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Comparative analysis of maize–soybean strip intercropping systems: a review

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ABSTRACT

Traditional maize (*Zea mays* L.) and soybean (*Glycine max* (L) Merrill) intercropping practice cannot be adapted to modern agriculture due to low light use efficiency, radiation use efficiency, low comparative profits of soybeans and incompatibility with mechanization. However, a new type of maize and soybean intercropping system (MSIS) with high land equivalent ratio (LER) provides substantial benefits for small-land hold farmers worldwide. Our research team has done a wide range of research to suggest the appropriate planting geometry that ensures high yield and LER as high as 2.36, nutrient acquisition and mechanical operations in MSISs. Increase in the distance between soybean and maize rows and decrease in the spacing of maize narrow rows is useful for the high light interception for the short soybean in MSISs. This review concludes that MSIS has multifold and convincing results of LER and compatible with mechanization, while those practiced other than China still require technological advancements, agronomic measures and compatible mechanization to further explore its adaptability.

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1. Introduction

To feed the exponentially growing world population, intercropping is an important agronomic strategy that involves the growing of two or more crops on the same piece of land (Katyayan, 2005). It is an ancient agronomic practice used in traditional agriculture and still in vogue in most of the developing countries. Intercropping system maximizes the productivity as well as resource utilization per unit of land. Almost all the concerns for agriculture (agriculture technologies, government farm policies, modern crop varieties and research efforts) are focused on the production of sole cropping, while some drawbacks in modern agriculture system force the farmers to take interest in intercropping for the production of fiber and food (Kirschenmann, 2007; Vandermeer, 1989). Intercropping systems provide 15–20% of food supply to the world (Lithourgidis et al., 2011). In fact, intercropping has ecological, biological and socioeconomic advantages over sole cropping (He et al., 2012; Waktola et al., 2014).

Several studies have shown the importance of cereal and legume intercropping system, which is considered as an old practice in tropical agriculture (Ghanbari et al., 2010; Tsubo et al., 2001; Waddington et al., 2007). The combination of tall and short-statured cereal–legumes

with adventitious and deep tap root system crops utilizes space and time more efficiently (Prasad & Brook, 2005). In addition, leguminous crops are identified to fix atmospheric nitrogen that consequently improves soil fertility (Manna et al., 2003). Moreover, in the absence of nitrogen fertilizers, reduced N input decreases the demand for nitrogenous fertilizers in cereal and legume intercropping systems (Adu-Gyamfi et al., 2007; Chen et al., 2017).

The analysis of numerous cereal and legume crops revealed that maize and soybean are best partners under intercropping conditions because both crops have complementary characteristics (Kocsy et al., 2001). Maize and soybean are the nitrogen-consuming C_4 and nitrogen-fixing C_3 crops, respectively, with same sowing season, which make them fit for the mechanized-based cultivation and harvesting (Yang et al., 2014). Maize and soybean have large cylindrical and small round leaves, respectively, which are good for light utilization on the same piece of land (Yang et al., 2015). Therefore, traditional maize–soybean intercropping has been practiced in different countries. However, the traditional maize and soybean intercropping practice cannot be adapted in modern agriculture owing to low light use efficiency (LUE), radiation use efficiency (RUE), low comparative profits of soybeans and incompatibility with

mechanization. The efficient utilization of resources is indispensable to achieve optimum crop yield. In traditional intercropping depletion of natural resources, inefficient utilization of nutrients and environmental pollution are the disappointing shortcomings. These disadvantages directly lead to the low crop productivity.

Moreover, reduced availability of labor and increased urbanization have necessitated the adoption of mechanized agriculture (Van Den Berg et al., 2007; Zhang et al., 2017). Under intercropping conditions, mechanization has variable space requirement that depends on crop width configuration. The optimum width of crop strips minimizes the hazards of mechanical implements or operations (Xiwen et al., 2015).

Therefore, our group developed a new type of mechanized-based maize–soybean strip intercropping model. The key focus of this system revolves around three critical strategies including expansion of row spacing, interplant space reduction and optimal cultivar screening (Yang et al., 2014). Through agronomic practices our mechanized-based maize–soybean strip intercropping maintained the proper competitiveness between two intercropped species and achieved higher yield. The technological advancement such as

mechanized cultivation and harvesting of crops is the key to success of this system (Figure 1).

New mechanized-based maize–soybean strip intercropping model consists of two systems including regular strip intercropping and relay strip intercropping. In recent years, a new maize–soybean relay strip intercropping system has been developed and popularized in the southwestern China (Yan et al., 2010) that provided substantial benefits for small-land hold farmers in terms of yields and economic prospects. In this model, wide-narrow row planting of alternating maize and soybean (200 cm bandwidth 2:2, maize-to-soybean rows) facilitates the mechanical operations. Strip intercropping systems are high-efficient and environment-friendly, which have also the potential to resolve food crises in developing countries.

