whereas soybean relies on atmospheric nitrification (Fan et al., 2018).

In intercropping practices, interspecies connections are also important for plant resistance (Zhang et al., 2020). Soybean is a regenerative crop that can replace soil nutrients (Zaeem et al., 2019).

### Effect on roots

Root growth is a major factor in MSI production. Stronger root development can explore a larger soil volume to adequately exploit the water resource in the soil profile and increase intercrop transpiration. Intercropping benefits the root density of maize. Ren et al. (2017) indicated that MSI increased root length density in both maize and soybean when compared to monocropping. Zhang et al. (2020) also found that intercropping improved the ability of maize root exudate to identify zoospores, inhibit zoospore motility, and decrease cystospore formation in a dosing system.

*Fusarium* root rot has been identified as one of the most devastating soil-borne infections that affects soybean growth and output, resulting in a significant economic loss (Arias et al., 2013; Chang et al., 2020). On the contrary, intercropping favors the impact on soil microbial populations, lessens pathogen attacks, and prevents soil-borne disease (Boudreau, 2013; Gao et al., 2014; Chang et al., 2020). Chang et al. (2020) also mentioned that intercropping maize-soybean relay strips decreases soybean root rot and modifies the variety and virulence of *Fusarium* species. As a result of maize-soybean relay strip intercropping, it was detected that *F. fujikuroi*, *F. proliferatum*, and *F. verticillioides* are mildly virulent (Chang et al., 2020). This suggests that intercropping maize and soybean is critical for reducing soybean root disease. It would also increase root formation in soybean, as evidenced by the root length density of intercropped soybean that is higher than in monocrops (Gao et al., 2010). Some of the advantages and disadvantages of intercropping are shown in Table 1.

## FUTURE PROSPECTS OF INTERCROPPING

### Improved root interactions

Several studies have been carried out to determine the best strategies to overcome the numerous drawbacks of intercropping systems. The mechanism of collaborative root connections in intercropped agriculture can be used in MSI. These can consist of soil exploitation via bacteria and fungi, N exchange between legume and non-leguminous plants, and soil-plant mechanisms that modify the deployment of plant development resources, such as amino acid exudation, enzymatic

**Table 1. Advantages and disadvantages of intercropping (modified from Chui and Shibles, 1984; van der Bom, 2010).**

Positive effect	Negative effect
Plant	
Not necessary to rely on a single crop.	Possibility that harvesting one crop component will damage the other.
Less frequent pesticide and fertilizer use.	Intercropping systems are usually a challenge to mechanize.
Promotes flora and fauna of the area.	Possibility of promoting the spread of harmful flora and fauna for the crops.
Allows a gradual shift in thinking from more reasonable external inputs to more environmentally friendly technologies.	Opposed to the social, economic, and political systems that are currently in place.
Agricultural land diversification.	Compared with individual crops, cropping systems are more complicated and less understood.
Biologically, intercropping has advantages over monocropping.	Believed to be economically inefficient in many actual economic systems.
Soil	
Improved crop output as a result of the better use of local resources.	Possibility of nutrient overextraction.
Roots	
Enhances root length density, allows plants to explore a larger soil volume, and maximizes water and nutrient consumption to promote plant growth and output.	When competing with another plant, the plant could generate more roots and less grain production than when grown separately.

activity, acidification, competition-induced modifications of root architecture, exudation of growth-promoting chemicals, and bio fumigation, all of which can be quite useful to pursue research (Hauggaard-Nielsen and Jensen, 2005). Due to significant interspecific competition for plant growth components, these root-facilitating interactions are particularly important in nutrient-poor soils and low input agro-environments (Ehrmann and Ritz, 2014).

### **Improved genetically modified breeds**

In a typical intercropping system, maize provides shade for the shorter crop, which is soybean in this case. When grown in the shade, most soybean cultivars display stem elongation, lodging, and reduced leaf size, all of which result in lower yields (Liu et al., 2016). Most shade-sensitive soybean strains in a maize-soybean strip intercropping system exhibit stem elongation and lodging, which directly influence soybean yield according to several analyses (Liu et al., 2015).

As a consequence of their shade-tolerant traits, a growing number of soybean landraces have been found. Several landraces are being used to breed cultivars for intercropping models in various regions worldwide, including China. Using a variety of semi-dwarf but high-yielding maize hybrids can also help reduce the shade effect on intercropped soybean (Gong et al., 2014). Semi-dwarf cultivars allow proximity planting, which reduces the differences in biomass and leaf area index among maize and soybean intercropping systems (Yang et al., 2014). The density of strip-crop intercropping is maximized when used with compact planting practices.

### **Improved mechanized systems**

Agricultural machinery for sowing, fertilizing, and harvesting can be designed or modified for numerous intercropping practices. A combination of seed drill and fertilizer drill for a typical maize-soybean strip intercropping system in the field is a good idea for future research. Using agricultural machines designed for this approach would considerably increase labor productivity. These ground-breaking advances in our modified intercropping strategy have the possibility to significantly increase soybean productivity in China and other developing countries (Du et al., 2018).

### **Improved planting density and distance**

Careful management of the planting density, which is controlled by the planting ratio and distance, can improve intercropping. This could be accomplished by designing the planting pattern in narrow and wide rows, which allows maize plants to grow in narrow rows and soybean plants to grow in wide rows all the while preserving the appropriate distance for soybean plants to receive adequate light for optimal growth and development. Designing an efficient intercropping planting setup with a maximum shade density ranging from 20% to 30% (Raza et al., 2019b) to increase the soybean crop seed production in an intercropping system could be a promising future research topic.

The compact maize 'Zhendan-958' has a smaller shade area, making it better for relay cropping. Compact type maize cultivars were found to be more useful to reinforce production, which help to create better light conditions for sweet potato development (Yulong et al., 2017).

## **CONCLUSIONS**

The benefits of maize-soybean intercropping (MSI) are largely noticeable in maize. In this study, it was revealed that MSI has become a popular crop production system in developing countries; it provides significant benefits in terms of resource use efficiency and productivity, erosion control, soil fertility through nutrient acquisition, pest, disease, and weed control, lodging resistance, and increased yield. However, mechanization, shading, and planting ratio of MSI still have certain limitations. Further study should be focused on finding solutions for these limitations.

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