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Review Article

The research progress and application prospects of maize intercropping systems in enhancing farmland ecosystem services

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Abstract

Agricultural systems increasingly face soil degradation, resource scarcity, and climate change, positioning maize intercropping systems as a promising strategy to enhance ecosystem services in farmlands. This review highlights recent advancements and future prospects of maize intercropping systems in enhancing soil fertility, resource efficiency, and ecological sustainability. Maize intercropping systems leveraging ecological niche complementarity and interspecies facilitation, boost biodiversity, improve water, nutrient, and light use efficiency, and minimize dependence on chemical inputs. Furthermore, these systems play a critical role in pest and weed management, leading to higher crop yields and improved quality with reduced environmental impact. Despite the ecological and economic benefits, challenges persist, including technical constraints, limited regional adaptability, and obstacles to widespread adoption. Overcoming these challenges requires targeted mechanization, region-specific trials, and robust policy support. Future research should prioritize refining intercropping models, integrating advanced technologies, and formulating region-specific strategies to unlock the full potential of maize intercropping systems for sustainable agriculture.

Keywords: allelopathy; ecological niche complementarity; farmland ecosystem services; interspecies facilitation; maize intercropping systems; productivity advantage

Introduction

With the global population expected to reach 10 billion by 2050, food demand will rise sharply, intensifying pressure on agricultural systems to increase yields on existing arable land (Bijl *et al.*, 2017; Van *et al.*, 2021; Damari *et al.*, 2024). Soil degradation, over-cultivation, and improper fertilization have significantly reduced soil fertility, posing serious threats to sustainable agricultural productivity (Vashisht *et al.*, 2015; Gao *et al.*, 2019; Zhang *et al.*, 2020). Climate change has increased the frequency of extreme weather events,

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negatively affecting crop growth and destabilizing agricultural ecosystems (Donmez *et al.*, 2024; Hou *et al.*, 2024; Shah *et al.*, 2024). Agricultural systems must adapt to changing climates and adopt effective strategies to mitigate their adverse effects. The development of new cropping patterns and agricultural technologies to enhance resource use efficiency is essential to address the global agricultural crisis. Agricultural ecosystem services, such as nutrient cycling, water regulation, and natural pest control, rely on biodiversity and natural processes to support crop growth, reduce reliance on external inputs, and minimize environmental impacts (Costanza *et al.*, 1997; Swinton *et al.*, 2007; Liu *et al.*, 2022), supporting crop growth while reducing dependence on external inputs and minimizing negative environmental impacts (Kazemi *et al.*, 2018; Dardonville *et al.*, 2022; Ditzler *et al.*, 2023). Sustainable agriculture emphasizes maintaining and enhancing ecosystem services to boost productivity and ecological stability while minimizing environmental harm. Such services are crucial for tackling challenges in global food security, climate change, and environmental protection (Liu *et al.*, 2019; Qiu *et al.*, 2021).

Maize intercropping systems integrate diverse crops, offering a promising strategy to enhance agroecosystem services. This approach enhances soil fertility, water retention, and resource use efficiency while reducing erosion and minimizing chemical inputs (Du *et al.*, 2018; Li *et al.*, 2021; Ablimit *et al.*, 2022; Zhao *et al.*, 2024). Intercropping also mitigates pest pressures, making it a practical solution for improving ecosystem services under climate change and land scarcity (Kou *et al.*, 2024; Soujanya *et al.*, 2024; Yang *et al.*, 2025). Continued research on maize intercropping is crucial for its widespread adoption, supporting sustainable agriculture and contributing to food security and ecological sustainability.

Development Status and Trend Analysis of Maize Intercropping in China

Intercropping and relay intercropping are deeply rooted in China's history and have significantly influenced traditional agricultural systems (Zhang, 2021). Intercropping practices in China date back to the Western Han Dynasty (1st century BC). By the 6th century, the Qi Min Yao Shu described methods like intercropping legumes with millet in mulberry orchards. In the Qing Dynasty, the Nong Sang Jing documented relay cropping methods involving wheat and soybeans. Maize-legume intercropping was widely practiced even before the establishment of the People's Republic of China. Over time, these systems evolved from low-input, low-output models to high-input, high-output systems, becoming integral to modern agriculture (Li, 2016; Li *et al.*, 2020; Shi *et al.*, 2022). By the 1980s, wheat-maize intercropping spanned over 4 million hectares, accounting for more than half of China's maize planting area. In the 1970s, researchers optimized wheat-maize crop combinations to address food security, leading to significant yield increases, especially in Gansu and Inner Mongolia. Water shortages in northwest China led to the adoption of water-efficient systems like pea-maize intercropping, which gained popularity in the 2000s (Li, 2016).

Recent advancements in maize-soybean intercropping emphasize improved variety selection, optimized row spacing, and plant density, with support from mechanization and integrated pest management (Yang *and* Yang, 2019). These innovations have increased yields and achieved a land equivalent ratio (LER) exceeding 1.4, while improving light distribution and reducing nitrogen inputs (Yang *et al.*, 2017; Liu *et al.*, 2018). National policies encouraging crop rotation and intercropping aim to enhance ecological services, improve resource efficiency, and foster sustainable agricultural development. Consequently, maize intercropping systems have become a cornerstone of China's green agriculture strategy.

The Role of Maize Intercropping in Enhancing the Ecosystem Service Function of Farmland

Maize intercropping systems play a crucial role in enhancing farmland ecosystem services by integrating diverse crops to increase biodiversity and yields. These systems optimize the use of light, water, and nutrients, enhancing crop quality while offering effective ecological pest and weed control. This approach reduces pesticide dependency and lowers the risk of environmental pollution. Ultimately, maize intercropping enhances ecosystem services and supports sustainable agricultural development (Figure 1).