The objective of this review is to put forward the comparative analysis of newly developed mechanized-based maize–soybean strip intercropping systems practiced in southwest of China and the traditional maize–soybean intercropping system that is a common practice in other developing countries. This analysis will help to promote mechanized-based maize–soybean strip intercropping system as a high-efficient and sustainable agricultural practice. Furthermore,

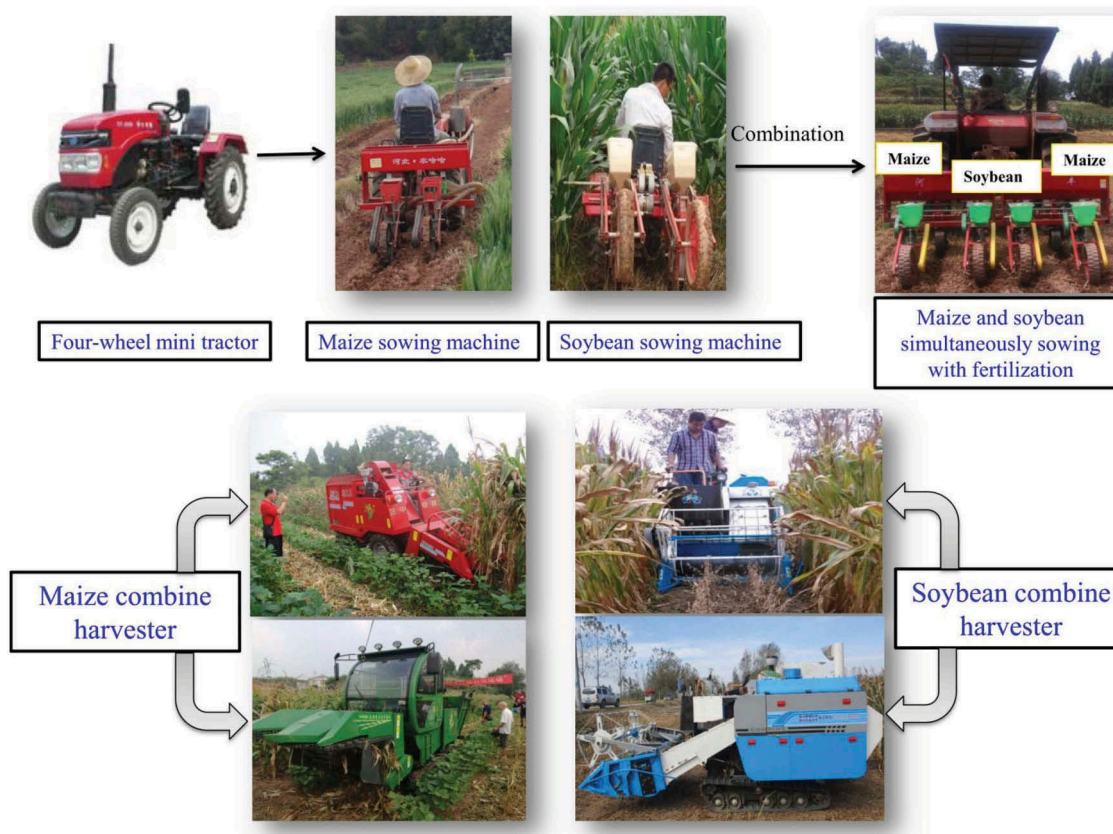


Figure 1. Mechanical operations in mechanized-based maize–soybean intercropping systems of China.

benefits and questions regarding its adaptability are also discussed in detail.

2. Benefits of maize-soybean strip intercropping

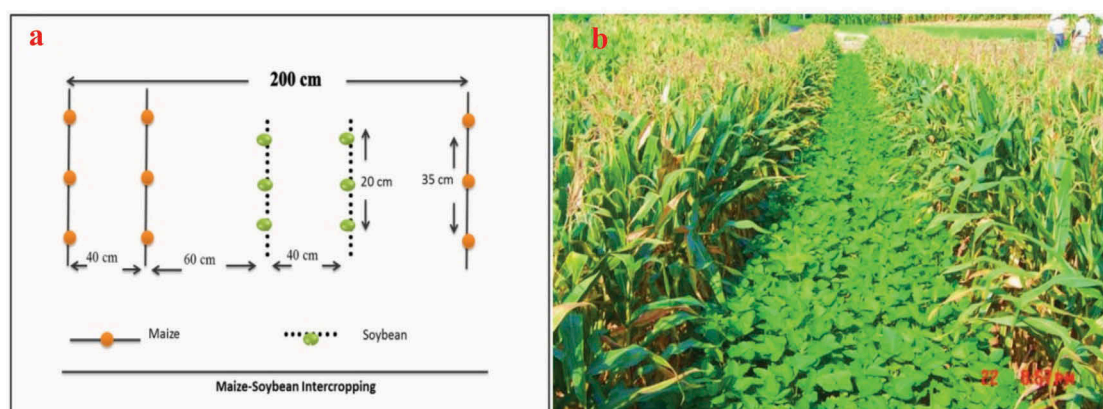
2.1. Resources utilization

Improvement of field microclimate including temperature, relative humidity and light intensity is considered a key factor for increased yield in maize-soybean intercropping systems (He et al., 2012). High temperature, light intensity and low humidity in intercropping systems raise the photosynthetic rate of leaves and improve the biological characters of maize plant. Maize is a dominant crop capturing more sunlight as compared to soybean in maize and soybean intercropping system (MSIS). The microclimate environment such as light intensity and spectral properties within the soybean plant canopies are changed (Yang et al., 2014). Morphophysiological changes are also observed such as stem elongation, increased lodging, reduction in chlorophyll *a/b* ratio and leaf size, improvement in soybean photosynthetic efficiency and specific leaf weight (Liang et al., 2014). However, the soybean recovery response to shade stress is very significant under maize-soybean intercropping systems (Wu et al., 2016) because wide-narrow row planting of alternating maize and soybean (200 cm bandwidth 2:2, maize-to-soybean

