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COMMENTARY

Soybean maize strip intercropping: A solution for maintaining food security in China

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Abstract

The practice of intercropping leguminous and gramineous crops is used for promoting sustainable agriculture, optimizing resource utilization, enhancing biodiversity, and reducing reliance on petroleum products. However, promoting conventional intercropping strategies in modern agriculture can prove challenging. The innovative technology of soybean maize strip intercropping (SMSI) has been proposed as a solution. This system has produced remarkable results in improving domestic soybean and maize production for both food security and sustainable agriculture. In this article, we provide an overview of SMSI and explain how it differs from traditional intercropping. We also discuss the core principles that foster higher yields and the prospects for its future development.

Keywords: strip intercropping, food security, soybean, maize, spatial arrangement

On February 13, 2023, the Chinese government released their 20th "No. 1 Central Document" with the goal of resolving issues surrounding agriculture, and it referenced soybean maize strip intercropping (SMSI) for the third time. SMSI is being promoted in China to raise the self-sufficiency rate of soybeans, which has been declining due to various factors such as decreasing per capita arable land and increasing food demand. Soybean cultivation is being displaced by the cultivation of other grains, leading to the annual importation of 100 million tons of soybeans, which creates political and economic pressures and increasing domestic environmental risks (Sun *et al.* 2018). In the past two decades, China has witnessed a consistent annual increase in soybean imports while experiencing a reduction in domestic self-sufficiency, which has reached a mere 15%. This concerning trend poses a significant threat to national food security. However, the adoption of the SMSI system has emerged as a pivotal solution for tackling these challenges. By covering an extensive area of 1.25 million ha in 2022 and yielding 1.22 million tons of soybeans, this innovative approach has successfully increased the self-sufficiency rate by 1.5 percentage points, marking the first surge in China's soybean production in decades.

The widespread implementation of this technology across China can be attributed to its seamless integration

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into modern agricultural practices through technological innovation, mechanization, and strategic alignment with national policies that are geared toward ensuring food production security (Iqbal *et al*. 2019). The "14th Five-Year Plan (2021–2025) for National Planting Development" of the Ministry of Agriculture and Rural Affairs of China stated that SMSI is projected to encompass over 3.3 million ha by 2025. With the continued promotion and adoption of this technology, China's soybean production capacity is set to grow, ultimately leading to self-sufficiency.

Overall, the efficient integration of SMSI into China's agricultural practices demonstrates a promising path towards improving food security through sustainable soybean production.

Beyond breeding: Revolutionizing cultivation practices for higher yields Ensuring food security in the face of limited arable land conditions requires innovative solutions. Cultivation techniques such as intercropping and dense planting have the potential to significantly increase crop yields and land productivity. In China, achieving soybean self-sufficiency through monoculture would require at least 100 million ha of arable land, whereas the current available land amounts to only 128 million ha. Intercropping presents a promising opportunity to expand soybean acreage despite the scarcity of cultivated land. If we view agriculture as a computer system, the breeding methods focused on increasing yield per plant can be considered the "microchips" of agriculture. On another level, cultivation can be likened to the "server" of agriculture, since it plays a crucial role in enhancing land productivity through an optimal field structure and support measures.

Inheritance and innovation: Not all intercropping is productive Traditional intercropping is characterized by either single-row cross intercropping (Fig. 1-A) or disorganized intercropping (Fig. 1-B). In these older models, light deficiency leads to very low yields of soybean, and the narrow row space is not suitable for mechanization. In the SMSI system, the single row is replaced by multiple-row strips, and the disorganization is replaced by a well-structured arrangement (Fig. 1-C). Compared to traditional intercropping, SMSI significantly increases the individual yield of the soybean crop by more than 40% (Liu *et al.* 2017). Additionally, SMSI allows for an additional harvest of 1,500–2,250 kg ha^{-1} of soybeans under conditions where the yield of intercropped maize is similar to the local net yield of maize. This is particularly notable considering that the average soybean yield in China is only 1,950 kg ha^{-1} (Liu *et al.* 2018). Additionally, shade-tolerant soybean varieties and compact leaf-oriented maize varieties can be selected to effectively improve the light condition of the soybean canopy and boost the soybean yield (Fig. 1-D) (Wu *et al.* 2021). Moreover, crop rotation within the same plot can be secured the following year by the switching planting locations in the maize strips and soybean strips (Fig. 1-E).

In recent years, SMSI has been widely demonstrated in China's most significant maize-producing regions. The SMSI system achieved an augmented output of soybean at 1,500–2,250 kg ha^{-1} and guaranteed a secure maize yield equal to that of monoculture maize. The entire area of maize in China is approximately 43 million ha. If 80% of the current maize area was used SMSI, an extra 52 million tons of soybean could be harvested, effectively controlling the contradiction between the supply and demand of maize and soybean (Wu *et al.* 2023). Moreover, SMSI effectively reduces energy consumption, diminishes greenhouse gas emissions, relieves monocropping restrictive effects, and fertilizes the soil, all of which make positive contributions to the efficient protection of arable land and the sustainable development of agriculture (Du *et al.* 2018).