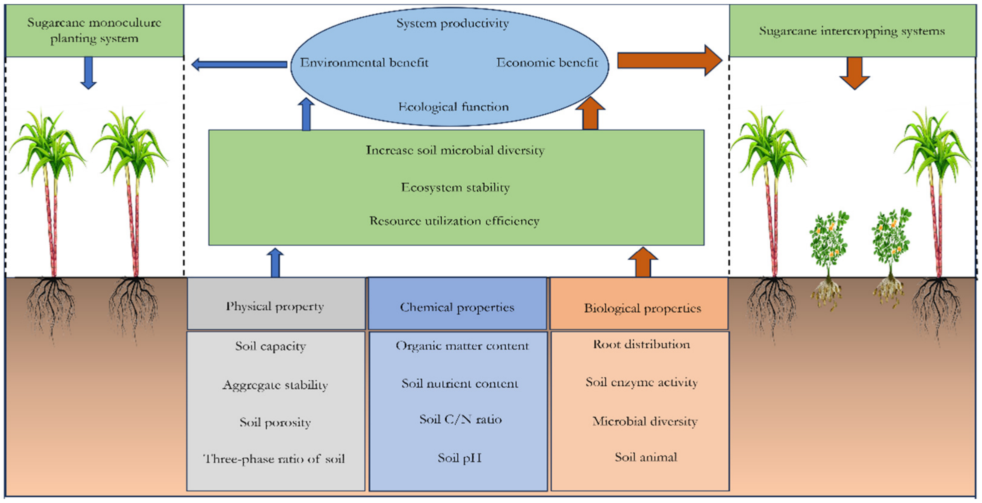

Figure 1. Maize intercropping systems strengthen farmland ecosystem services

Increasing farmland biodiversity

China's agricultural system is undergoing intensification aimed at maximizing monoculture productivity. While this approach has increased crop yields, it has also caused severe environmental challenges, including soil degradation, pest outbreaks, elevated greenhouse gas emissions, groundwater pollution, and reduced biodiversity due to excessive pesticide and fertilizer use. The focus on high-yield monocultures has further reduced crop diversity, exacerbating soil and environmental degradation (Liu *et al.*, 2010).

Intercropping, especially cereal-legume combinations such as maize with soybean (Liu *et al.*, 2016; Zhou *et al.*, 2016), peanut (Zou *et al.*, 2023), or faba bean (Stoltz *et al.*, 2014), effectively enhances crop diversity by cultivating multiple species together. Maize intercropping with non-legumes, such as wheat (Xia *et al.*, 2024), cumin (Zhang, 2021), and alfalfa (Xu *et al.*, 2022; Tao *et al.*, 2024), is also widely practiced. The diversity of crop traits, such as root structure and canopy distribution, enhances resource use efficiency and alleviates the drawbacks of monoculture systems. Aboveground diversity correlates with belowground biodiversity, improving root chemical profiles, exudate patterns, and microbial community structures. Tao et al. (2024) highlighted the importance of root traits in enhancing rhizosphere ecosystem services under intensive land use, while Zhu *et al.* (2022) found that intercropping consistently produces positive net effects across diverse environmental conditions. In phosphorus- and moisture-deficient soils, maize intercropping enhances rhizosphere interactions, leading to increased soil acidification, higher phosphatase activity, and greater microbial biomass phosphorus, ultimately boosting resource use efficiency and facilitation effects.

Increasing farmland productivity and economic benefits

Maize intercropping systems provide significant productivity benefits over monocropping, often measured using the land equivalent ratio (LER) (Zhang *et al.*, 2007; Shah *et al.*, 2016). An LER greater than 1 indicates that intercropping requires less land to achieve the same yields as monocropping (Willey, 1979;

Vandermeer,1989). In addition to productivity, economic benefits are a major driver for the adoption and development of intercropping systems (Qian *et al.*, 2018; Zhu *et al.*, 2022). Optimizing crop arrangements in intercropping systems enables multifunctional land use and multiple harvests, thereby enhancing resource efficiency, production stability, and farmer income. Kou et al. (2024) found that a two-row maize, four-row soybean intercropping system had LERs of 1.61 in 2022 and 1.42 in 2023, with significantly higher water productivity and economic profitability than monocropping. Similarly, Raza *et al.* (2021) found LERs between 1.31 and 1.45 in maize-soybean intercropping, along with improvements in water use efficiency. Du et al. (2018) found that selecting optimal cultivars and increasing planting density in maize-soybean intercropping can raise the LER to 2.2, enhancing nutrient uptake and preventing continuous cropping challenges. This system achieved high productivity without sacrificing maize yield, promoting sustainable agricultural practices.

Enhancing light and heat utilization efficiency and climate regulation functions

Maize intercropping improves light and heat efficiency through complementary crop arrangements and growth stages, maximizing solar radiation utilization and heat efficiency to enhance productivity (Liu *et al.*, 2018; Yang *et al.*, 2025). Intercropping improves microclimate conditions by reducing soil moisture loss, stabilizing temperatures, and increasing air humidity, thereby enhancing crop resilience and stability. Optimized resource use, combined with climate regulation, boosts yield and provides an effective strategy for mitigating climate change impacts (Knörzer *et al.*, 2011; Gou *et al.*, 2021). Zou *et al.* (2021) demonstrated that the rotational strip intercropping of maize (*Zea mays* L.) and peanut (*Arachis hypogaea* L.) (RMP) improved crop productivity compared to the continuous monoculture of maize (CM) or peanut (CP). Increased productivity in RMP mainly resulted from higher maize photosynthesis due to aboveground interspecific competition and optimized soil nutrients and bacterial communities for peanuts through below-ground interactions. Feng *et al.* (2020) observed that a narrow-wide row planting pattern in the maize-soybean relay intercropping system (MS) enhanced leaf greenness and green leaf area, delayed leaf senescence in maize, and increased the photosynthetic rate of maize leaves during the reproductive stages in MS. Guo *et al.* (2021) found that faba bean-wheat intercropping reduced the relative humidity of the faba bean canopy while increasing canopy temperature and light transmittance, creating a micro-ecological environment unfavorable for rust disease. Liu *et al.* (2019) found that maize-cotton intercropping significantly raised canopy temperatures of maize at upper, middle, and lower levels and of cotton at the middle level compared to monoculture.

Improving crop quality

Maize intercropping enhances yield and quality through complementary interactions between crops. Intercropping maize with legumes improves soil fertility through nitrogen fixation, thereby enhancing crop nutrition. Moreover, intercropping optimizes the microenvironment, reduces pest and disease incidence, minimizes pesticide use, and enhances food safety (Ning *et al.*, 2012; Zou *et al.*, 2021). Maize intercropping enhances nutrient uptake, improves soil structure, and strengthens crop resilience, leading to higher crop quality and market value. Begam *et al.* (2024) found that while sole maize cultivation resulted in better growth and yield, maize-cowpea intercropping significantly increased the total system yield by 13.6%. This strategy also improved grain quality by enhancing crude protein content and nutrient composition. Wang *et al.* (2024) found that compared to monoculture, maize-lablab bean intercropping significantly increased fresh forage yield (by 9.8%-17.0%), hay yield (by 9.59%-13.1%), crude protein yield (by 22.9%-25.9%), and water productivity (by 7.8%-8.7%). Javanmard *et al.* (2020) found that intercropping maize ('KSc301' variety) with hairy vetch produced the highest total forage and crude protein yields, while maize monoculture yielded the lowest. Intercropping 'KSc301' with grass pea improved total digestible nutrients, dry matter digestibility, dry matter intake, and net energy for lactation. In contrast, maize monoculture exhibited 19% and 29% higher acid detergent fiber and neutral detergent fiber contents, respectively, compared to intercropping systems.