rows) is useful for the high light interception for the soybean (Figure 2(a)). In addition, it is also found that maize-soybean intercropping patterns affected the leaf area index and photosynthetically active radiations (PAR) interception. On the other hand, two maize and two soybean strips intercropping pattern appeared as an efficient resource user with maximum yield (Matusso et al., 2014). Moreover, in our recent research the maximum group water use efficiency was observed under maize-soybean relay strip intercropping compared to sole cropping, and maximum total yield, group water use efficiency and water equivalent ratio were recorded in 40–50 cm maize narrow spacing (Rahman et al., 2017b).

2.2. Weed, pest and disease control

Weed, pest and diseases cause serious damage to crops. They reduce the quality and yields of crop products. Intercropping plays an important role to minimize weed, pest and disease attacks (Eskandari, 2011; Xiao & Zheng, 2004). Among different intercropping systems, we found strip intercropping has an important role to suppress the pest incidence (Ramert et al., 2002). Different field experiments were conducted to investigate the yield reduction and level of damage caused by stem borers in sole maize and maize intercropped with cassava, soybean and cowpea (Chabi-Olaye et al., 2005). The result demonstrated that a high larval density



1. Resource Utilization

- Field microclimate improvement
- High light interception

2. Weed, pest and disease control

- Suppress pest incidence
- Less weed infestation

3. Improve soil fertility and N acquisition

- Long term immobilization of N
- Reduces application of N

4. Yield and economic benefits

- Maximum land use efficiency
- Maximum net income

Figure 2. (a) Planting geometry of maize-soybean relay strip intercropping system. The green circles indicate soybean plants and the orange circles indicate maize plants. (b) Maize-soybean relay strip intercropping system that has been popularized in the southwestern China due to numerous benefits.

(21.3–48.1%) was found at early stage of plant growth in sole crop of maize compared with intercrop. Sole crop of maize had more stems tunneled and cobs were damaged than intercrop that resulted in lower maize grain yield. Moreover, significantly lower termite attack was found in maize–soybean intercropping than maize intercropped with common beans and groundnuts (Sekamatte et al., 2003). Substantial advantages of MSIS were also observed as weed control (Dolijanović et al., 2008). Less weed infestation, weeds biomass, numbers of weed species and weed plants per species were recorded in maize–soybean intercropping systems than that of sole crops (Kumar et al., 2003; Matusso et al., 2014). Particularly, less weed biomass was observed in 1:3 row ratios than that of 1:1 and 1:2 row ratios in MSIS (Kumar et al., 2003). Consequently, less weed, pest and disease attack aided to increase total intercropped yields in maize–soybean intercropping system.

2.3. Improve soil fertility and nitrogen acquisition

Cereal–legume intercropping is a sustainable land management practice. This practice contributes to long-term immobilization of nitrogen and controls the currently growing dependence on nitrogenous fertilizers (Regehr et al., 2015). Additionally, it helps to maintain and improve the soil fertility because leguminous crops like soybean, cowpea and groundnuts accumulate nitrogen from 80 to 350 kg ha⁻¹ (Mobasser et al., 2014). These practices not only facilitate the nitrogen uptake but also decrease the nitrogen losses and increase the biomass. According to Shaoming et al. (2004), the biomass and nitrogen uptake amount increased 47.02% and 57.53%, respectively, by maize plant in intercropping, while the lower biomass (14.56%) and nitrogen uptake (1.21%) were recorded by intercropped soybean. Former studies have shown that increased rate of nitrogen application such as 240 kg ha⁻¹ has weakened the excellence of maize–soybean relay strip intercropping. Therefore, we can improve nodules per plant, nitrogen fixation potential and ultimately nitrogen uptake by reducing nitrogen application rate from 240 to 180 kg ha⁻¹ (Yang et al., 2014). Reduced application of nitrogen fertilizer in maize–soybean relay strip intercropping increased the component yield for maize, soybean and total yield by 4.95%, 7.07% and 5.35%, respectively (Chen et al., 2017; Qian et al., 2014). In addition, maize intercropped with soybean significantly accumulated high total N than the sole maize and thus improved the system capacity (Zhang et al., 2015).

2.4. Yield and economic benefits

Land equivalent ratio (LER) is a common index used to measure the land productivity of intercropping systems. LER > 1 indicates the effective utilization of land in any intercropping system because of efficient utilization of resources by intercrops (Willey & Osiru, 1972). The following formula is used to assess the performance of intercropped crops relative to that of the corresponding sole crops in our systems (Li et al., 1999):

$$\text{LER} = \text{LER}_M + \text{LER}_S = \frac{Y_{M,I}}{Y_{M,S}} + \frac{Y_{S,I}}{Y_{S,S}} \quad (1)$$

where LER_M and LER_S are the relative yield of maize and soybean in intercropping, Y_{M,S} and Y_{M,I} are the sole and intercropped maize yield, whereas Y_{S,S} and Y_{S,I} are the sole and intercropped soybean yield, respectively.