Fundamental principles: Variety, light conditions, and planting density The successful implementation of SMSI relies on three core principles: the utilization of special varieties for optimal system suitability, the expansion of strip spacing for enhanced lighting, and the reduction of plant spacing to achieve higher density. The tolerance of soybeans for shade is improved by incorporating compact maize varieties with a smaller leaf angle (Fig. 1-F) (Liang *et al.* 2015). The expansion of spacing between the soybean and maize strips improves light conditions within soybean canopies (Liu *et al.* 2018) and enhances agricultural machinery passage through the rows (Fig. 1-G) (Iqbal *et al.* 2019). Furthermore, reducing plant spacing increases potential yield per unit area (Fig. 1-H). Specifically, when soybean and maize are intercropped in an optimal field configuration, the land equivalent ratio (LER) exceeds 1.6 (Yang *et al.* 2015). Crop density in the SMSI system is higher than in traditional intercropping. In the old intercropping system, maize is replaced directly by soybean, which reduces the maize density. In contrast, SMSI is an additive intercropping system in which maize is cultivated with a similar arrangement and plant number as its monoculture cropping equivalent; then, on the basis of a constant density of maize, soybean is added, thus increasing the total planting density (Chen *et al.* 2019). To illustrate, consider the density of monoculture maize in the local area, which is 76,923 plants ha^{-1}. In the SMSI system, the density of maize plants is also 76,923 ha^{-1}, while roughly 100,000 soybean plants are added to the maize field (Fig. 1-H).

Tackling the global food crisis: SMSI strengthens our position to ensure the food supply Like many other countries, China has seen its food security undermined

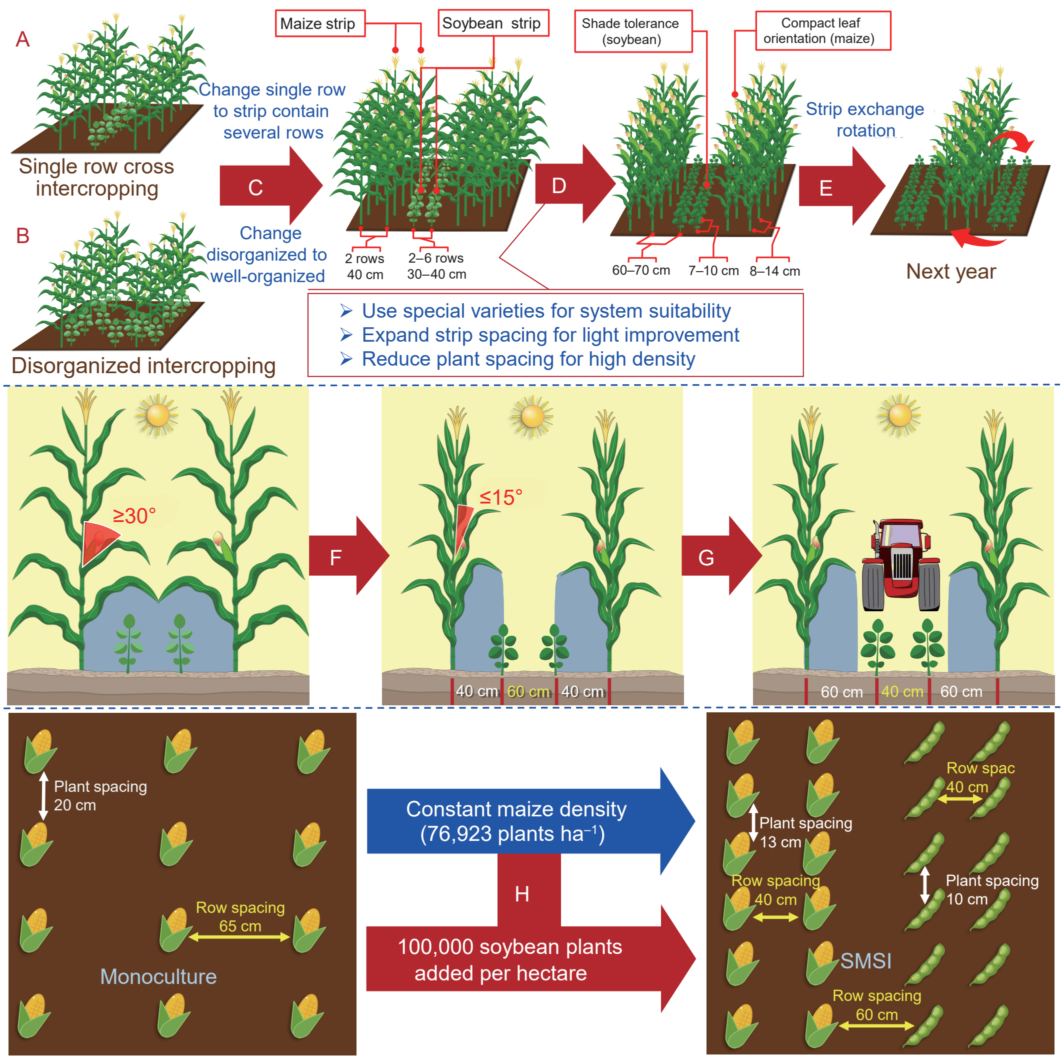

Fig. 1 Optimization process of soybean maize strip intercropping (SMSI) (A–E) and its core principles (F–H).

in recent years by extreme climate conditions and the COVID-19 pandemic. To tackle such challenges, the Chinese government needs to strategically increase land productivity and grain production. Since 2009, SMSI has been implemented on 6.7 million ha in China, with an additional 3.3 million ha expected by 2025. SMSI technology has been successfully introduced in South Asia, Europe, and Africa, with Pakistan in particular achieving notable success. Despite that country's previous lack of capacity for soybean production, the promotion of SMSI technology has resulted in a substantial advancement in the production of soybeans in Pakistan (Raza *et al.* 2021). The Pakistani government expects that SMSI will bring about a new "Green Revolution" in agriculture. Technological optimization and upgrading are crucial for SMSI success, such as breeding shade-tolerant soybean varieties, developing versatile herbicides, implementing intelligent agricultural machinery, and conducting basic research on symbiotic physiology and chemoecology. If implemented properly, SMSI can serve as a global reference in modern agriculture for increasing yields, optimizing resource utilization, reducing emissions, and enhancing soil fertility. These improvements will support sustainable development and food security, especially in developing countries.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

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