Enhancing nutrient utilization efficiency

Maize intercropping improves nutrient use efficiency by leveraging complementary crop interactions to optimize soil resource utilization. Diverse root distributions and nutrient demands mitigate competition, while legumes intercropped with maize fix nitrogen and enhance phosphorus and potassium uptake. Moreover, intercropping stimulates beneficial microbial activity, enhancing nutrient transformation and overall efficiency (Wang *et al.*, 2017). Liu *et al.* (2024) reported that intercropping systems increased soil organic matter and total nitrogen by 4.4-14.3% compared to monocultures, with consistent effects across maize growth stages and irrespective of nitrogen application levels. Likewise, Ma *et al.* (2020) found that intercropping increased total yield by 68% relative to maize monoculture, with phosphorus uptake and use efficiency rising by 61% and 53%, respectively. Zhang *et al.* (2023) found that soybean-based intercropping systems with film mulching reduced nitrogen fertilizer use by 20% and improved nitrogen use efficiency (NUE) in maize. These findings highlight maize intercropping as a sustainable practice that enhances nutrient efficiency, minimizes fertilizer inputs, and boosts yields.

Promoting soil health

Maize intercropping promotes soil health by fostering diverse crop-root interactions that improve soil structure, water retention, and organic matter. It reduces erosion and enhances the soil's physicochemical and biological properties, laying a strong foundation for sustainable agriculture (Zuazo *et al.*, 2008; Berendse *et al.*, 2015; Kumari *et al.*, 2015). Secco *et al.* (2023) found that, in the short term, bulk density in the 10-20 cm soil layer was 10% lower when ruzigrass was sown before maize than under sole maize. Macroporosity was 17% higher when ruzigrass was sown before maize than when sown 15 days later and 33% higher than in sole maize without ruzigrass between the rows. Intercropping maize with ruzigrass improved soil physical quality most when ruzigrass was sown before or concurrently with maize. Sharma et al. found that, compared to maize monoculture, cereal-legume intercropping (maize and cowpea) reduced runoff by 26% and soil loss by 43%. It also increased income, promoted crop diversification, and strengthened soil conservation (Sharma *et al.*, 2017). Khokhar *et al.* (2021) found that maize-cowpea strip intercropping, with a 4.8 m maize strip and 1.2 m cowpea strip, significantly increased maize equivalent yield compared to sole maize and other intercropping systems. This system achieved the highest land equivalent ratio (1.24), offering a 24% yield advantage over monocropping. It also achieved the highest net returns (US$ 530 ha^{-1}) with a benefit-cost ratio of 2.09. Moreover, it reduced runoff and soil loss by 10.9% and 8.3%, respectively, relative to sole maize. Across all slopes, strip intercropping significantly reduced losses of N, P, K, and organic carbon while boosting yields and farmer income compared to sole maize.

Controlling disease and pests, suppressing weed growth

Maize intercropping systems manage pests and suppress weeds by disrupting their life cycles through diverse crop combinations (Gu *et al.*, 2021; Wu *et al.*, 2022; Agbor *et al.*, 2023). Leguminous crops, for instance, release volatile compounds that disrupt pest navigation and reproduction, while dense planting limits light for weeds, inhibiting their growth (Silberg *et al.*, 2019). Furthermore, biodiversity within intercropping systems attracts natural enemies and beneficial insects, effectively reducing pest pressure (Zhang *et al.*, 2000; Lin *et al.*, 2003; Men *et al.*, 2004). These mechanisms reduce reliance on pesticides and herbicides while promoting sustainable and eco-friendly agriculture (Poveda *et al.*, 2019). Soujanya *et al.* (2024) found that location-specific intercropping of maize with cowpea, groundnut, green gram, black gram, and red amaranthus effectively mitigated Fall armyworm damage, enhanced natural enemy populations, suppressed weed growth, and significantly boosted maize yields compared to monoculture. Pierre *et al.* (2022) found that maize-cowpea intercropping serves as a viable alternative to sole maize systems, enhancing maize yield and beneficial insect abundance without intensifying interspecific competition. Saudy *et al.* (2015) reported that maize-cowpea alternating ridge intercropping reduced weed biomass by 49.5% compared to sole maize, while maize grain yield remained comparable, particularly under medium to high nitrogen application (216 or 288 kg N ha^{-1}). The intercropping system also achieved the highest agronomic efficiency, producing 14.6 kg grain per kg N at 216 kg N ha^{-1} and saving 26% of cultivated land.

Mechanisms of Maize Intercropping Systems for Enhancing Farmland Ecosystem Service Functions

In maize intercropping systems, several fundamental mechanisms synergistically enhance farmland ecosystem services by optimizing resource utilization, boosting crop productivity, and promoting long-term ecological sustainability. Understanding and applying these processes are crucial for maximizing the agronomic, environmental, and economic benefits of intercropping. The following sections explore three key mechanisms—ecological niche complementarity, crop species interactions, and allelopathy—that underpin the successful implementation of maize intercropping systems, improving resource efficiency, increasing biodiversity, and stabilizing agroecosystems (Figure 2.) (Li, 2016; Li *et al*., 2020).