In China, previous research on traditionally sown maize–soybean intercropping revealed that the maximum LER did not exceed 1.2, and the average grain yield of maize and soybean can reach up to 7274 and 1004 kg ha⁻¹, respectively (Lv et al., 2014). Whereas in Pakistan Ullah et al. (2007) recorded a high LER of about 1.62 when maize was intercropped at 90 cm double row strips with soybean, which also indicated the higher land use efficiency and maize grain yield (6710 kg ha⁻¹) over sole cropping. Furthermore, they also observed the maximum net income (Rs. 56043.50 ha⁻¹) in intercropping over sole crop of maize (Rs. 52653.50 ha⁻¹). Similar results were obtained by Khan et al. (1999) about high total relative yield with maximum LER (1.48) and gross income (Rs. 23197 ha⁻¹) in maize–soybean intercropping system over sole cropping. A field experiment was carried out by Kumar et al. (2003), and they also confirmed the importance of maize–soybean intercropping system in terms of yields and economics prospects in India. They observed the high mean maize equivalent yield of about 4262 kg ha⁻¹, LER (1.34), benefit–cost ratio (1.60) and net returns (Rs. 6909 ha⁻¹) with 1:1 row ratio in maize–soybean intercropping system, whereas Waktola et al. (2014) recorded the maximum gross monetary value of intercrops in Ethiopia (ETB 12176.00 ha⁻¹).

However, by comparing the mechanized-based maize–soybean relay strip intercropping system with the other intercropping systems practicing across the world, it is clear that the new maize–soybean intercropping practice is more efficient in terms of LER. Mechanized-based maize–soybean relay strip intercropping system has multifold and convincing results of LER and average grain yield in

Table 1. Comparative analysis of maize and soybean intercropping systems in different countries.

Country	Plant density in monocropping system ($\times 10^3$ plants ha^{-1})		Plant density in intercropping system ($\times 10^3$ plants ha^{-1})		Sole crop yield (kg ha^{-1})		Intercrop yield (kg ha^{-1})		LER	Reference
	Maize	Soybean	Maize	Soybean	Maize	Soybean	Maize	Soybean		
China (traditional)	167	167	83	83	10,186	2414	7274	1004	1.14	(Lv et al., 2014)
China (MSIS)	59	117	59	117	7190	1470	6350	2180	2.36	(Chen et al., 2017)
Democratic Republic of the Congo	53	160	40	160	1558	568	985	423	1.52	(Muyayabantu, Kadiata, & Nkongolo, 2013)
Egypt	71	143	24	95	8781	2322	6890	1446	1.41	(Aziz et al., 2012)
Ethiopia	44	500	44	375	3190	1994	2769	909	1.28	(Waktola et al., 2014)
Ghana	56	111	56	222	3360	1550	4000	590	1.56	(Addo-Quaye, Darkwa, & Ocloo, 2011)
India	83	333	42	250	3545	1090	2465	960	1.54	(Yogesh et al., 2014)
Iran	90	330	45	165	10,052	2232	10,192	1850	1.67	(Mahmoudi et al., 2013)
Kenya	27	222	19	143	4950	1440	6110	350	1.81	(Matusso, Mugwe, & Mucheru-Muna, 2013)
Nepal	40	200	40	200	4760	1990	4270	1260	1.38	(Khatri, Dahal, Amgain, & Karki, 2014)
Nigeria	33	200	33	200	5200	1280	4800	1210	1.87	(Ijoyaha & Fanen, 2012)
Serbia	36	400	36	400	10,682	2218	13,257	1929	2.11	(Dolijanović et al., 2009)

China (traditional): Intercrop yields were adjusted to whole plot basis.

Democratic Republic of the Congo: Maize sole crop yield was calculated from gross income and maize unit price (300 CDF/kg).

Egypt: 1 aradab = 200 kg, 1 feddan (fed.) = 0.42 ha.

India: 1 q = 50 kg.

China. The LER typically ranged between 1.64 and 2.36 (Table 1). Moreover, the corresponding average grain yield is approximately 6790–11475 kg ha^{-1} for maize and 1510–2364 kg ha^{-1} for soybean, which indicates much higher values than those obtained using the previous traditional models (Xiwen et al., 2015; Zhang et al., 2011).

3. Comparative analysis

Maize–soybean intercropping systems provide massive advantages for small land-holder farmers in low-input and high-risky environment. Both crops can usually grow simultaneously in narrow and adjacent strips, which is called strip intercropping. These strips are wide and close enough to allow separate crop production using machines and interaction with each other. Planting a second crop into existing crop in the field at the time of reproductive stage is known as relay strip intercropping system. Relay strip intercropping of maize and soybean is famous in southwestern China (Figure 2(b)). As described before, both intercropping systems are used to improve the land use efficiency and to increase yield of crops. Moreover, efficient resource utilization and minimum incidence of pests, diseases and weeds are additional benefits of intercropping systems. Below we tried to compare the maize–soybean strip and relay strip intercropping system (200 cm bandwidth 2:2, maize-to-soybean rows) practice in the southwest of China with those practicing in the other developing countries.