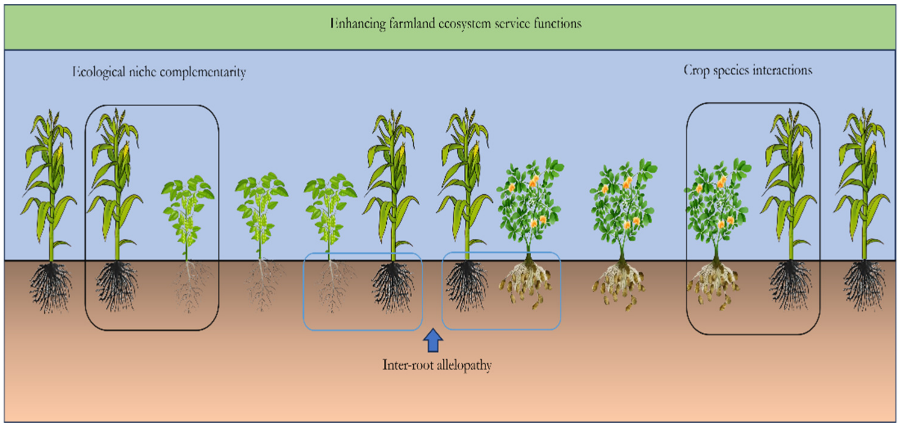

Figure 2. Mechanisms related to the enhancement of farmland ecosystem services by maize intercropping systems

Ecological niche complementarity

Ecological niche complementarity refers to how plants utilize resources differently across time and space, optimizing the allocation of light, water, and nutrients while reducing interspecies competition (Li, 2016). This mechanism plays a vital role in intercropping systems, enhancing resource use efficiency, crop growth, and yield, thereby promoting agricultural ecosystem stability and sustainability (Zhang *et al*., 2016). In maize intercropping systems, strategic crop arrangements—such as pairing tall with short crops, grasses with legumes, and deep-rooted with shallow-rooted plants—optimize spatial and temporal niche utilization, enhancing photosynthetic efficiency and overall yield. Functional synergy among crops fosters higher productivity and resilience, supporting long-term agricultural sustainability (Yang *et al*., 2012; Yin, 2017; Zhou *et al*., 2021).

For example, maize-cumin intercropping, with staggered sowing and growth periods, enables canopy differentiation across ecological niches, significantly improving light interception per unit area compared to monoculture. Intercropping systems also enhance belowground complementarity. Te *et al.* (2023) found that maize-soybean intercropping improved root growth, increasing root length density (RLD) by 72.15% in maize and 15.72% in soybean, as lateral roots expanded into inter-row spaces. Shen *et al.* (2023) found that maize roots extended beyond soybean rows, concentrating in the 0-20 cm soil layer, whereas soybean root growth was suppressed by maize. Despite this, intercropped systems maintained high nutrient and water uptake efficiency, even under resource-constrained conditions. Zhang *et al.* (2022) found that maize-soybean intercropping achieved a land equivalent ratio (LER) and water equivalent ratio (WER) of 1.10, with maize yield increasing by 45% due to a rise in kernel numbers. Furthermore, temporal water use complementarity promoted maize kernel formation and mitigated shading effects on soybean grain filling.

Crop species interactions

Inter-crop interactions involve competitive, facilitative, and compensatory relationships between plant species, which significantly influence crop performance, yield, and ecological outcomes (Hetrick *et al.*, 1989; Li *et al.*, 2001; Sekiya and Yano, 2004). Competition occurs when plants compete for limited resources like light, water, and nutrients, potentially suppressing the growth of some species. Facilitation, in contrast, happens when plants mutually enhance each other's growth by optimizing resource use or boosting biodiversity, a common feature of intercropping systems. Understanding these interspecies interactions allows for optimizing agricultural production, enhancing soil health, and promoting ecosystem services, ultimately supporting sustainable agricultural development (Callaway, 1995; Li *et al.*, 2020).

Many studies underscore facilitation in maize intercropping systems. For instance, Zuo and Zhang (2004) reported that peanut monocultures suffered from severe iron deficiency, whereas maize-peanut intercropping alleviated these symptoms, illustrating strong facilitation between the two crops (Zou and Zhang, 2004). Lv *et al.* (2014) found that in maize-soybean intercropping, maize increased its photosynthetic rate by absorbing more soil nutrients and water, which promoted maize growth but hindered soybean development, reflecting both competitive and facilitative interactions. Cheng *et al.* (2016) also found that maize-soybean intercropping enhanced light utilization and nutrient uptake, increasing crop biomass and yield and demonstrating the productivity benefits of intercropping These benefits stem from the optimal allocation of resources—light, temperature, water, air, and nutrients—which fosters complementarity, minimizes competition, and maximizes resource use efficiency, thereby fully realizing the yield potential of intercropping systems (Karlidag and Yildirim, 2009; Xia *et al.*, 2013).

Allelopathy

Allelopathy is the process by which plants release chemical substances from their leaves and root zones, altering the surrounding microenvironment and influencing the growth, development, and physiology of neighboring plants (Kong *et al.*, 2016; Latif *et al.*, 2017; Li *et al.*, 2020). This interaction is crucial in intercropping systems, where root exudates stimulate crop growth, boost yields, and decrease reliance on chemical inputs, thereby promoting sustainable agriculture (Robbins *et al.*, 2017; Jones, 2018; Brown *et al.*, 2019). Harnessing allelopathic effects can optimize crop performance, enhance yield and quality, and mitigate environmental pressures. Zhu *et al.* (2022) found that rhizosphere interactions in phosphorus-deficient soils enhance intercropping facilitation, primarily via soil acidification and microbial activity that stimulate phosphorus mineralization. This mechanism bolsters crop growth under stress and underscores the role of root exudates in facilitating interspecies interactions. Zi *et al.* (2019) observed that maize root exudates stimulate potato stem, root, and tuber growth, providing insight into the yield-enhancing effects of maize-potato intercropping. Additionally, allelopathy can be leveraged to suppress weeds and minimize pesticide use. Stoltz *et al.* (2014) found that intercropping maize and faba beans in organic systems reduced soil nitrogen residuals and weed incidence, enhanced protein content, and increased land use efficiency, achieving a land equivalent ratio (LER) greater than 1.

Key Issues and Future Directions for Maize Intercropping Systems

Although maize intercropping systems offer substantial ecological and economic benefits, their widespread adoption is hindered by several challenges. Technical and managerial challenges, including optimizing crop configurations and mechanization, limit their potential. Regional adaptability is crucial for performance across diverse climatic and soil conditions, necessitating resilient intercropping models tailored to specific environments. In arid regions, incorporating drought-resistant crops can enhance system stability and productivity. Site-specific soil analyses are critical, as variations in soil properties significantly influence crop interactions. Economic feasibility and promotional barriers also affect farmers' willingness to adopt intercropping, emphasizing the importance of comprehensive cost-benefit analyses and strong policy and financial support.

Addressing these challenges requires future research to focus on several key areas. Developing multifunctional maize intercropping systems is essential to enhance soil health and optimize resource use efficiency. Techniques like intercropping with legumes and nitrogen-fixing crops can boost soil fertility, lower input costs, and support sustainable, low-carbon agriculture. Integrating modern agricultural technologies, including precision farming, remote sensing, and advanced mechanization, can enhance the efficiency and scalability of intercropping systems. Strengthening regional adaptability and establishing effective promotion strategies are crucial for the broader adoption of maize intercropping systems. Tailored solutions, supported by robust policy frameworks and market incentives, are necessary to align intercropping models with local agricultural conditions. Finally, research should prioritize mitigating climate change impacts, improving resource use efficiency, and conducting extensive regional trials. These efforts will refine intercropping models for resilience and adaptability, thereby advancing the sustainable development of maize intercropping systems (Figure 3).

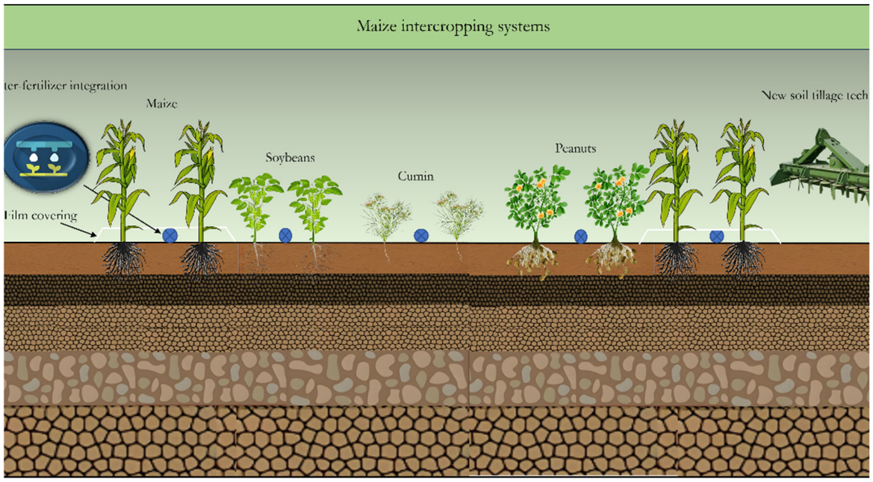

Figure 3. Future development of maize intercropping systems - integrated application of technology

Conclusions

Maize intercropping systems offer a promising solution to enhance farmland ecosystem services by improving biodiversity, optimizing resource utilization, and promoting soil health. Through complementary interactions between crops, intercropping increases productivity, enhances nutrient use efficiency, and improves resilience against environmental stresses. The integration of ecological niche complementarity, species interactions, and allelopathy in these systems significantly contributes to sustainable agricultural practices. Despite the evident benefits, challenges such as technical difficulties, regional adaptability, and economic feasibility must be addressed to ensure broader adoption. Future research should focus on refining intercropping models tailored to local conditions, optimizing resource efficiency, and addressing the impacts of climate change. With proper support and innovation, maize intercropping systems has the potential to contribute substantially to global food security and ecological sustainability.

Authors' Contributions

Conceptualization and Writing-Original draft: Wenlong Zhang; Project funding and resources: Wenlong Zhang, Jinhua Shao, and Kai Huang; Data curation: Jia Wang and Limin Chen; Software analysis and Visualization: Quan Li and Guanghui Niu; Writing-Review and Editing: Wenlong Zhang and Guoqin Huang. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Ablimit R, Li W, Zhang J, Gao H, Zhao Y, Cheng M, … Chen Y (2022). Altering microbial community for improving soil properties and agricultural sustainability during a 10-year maize-green manure intercropping in Northwest China. Journal of Environmental Management 321:115859. *https://doi.org/10.1016/j.jenvman.2022.115859*

Agbor DT, Eboh KS, Sama DK, Teche LM, Tanyi GT, Nkongho RN (2023). Maize-legume intercropping and botanical piper mitigating effect on pest populations while enhancing the yield of maize. Journal of Natural Pesticide Research 6:100060. *https://doi.org/10.1016/j.napere.2023.100060*

Bais HP, Weir TL, Perry LG, Gilroy S, Vivanco JM (2006). The role of root exudates in rhizosphere interactions with plants and other organisms. Annual Review of Plant Biology 57(1):233-266. *https://doi.org/10.1146/annurev.arplant.57.032905.105159*

Begam A, Pramanick M, Dutta S, Paramanik B, Dutta G, Patra PS, … Biswas A (2024). Inter-cropping patterns and nutrient management effects on maize growth, yield and quality. Field Crops Research 310:109363. *https://doi.org/10.1016/j.fcr.2024.109363*

Berendse F, Van Ruijven J, Jongejans E, Keesstra S (2015). Loss of plant species diversity reduces soil erosion resistance. Ecosystems 18:881-888. *https://doi.org/10.1007/s10021-015-9869-6*

Biedrzycki ML, Jilany TA, Dudley SA, Bais HP (2010). Root exudates mediate kin recognition in plants. Communicative & Integrative Biology 3(1):28-35. *https://doi.org/10.4161/cib.3.1.10118*

Bijl DL, Bogaart PW, Dekker SC, Stehfest E, De Vries BJ, Van Vuuren DP (2017). A physically-based model of long-term food demand. Global Environmental Change 45:47-62. *https://doi.org/10.1016/j.gloenvcha.2017.04.003*

Callaway RM (1995). Positive interactions among plants. The Botanical Review 61:306-349. *https://doi.org/10.1007/bf02912621*

Cheng YZ, Li L, Zhou Q, Guo N, Xing H, Jiang HD (2016). Growth and yield formation of maize under different maize/soybean intercropping patterns. Journal of Nanjing Agricultural University 39(1):34-39. *https://doi.org/10.7685/jnau.201504030*

Costanza R, D'Arge R, De Groot R, Farber S, Grasso M, Hannon B, ... Van Den Belt M (1997). The value of the world's ecosystem services and natural capital. Nature 387(6630):253-260. *https://doi.org/10.1038/387253a0*

Damari Y, Avital K, Tepper S, Shahar DR, Kissinger M (2024). Sustainable future food demand: integrating social, health, and environmental considerations in forecasting. Sustainable Production and Consumption 49:354-361. *https://doi.org/10.1016/j.spc.2024.07.003*

Dardonville M, Legrand B, Clivot H, Bernardin C, Bockstaller C, Therond O (2022). Assessment of ecosystem services and natural capital dynamics in agroecosystems. Ecosystem Services 54:101415. *https://doi.org/10.1016/j.ecoser.2022.101415*

Ditzler L, Rossing WA, Schulte RP, Hageman J, Van Apeldoorn DF (2023). Prospects for increasing the resolution of crop diversity for agroecosystem service delivery in a Dutch arable system. Agriculture, Ecosystems & Environment 351:108472. *https://doi.org/10.1016/j.agee.2023.108472*