3.1. Asia

3.1.1. China

The current world population is around 7 billion, and it is estimated to be 9 billion by the end of 2050. With the bulk of this growth, providing food for the 9 billion people in the future is a big challenge. China will have to face the largest challenge of this century to increase cereal production to about 600 Mt by 2030 to ensure food security (Miao et al., 2010). Therefore, several strategies have been practiced such as crop rotations, high rate of fertilizer application and intercropping by Chinese farmers in traditional farming systems. It is obvious that the crop yield also increased because of fertilizer application. On the contrary, inappropriate application of fertilizers also contributed to boosting the environmental hazards. Phosphorus accumulation and its leaching have been increased severely in Chinese soils, about 67% of phosphorus source resulting in water pollution (Zhong et al., 2003). Moreover, traditional intercropping systems are not capable to fulfill the demand of growing population and cause depletion of natural resources, inefficient utilization of nutrients and environmental pollution. Chinese farmers have intercropped soybean with wheat, maize, millet, cotton, etc., in traditional ways (Knörzer et al., 2009; Li et al., 2013). Traditionally MSIS was grown in single row with 40–50 cm row distance between maize and soybean. Conventional intercropping field layout often resulted in low LUE, RUE, low comparative profits of soybeans and incompatibility with mechanization (Lv et al., 2014; Yang et al., 2014). Moreover, farmers had no suitable high yield variety for intercropping and always used manpower to manage

crops in the field, which is not optimal to increase crop yields.

A new maize–soybean intercropping played a vital role to increase the maize production with minimal to no yield loss and successively soybean yield. This system was developed through collaborative research for over a decade. Several studies have been carried out on the critical aspects of intercropping such as varietal breeding and screening, planting pattern (Yang et al., 2015), lodging resistance (Luo et al., 2015), fertilizer management (Yong et al., 2014), water use efficiency and water distribution (Rahman et al., 2017b), relative crowding coefficient, competitive ratio, actual yield loss, intercropping advantage indices, growth improvement and light irradiance (Yang et al., 2014).

In this system, border row effect contributes to intercrops over yield with small mechanical operations (Knörzer et al., 2009). Mechanical operations are possible with proper space of crop width configurations and optimum crop widths ensure the proper mechanization implementation in intercropping system (Xiwen et al., 2015). In our research team, a wide range of research has previously been reported to suggest the appropriate planting geometry that can ensure high yield and LER, nutrient acquisition, light interception and mechanical operations in maize–soybean intercropping systems (Yang et al., 2015). One strip of soybean consists of two or three rows of soybean with a row-to-row distance 40 or 30 cm, respectively. Another strip contains two rows with a distance of 30 or 40 cm used for maize in mechanized-based maize–soybean strip intercropping system. Traditionally, 40 cm was kept between the strips of maize and soybean but in our system 60–70 cm distance is used to facilitate the maize and soybean plants for efficient utilization of resources (Figure 2(a)). The grain yield of recently conducted 2-year experiment in Shandong province was 9765–11,710 kg ha⁻¹ and 1527–1538 kg ha⁻¹ for maize and soybean, respectively, with a LER of 1.4. In another field demonstration of maize–soybean relay intercropping, we obtained the maximum grain yield of 12,750 kg ha⁻¹ for maize and 1650 kg ha⁻¹ for soybean in Ningxia Hui autonomous region in 2014. These results revealed that the output potential of new mechanized-based maize–soybean strip intercropping is much higher than that of traditional maize–soybean intercropping systems (Liu et al., 2017c; Lv et al., 2014).

An important revolution in improved intercropping systems is the mechanized sowing; fertilizing and harvesting. A special four-wheel tractor decreases the wheel distance (2870 × 1300 × 1900 mm). A series of machinery like maize sowing machine, soybean sowing machine, maize combine harvester, soybean combine

harvester and maize soybean simultaneously sowing machine with fertilization has innovated for intercropping systems (Figure 1). This machinery can even be used in plain areas as well as in hilly areas.

The success of intercropping system profoundly depends on the temporal and spatial complementarity of resource utilization (Xue et al., 2016). Maize–soybean relay strip intercropping not only decreases nitrogen losses but also reduces the ammonia volatilization rate. In maize–soybean relay strip intercropping followed by 2:2 maize-to-soybean rows, the reduced application of nitrogen fertilizer increases the component yield for the maize crop, soybean crop and the total yield by 4.95%, 7.07% and 5.35%, respectively (Qian et al., 2014). The onset of efficiently functional nodule system is important for nitrogen fixation, and the chances of nitrate leaching can be minimized by intercropping (Graham, 2008). A previous study has shown 20.2% higher nitrogen uptake for maize in maize–soybean relay strip intercropping (Yong et al., 2014). Another study reported on the rational application of phosphorus demonstrated that interspecific interactions and rational application of P can enhance the phosphorus uptake and increase yield for maize–soybean relay strip intercropping (Wang et al., 2017).