Donmez C, Sahingoz M, Paul C, Cilek A, Hoffmann C, Berberoglu S, ... Helming K (2024). Climate change causes spatial shifts in the productivity of agricultural long-term field experiments. European Journal of Agronomy 155:127121. *https://doi.org/10.1016/j.eja.2024.127121*

Du JB, Han TF, Gai JY, Yong TW, Xin S, Wang XC, ... Yang WY (2018). Maize-soybean strip intercropping: achieved a balance between high productivity and sustainability. Journal of Integrative Agriculture 17(4):747-754. *https://doi.org/10.1016/S2095-3119(17)61789-1*

Faget M, Nagel KA, Walter A, Herrera JM, Jahnke S, Schurr U, Temperton VM (2013). Root–root interactions: extending our perspective to be more inclusive of the range of theories in ecology and agriculture using in-vivo analyses. Annals of Botany 112(2):253-266. *https://doi.org/10.1093/aob/mcs296*

Feng L, Raza MA, Shi J, Ansar M, Titriku JK, Meraj TA, ... Yang W (2020). Delayed maize leaf senescence increases the land equivalent ratio of maize soybean relay intercropping system. European Journal of Agronomy 118:126092. *https://doi.org/10.1016/j.eja.2020.126092*

Gao R, Pan Z, Zhang J, Chen X, Qi Y, Zhang Z, ... Xu X (2023). Optimal cooperative application solutions of irrigation and nitrogen fertilization for high crop yield and friendly environment in the semi-arid region of North China. Agricultural Water Management 283:108326. *https://doi.org/10.1016/j.agwat.2023.108326*

Gu C, Bastiaans L, Anten NP, Makowski D, Van Der Werf W (2021). Annual intercropping suppresses weeds: a meta-analysis. Agriculture, Ecosystems & Environment 322:107658. *https://doi.org/10.1016/j.agee.2021.107658*

Guo Z, Luo C, Dong Y, Dong K, Zhu J, Ma L (2021). Effect of nitrogen regulation on the epidemic characteristics of intercropping faba bean rust disease primarily depends on the canopy microclimate and nitrogen nutrition. Field Crops Research 274:108339. *https://doi.org/10.1016/j.fcr.2021.108339*

Hetrick BD, Wilson GT, Hartnett D (1989). Relationship between mycorrhizal dependence and competitive ability of two tallgrass prairie grasses. Canadian Journal of Botany 67(9):2608-2615. *https://doi.org/10.1139/b89-337*

Hou M, Li Y, Biswas A, Chen X, Xie L, Liu D, ... Siddique KH (2024). Concurrent drought threaten wheat and maize production and widen crop yield gaps in the future. Agricultural Systems 220:104056. *https://doi.org/10.1016/j.agsy.2024.104056*

Javanmard A, Machiani MA, Lithourgidis A, Morshedloo MR, Ostadi A (2020). Intercropping of maize with legumes: a cleaner strategy for improving the quantity and quality of forage. Cleaner Engineering and Technology 1:100003. *https://doi.org/10.1016/j.clet.2020.100003*

Karlidag H, Yildirim E (2009). Strawberry intercropping with vegetables for proper utilization of space and resources. Journal of Sustainable Agriculture 33(1):107-116. *https://doi.org/10.1080/10440040802587462*

Kazemi H, Klug H, Kamkar B (2018). New services and roles of biodiversity in modern agroecosystems: a review. Ecological Indicators 93:1126-1135. *https://doi.org/10.1016/j.ecolind.2018.06.018*

Khokhar A, Yousuf A, Singh M, Sharma V, Sandhu PS, Chary GR (2021). Impact of land configuration and strip-intercropping on runoff, soil loss and crop yields under rainfed conditions in the *Shivalik* foothills of north-west, India. Sustainability 13(11):6282. *https://doi.org/10.3390/su13116282*

Knörzer H, Grözinger H, Graeff-Hönninger S, Hartung K, Piepho HP, Claupein W (2011). Integrating a simple shading algorithm into CERES-wheat and CERES-maize with particular regard to a changing microclimate within a relay-intercropping system. Field Crops Research 121(2):274-285. *https://doi.org/10.1016/j.fcr.2010.12.016*

Kong CH, Hu F, Wang P (2016). Plant allelopathy and its application. Higher Education Press, Beijing.

Kou H, Liao Z, Zhang H, Lai Z, Liu Y, Kong H, ... Fan J (2024). Grain yield, water-land productivity and economic profit responses to row configuration in maize-soybean strip intercropping systems under drip fertigation in arid northwest China. Agricultural Water Management 297:108817. *https://doi.org/https://doi.org/10.1016/j.agwat.2024.108817*

Kumari VV, Balloli S, Kumar M, Ramana D, Prabhakar M, Osman M, ... Timsina J (2024). Diversified cropping systems for reducing soil erosion and nutrient loss and for increasing crop productivity and profitability in rainfed environments. Agricultural Systems 217:103919. *https://doi.org/10.1016/j.agsy.2024.103919*

Latif S, Chiapusio G, Weston LA (2017). Allelopathy and the role of allelochemicals in plant defence. Advances in Botanical Research 82:19-54. *https://doi.org/10.1016/bs.abr.2016.12.001*

Li L, Sun J, Zhang F, Li X, Rengel Z, Yang S (2001). Wheat/maize or wheat/soybean strip intercropping: II. Recovery or compensation of maize and soybean after wheat harvesting. Field Crops Research 71(3):173-181. *https://doi.org/10.1016/S0378-4290(01)00157-5*

Li L, Tilman D, Lambers H, Zhang FS (2014). Plant diversity and overyielding: insights from belowground facilitation of intercropping in agriculture. New Phytologist 203(1):63-69. *https://doi.org/10.1111/nph.12778*

Li XF, Han YC, Wang GP, Wang ZB, Feng L, Yang BF, ... Li YB (2020). Recent advances in the enhancement of agroecosystem services and functioning by cotton-based intercropping systems. Cotton Science 32(5):472-482. *https://doi.org/10.11963/1002-7807.lxflyb.20200826*

Li XF, Wang ZG, Bao XG, Sun JH, Yang SC, Wang P, ... Li L (2021). Long-term increased grain yield and soil fertility from intercropping. Nature Sustainability 4(11):943-950. *https://doi.org/10.1038/s41893-021-00767-7*

Lin R, Liang H, Zhang R, Tian C, Ma Y (2003). Impact of alfalfa/cotton intercropping and management on some aphid predators in China. Journal of Applied Entomology 127(1):33-36. *https://doi.org/10.1046/j.1439-0418.2003.00672.x*

Liu Q, Sun X, Wu W, Liu Z, Fang G, Yang P (2022). Agroecosystem services: a review of concepts, indicators, assessment methods and future research perspectives. Ecological Indicators 142:109218. *https://doi.org/10.1016/j.ecolind.2022.109218*

Liu R, Yang L, Zhang J, Zhou G, Chang D, Chai Q, Cao W (2024). Maize and legume intercropping enhanced crop growth and soil carbon and nutrient cycling through regulating soil enzyme activities. European Journal of Agronomy 159:127237. *https://doi.org/10.1016/j.eja.2024.127237*

Liu TT, Teng YX, Yang T, Li B, Wan SM, Chen GD, Zhang W (2019). Study on physiological and root morphological characteristics of maize and cotton intercropping. Agricultural Research in the Arid Areas 37(6):160-165. *https://doi.org/10.7606/j.issn.1000-7601.2019.06.23*

Liu W, Deng Y, Hussain S, Zou J, Yuan J, Luo L, ... Yang W (2016). Relationship between cellulose accumulation and lodging resistance in the stem of relay intercropped soybean [*Glycine max* (L.) Merr.]. Field Crops Research 196:261-267. *https://doi.org/10.1016/j.fcr.2016.07.008*

Liu W, Wang J, Li C, Chen B, Sun Y (2019). Using bibliometric analysis to understand the recent progress in agroecosystem services research. Ecological Economics 156:293-305. *https://doi.org/10.1016/j.ecolecon.2018.09.001*

Liu X, Rahman T, Song C, Yang F, Su B, Cui L, ... Yang W (2018). Relationships among light distribution, radiation use efficiency and land equivalent ratio in maize-soybean strip intercropping. Field Crops Research 224:91-101. *https://doi.org/10.1016/j.fcr.2018.05.010*

Liu X, Zhang X, Wang Y, Sui Y, Zhang S, Herbert S, Ding G (2010). Soil degradation: a problem threatening the sustainable development of agriculture in Northeast China. Plant, Soil and Environment 56(2):87-97. *https://doi.org/10.17221/155/2009-PSE*

Long L (2016). Intercropping enhances agroecosystem services and functioning: current knowledge and perspectives. Chinese Journal of Eco-Agriculture 24(4):403-415. *https://doi.org/10.13930/j.cnki.cjea.160061*

Lv Y, Wu PT, Chen XL, Wang YB, Zhao XN (2014). Crop resource competition in maize/soybean intercropping system. Chinese Journal of Applied Ecology 25(1):139-146. *https://doi.org/10.13287/j.1001-9332.2014.01.019*

Ma L, Li Y, Wu P, Zhao X, Gao X, Chen X (2020). Recovery growth and water use of intercropped maize following wheat harvest in wheat/maize relay strip intercropping. Field Crops Research 256:107924. *https://doi.org/10.1016/j.fcr.2020.107924*

Men X, Ge F, Yardim E, Parajulee M (2004). Evaluation of winter wheat as a potential relay crop for enhancing biological control of cotton aphids. Biocontrol 49:701-714. *https://doi.org/10.1007/s10526-004-5278-z*

Ning T, Zheng Y, Han H, Jiang G, Li Z (2012). Nitrogen uptake, biomass yield and quality of intercropped spring-and summer-sown maize at different nitrogen levels in the North China Plain. Biomass and Bioenergy 47:91-98. *https://doi.org/10.1016/j.biombioe.2012.09.059*

Pierre JF, Latournerie-Moreno L, Garruña R, Jacobsen KL, Laboski CA, Us-Santamaría R, Ruiz-Sánchez E (2022). Effect of maize–legume intercropping on maize physio-agronomic parameters and beneficial insect abundance. Sustainability 14(19):12385. *https://doi.org/10.3390/su141912385*

Poveda K, Gómez MI, Martinez E (2008). Diversification practices: their effect on pest regulation and production. Revista Colombiana de Entomologia 34(2):131-144. *https://doi.org/10.25100/socolen.v34i2.9269*

Qian X, Zang H, Xu H, Hu Y, Ren C, Guo L, ... Zeng Z (2018). Relay strip intercropping of oat with maize, sunflower and mung bean in semi-arid regions of Northeast China: yield advantages and economic benefits. Field Crops Research 223:33-40. *https://doi.org/10.1016/j.fcr.2018.04.004*

Qiu M, Van De Voorde T, Li T, Yuan C, Yin G (2021). Spatiotemporal variation of agroecosystem service trade-offs and its driving factors across different climate zones. Ecological Indicators 130:108154. *https://doi.org/10.1016/j.ecolind.2021.108154*

Raza MA, Gul H, Wang J, Yasin HS, Qin R, Khalid MHB, ... Yang W (2021). Land productivity and water use efficiency of maize-soybean strip intercropping systems in semi-arid areas: a case study in Punjab Province, Pakistan. Journal of Cleaner Production 308:127282. *https://doi.org/10.1016/j.jclepro.2021.127282*

Saudy HS (2015). Maize–cowpea intercropping as an ecological approach for nitrogen-use rationalization and weed suppression. Archives of Agronomy and Soil Science 61(1):1-14. *https://doi.org/10.1080/03650340.2014.920499*

Secco D, Bassegio D, De Marins AC, Chang P, Savioli MR, Castro MBS, ... Wendt EJ (2023). Short-term impacts of different intercropping times of maize and ruzigrass on soil physical properties in subtropical Brazil. Soil and Tillage Research 234:105838. *https://doi.org/10.1016/j.still.2023.105838*

Sekiya N, Yano K (2004). Do pigeon pea and sesbania supply groundwater to intercropped maize through hydraulic lift?—Hydrogen stable isotope investigation of xylem waters. Field Crops Research 86(2-3):167-173. *https://doi.org/10.1016/j.fcr.2003.08.007*

Shah MA, Farooq M, Hussain M (2016). Productivity and profitability of cotton–wheat system as influenced by relay intercropping of insect resistant transgenic cotton in bed planted wheat. European Journal of Agronomy 75:33-41. *https://doi.org/10.1016/j.eja.2015.12.014*