The better use of aboveground resource, for example, high interception of sunlight, and efficient conversion of intercepted radiation within time and space is attributed to the fundamental features of maize–soybean intercropping. The space between maize and soybean plants not only affects the PAR efficiency, but also influences canopy structure for the intercropped soybean. Therefore, it is important to explore an optimum spatial-temporal configuration of intercropping systems. After a collaborative research on space deployment, it was evaluated that increase in the distance between soybean and maize rows and decrease in the spacing of maize narrow rows might be useful for the high light interception for the short soybeans and high group water use efficiency in maize–soybean intercrops systems (Liu et al., 2017b; Rahman et al., 2017a). Furthermore, due to shading effect caused by maize, the morphological changes in soybean plants were observed such as soybean stem elongation, reduction in leaf size and ultimately lodging of the soybeans in traditional maize–soybean intercropping system (Liu et al., 2017a). Keeping in view this problem, the shade-susceptible and shade-insensitive genotypes have been screened out (Liu et al., 2017a, 2015). It seems that the cultivation of semi-dwarf and shade-tolerant soybean cultivars in maize–soybean mechanized-based intercropping could be helpful in minimizing the influence of shade.

The optimum bandwidth and maize narrow-row spacing 200 and 40 cm, respectively, are considered best in maize–soybean relay strip intercropping with 2:2 rows ratio (Yang et al., 2015) (Figure 2). The maximum LER 2.36, which indicates the effective utilization of land in intercropping system, was recorded (Chen et al., 2017). In maize–soybean relay strip intercropping system, soybean is sown into existing maize in the field at the time of reproductive stage and maize plant controls the vegetative growth of soybean. However, after maize harvesting, soybean shows recovery growth at reproductive stage. Eventually, it increases the total yields and LER of system (Chen et al., 2017). Maize–soybean relay intercropping system is widely practiced in southwestern China that involves the same planting density with sole crop and ensures the yield stability of sole crop and total yields in intercropped maize with soybean (Yan et al., 2010). Therefore, we suggest that popularity of fully mechanized-based ‘2:2’ maize–soybean intercropping model with an appropriate rows arrangement can facilitate the mechanization in plain areas as well as in hilly areas.

3.1.2. Iran

Soybean cultivation in Golestan province with several biological advantages of intercropping to increase yield has been reported. As mentioned before, intercropping shows a complementarity effect of intercrop components on environmental resources consumption. Maize–soybean intercropping system can increase the production and yield of both crops. Amini et al. (2013) carried out a research to evaluate the yield and yield components of maize with soybean and sunflower in different strip intercropping systems. They revealed the significance of maize intercropped with soybean. They found that maximum chlorophyll content of maize, ear length, grain number of row in ear, number of grain in plant, grain yield and harvest index were attained in maize–soybean intercropping. Amjadian et al. (2013) observed the maximum yield in mixed planting ratio at 50 cm space between rows; soybean P × P distance 4 cm and maize P × P distance was 15 cm. Actually, planting pattern is the mixed ratio of maize and soybean (50/50) with suitable space between rows that improved the land use efficiency and increased the total productivity per unit area (Rezvani et al., 2011). However, question arises for mechanization in MSISs. Moreover, competition for resources occurs in mixed planting that may lead to yield reduction (Carruthers et al., 2000). Considering the best row ratio, 3:4 and 3:6 gave the maximum grain yield of maize (10,192 kg ha⁻¹) and soybean (1850 kg ha⁻¹), respectively, in maize–soybean intercropping system with LER > 1

(Mahmoudi et al., 2013). They kept the row distance at about 75 and 37.5 cm, respectively, for maize and soybean.

However, proper row arrangement can ensure the maximum grain yield stability with mechanical operations in maize–soybean intercropping system. Proper spatial arrangements for both crops can reduce competition with possibility of growing plants in strips. Both crops can get advantage by growing in strips and such maize–soybean strip and relay strip intercropping in wide-narrow row combination can facilitate the mechanical operations.

3.1.3. Pakistan

Pakistan is a country where population and food demand are increasing day by day. Shortage of edible oil is a critical problem in the country. In 2009–2010 the total demand of edible oil was 4.12 million tons. Therefore, 65% of the country’s requirement of food oil was met through imports (Wing, 2010). Maize and soybean have an ability to overcome the edible oil shortage. Both are valuable food grain crops and can be a high substitute as maize and soybean oil (Hayder et al., 2003).

Several attempts have been made to introduce soybean crop for commercial planting in all provinces of Pakistan. Intercropping of maize with soybean and sunflower was initially introduced in northwest Khyber Pakhtunkhwa province (Khan et al., 1999). The relative yield total, LER (1.48) and gross income of Rs. 23,197 ha⁻¹ were reported maximum in maize–soybean intercropping. Mechanization could be possible for potentially beneficial system as it is noted that maize with row-to-row distance of 75 cm and two rows of soybean among maize rows having row to row distance of 30 cm gave the highest yield, LER and net income (Hayder et al., 2003). A similar research by Ullah et al. (2007) concluded that 90 cm spaced double row strips produced highest grain yield, LER and net income. Further research is needed to make this system more compatible with mechanization, which will be helpful toward yield stability. Although farmers’ fields have high yield potential in Pakistan but yield recovery is still very low because of inadequate input use (high yielding varieties, etc.) and lack of suitable crop management technologies (Harris, 1975).

3.2 Africa

3.2.1. Nigeria

Maize and soybean cultivation in Nigeria has a wide scope in terms of major source of food, economic

importance and sustainability. Soybean is cultivated on a large scale in Nigeria, especially in west of Nigeria and central Africa (Root et al., 1987). There is a dire need to improve the planting techniques so that crop yields could be increased in the farming systems. In savanna zone of south western Nigeria, maize and soybean are planted together on flat with inter- and intra-row planting arrangements that gave maximum intercrop returns from maize and soybean however less than total returns by 5.88% from sole cropping of soybean (Raji, 2007).

Moreover, an identical plant density confirmed the yield and economic stability. A high total monetary return was recorded with 53,330 ha⁻¹ maize densities in intercropping (same density as sole cropping) in both early and late seasons (Muoneke et al., 2007). For mechanical-based intercropping, it is crucial to develop such planting patterns with proper narrow-wide rows combination that ensure the maximum yield, LER and economic return. Since crop row arrangement is also a function of plant density, therefore suitable row arrangement can intercept maximum light at wide row spacing than at narrow. Considering the row arrangement, Undie et al. (2012) noted that 2:2 arrangement in late season of maize–soybean intercropping at the spacing of 37.5 cm from maize to maize or maize to soybean produced highest soybean and maize grain yield in the humid southern Nigeria. However, it does not confirm that either these cropping patterns allow mechanization or not and still more work is needed for better production of maize–soybean intercropping in Nigeria.

3.2.2. Egypt

Maize and soybean could be considered as important cereal and legume crops for human food and livestock feed in Egypt. There is a need to increase the choice of soybean and maize cultivation through intercropping system. This system could increase the profitability and agricultural production for Egyptian farmers (Metwally, 1999). Several researches have been reported to improve LER and grain yield of maize and soybean intercropping. For example, El-Edward et al. (1985) reported that LER, grain yield and weight of 100-grain increased when soybean was intercropped with maize. Metwally et al. (2005) carried out a research to study the effect of LER and yield of intercropped maize with soybean under three intercropping patterns. Results showed that alternating ridge 2:2 give higher yield, LER and net return than other cropping patterns. Similar result was found by Aziz et al. (2012) that 2:2 and 2:4 intercropping systems give the maximum values of LER, net return and grain yield.

Maize productivity is greatly affected by keeping the distance 30–90 cm between maize hills, and it increases at 90 cm distance between hills in maize intercropped with soybean. In addition, it reduces inter- and intra-specific competition (Abdel-Galil et al., 2014). Nevertheless, they recorded the highest maize grains and soybean seeds (7650 and 1950 kg ha⁻¹, respectively) in mixed intercropping pattern. El-Shamy et al. (2015) also observed that maize plants of mixed pattern have the highest nitrogen use efficiency (NUE) and ear leaf N content by improved underground conditions in rhizosphere. The maximum NUE in mixed pattern mainly due to plant density reached at 100% of sole cropping. The intercrop planting density matches with sole crop that confirms the yield stability of sole crop and mixed yields in intercropping maize with soybean. However, still more work is needed on spatial arrangements to maximize yields and introduction of mechanized-based maize–soybean intercropping system in a country.

3.3 Questions and implications of maize soybean intercropping systems

The maize–soybean intercropping system can be practiced in any region of the world, where either maize or soybean can grow. As mentioned above, the use of intercropping has many benefits for crop production, but why is it most applicable in China? This is an important question. This intercropping system can be a remarkable breakthrough for high output in the field of agriculture. Strip intercropping is an environment-friendly strategy, which is highly efficient in nutrient utilization, and light interception. It is worth mentioning that formerly Sichuan province was not a major soybean production area. But now due to potential benefits of maize–soybean mechanized-based intercropping system, this province occupied sixth position in terms of area and fifth position in terms of production in the major soybean-producing provinces in China. The accumulated promoted area reached 2204 million ha and obtained 12,876 billion yuan of social and economic benefits since started to demonstrate and promote in 2003 (<http://www.moa.gov.cn>). Chinese farmers and government have accepted environment-friendly system; therefore, it has been extended to 21 provinces of China (Figure 3). Recently, the Ministry of Agriculture of China has recommended soybean strip intercropping as a major technology to farmers in maize and soybean planting regions. Combined with compact planting strategies, the crop density of strip intercropping has increased. As a result, the yield of maize can be maintained at a monoculture level and extra soybean production can be obtained, providing additional benefits

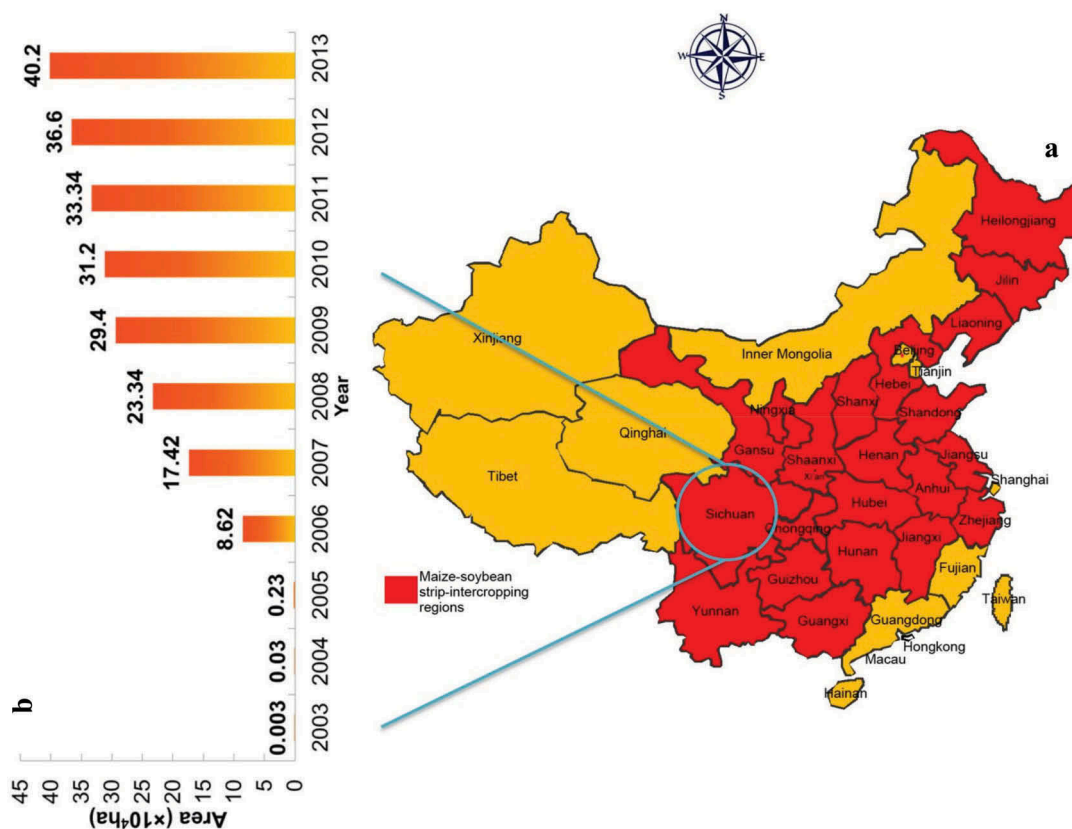


Figure 3. (a) Popularization of mechanized-based maize–soybean intercropping system in China. (b) Production area of soybean under mechanized-based maize–soybean intercropping system in Sichuan Province, China.

compared with maize monocropping. Improved intercropping systems due to the advancement of breakthrough innovative techniques can play a pivotal role to boost domestic soybean production in China.

Another question concerning the maize–soybean intercropping system is its applicability worldwide. As maize–soybean intercropping has a potential to increase the soil fertility, LER, yield per unit land area and net return in world farming system. Therefore, several researchers other than above-mentioned countries have also indicated the significance of this system (Dolijanović et al., 2009; Duàa & Roman, 2013; Polthanee & Trelo-Ges, 2003). However, this system is adopted on small scales because many modifications and alterations are needed to be considered, for example, row arrangements, light and nutrients availability, inter- and intra-specific competition and mechanization. In addition, to optimize this system in more eco-regions especially in arid and semi-arid, we need to produce drought-resistant seeds.

The FAO statistical data (2009–2013) showed that on annual basis croplands are covered by approximately 56.53 million hectares of maize and 19.12 million hectares of soybean in developing Asian countries, and approximately 33.13 million hectares of maize and 1.52 million hectares of soybean in Africa (<http://faostat3.fao.org/>

[browse/Q/QC/E](#)). If maize and soybean strip intercropping practice is applied in all of these regions, at least 15,458 billion tons of extra maize grains and 14,933 billion tons of extra soybean grains could be obtained annually, indicating that it has great potential for current soybean intercropping systems to prevent future threats of food crises in developing countries. Undoubtedly, it will take a long time before mechanized-based intercropping systems will replace the existing intercropping and sole cropping. Therefore, maize–soybean strip and relay strip intercropping in wide-narrow row combination should be employed as an ideal technique to improve crop productivity in developing countries.

4. Conclusions

Intercropping of maize with soybean is a potentially high-efficient and sustainable cropping system. Conventional intercropping field layout most often results in low LUE, RUE and low comparative profits of soybeans. A new type of maize–soybean intercropping with higher LER, especially strip intercropping system, is widely practiced in the southwest of China since the last two decades. By contrast, the traditional maize–soybean intercropping systems used in countries other than China are not capable of adapting it in modern agriculture. Moreover, they are incompatible with

mechanization, which leads to low productivity. To fully exploit the potential benefits of mechanized-based maize–soybean intercropping systems, the role of agronomic measures and advancements in technology should be taken into account. Therefore, maize narrow-row and strip planting pattern along with soybean planted in wide rows between the maize rows emerged as an ideal technique to be considered and practiced widely in different agro-ecological zones to further elucidate its applicability.

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