Shah WUH, Lu Y, Liu J, Rehman A, Yasmeen R (2024). The impact of climate change and production technology heterogeneity on China's agricultural total factor productivity and production efficiency. Science of the Total Environment 907:168027. *https://doi.org/10.1016/j.scitotenv.2023.168027*

Sharma N, Singh RJ, Mandal D, Kumar A, Alam N, Keesstra S (2017). Increasing farmer's income and reducing soil erosion using intercropping in rainfed maize-wheat rotation of Himalaya, India. Agriculture, Ecosystems & Environment 247:43-53. *https://doi.org/10.1016/j.agee.2017.06.026*

Shen L, Wang X, Liu T, Wei W, Zhang S, Keyhani AB, ... Zhang W (2023). Border row effects on the distribution of root and soil resources in maize–soybean strip intercropping systems. Soil and Tillage Research 233:105812. *https://doi.org/10.1016/j.still.2023.105812*

Shi F, Huang HJ, Chen YT, Chen LL (2022). Effects of intercropping functional plants on the ecosystem functions and services in tea garden. Journal of Tea Science 42:151-168. *https://doi.org/10.5555/20230012136*

Silberg TR, Chimonyo VGP, Richardson RB, Snapp SS, Renner K (2019). Legume diversification and weed management in African cereal-based systems. Agricultural Systems 174:83-94. *https://doi.org/10.1016/j.agsy.2019.05.004*

Soujanya PL, Vanisree K, Giri GS, Mahadik S, Jat S, Sekhar J, Jat H (2024). Intercropping in maize reduces fall armyworm *Spodoptera frugiperda* (JE Smith) infestation, supports natural enemies, and enhances yield. Agriculture, Ecosystems & Environment 373:109130. *https://doi.org/10.1016/j.agee.2024.109130*

Stoltz E, Nadeau E (2014). Effects of intercropping on yield, weed incidence, forage quality and soil residual N in organically grown forage maize (*Zea mays* L.) and faba bean (*Vicia faba* L.). Field Crops Research 169:21-29. *https://doi.org/10.1016/j.fcr.2014.09.004*

Swinton SM, Lupi F, Robertson GP, Hamilton SK (2007). Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits. Ecological Economics 64(2):245-252. *https://doi.org/10.1016/j.ecolecon.2007.09.020*

Tao D, Delgado-Baquerizo M, Zhou G, Revillini D, He Q, Swanson CS, Gao Y (2024). Maize-alfalfa intercropping alleviates the dependence of multiple ecosystem services on nonrenewable fertilization. Agriculture, Ecosystems & Environment 373:109141. *https://doi.org/10.1016/j.agee.2024.109141*

Te X, Din AMU, Cui K, Raza MA, Ali MF, Xiao J (2023). Inter-specific root interactions and water use efficiency of maize/soybean relay strip intercropping. Field Crops Research 291:108793. *https://doi.org/10.1016/j.fcr.2022.108793*

Van Dijk M, Morley T, Rau ML, Saghai Y (2021). A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. Nature Food 2(7):494-501. *https://doi.org/10.1038/s43016-021-00322-9*

Vandermeer JH (1989). The ecology of intercropping. Cambridge University Press, Cambridge.

Vashisht B, Nigon T, Mulla D, Rosen C, Xu H, Twine T, Jalota S (2015). Adaptation of water and nitrogen management to future climates for sustaining potato yield in Minnesota: field and simulation study. Agricultural Water Management 152:198-206. *https://doi.org/10.1016/j.agwat.2015.01.011*

Wang M, Shi W, Kamran M, Chang S, Jia Q, Hou F (2024). Effects of intercropping and regulated deficit irrigation on the yield, water and land resource utilization, and economic benefits of forage maize in arid region of Northwest China. Agricultural Water Management 298:108876. *https://doi.org/10.1016/j.agwat.2024.108876*

Wang X, Deng X, Pu T, Song C, Yong T, Yang F, ... Yang W (2017). Contribution of interspecific interactions and phosphorus application to increasing soil phosphorus availability in relay intercropping systems. Field Crops Research 204:12-22. *https://doi.org/10.1016/j.fcr.2016.12.020*

Willey R (1979). Intercropping its importance and research needs part 1. competition and yield advantages vol-32. Field Crop Abstracts 32:1-10.

Wu K, Jiang C, Zhou S, Yang H (2022). Optimizing arrangement and density in maize and alfalfa intercropping and the reduced incidence of the invasive fall armyworm (*Spodoptera frugiperda*) in southern China. Field Crops Research 287:108637. *https://doi.org/10.1016/j.fcr.2022.108637*

Xia H, Li X, Qiao Y, Xue Y, Yan W, Xue Y, ... Van Der Werf W (2024). Diversification of wheat-maize double cropping with legume intercrops improves nitrogen-use efficiency: evidence at crop and cropping system levels. Field Crops Research 307:109262. *https://doi.org/10.1016/j.fcr.2024.109262*

Xia HY, Zhao JH, Sun JH, Bao XG, Christie P, Zhang FS, Li L (2013). Dynamics of root length and distribution and shoot biomass of maize as affected by intercropping with different companion crops and phosphorus application rates. Field Crops Research 150:52-62. *https://doi.org/10.1016/j.fcr.2013.05.027*

Xu R, Zhao H, Liu G, Li Y, Li S, Zhang Y, ... Ma L (2022). Alfalfa and silage maize intercropping provides comparable productivity and profitability with lower environmental impacts than wheat–maize system in the North China plain. Agricultural Systems 195:103305. *https://doi.org/10.1016/j.agsy.2021.103305*

Yang F, Liao D, Wu X, Gao R, Fan Y, Raza MA, ... Yang W (2017). Effect of aboveground and belowground interactions on the intercrop yields in maize-soybean relay intercropping systems. Field Crops Research 203:16-23. *https://doi.org/10.1016/j.fcr.2016.12.007*

Yang H, Su Y, Wang L, Whalen JK, Pu T, Wang X, ... Wu Y (2025). Strip intercropped maize with more light interception during post-silking promotes photosynthesized carbon sequestration in the soil. Agriculture, Ecosystems & Environment 378:109301. *https://doi.org/10.1016/j.agee.2024.109301*

Yang WY, Yang F (2019). We will develop belt and compound planting of jade bean to ensure national food security. Scientia Agricultura Sinica 52(21):3748-3750. *https://doi.org/10.3864/j.issn.0578-1752.2019.21.003*

Yang XC, Hu YG, Qian X, Ren CZ, Lin YC, Guo LC, … Zeng ZH (2012). Effects of nitrogen applicaton level on system productivity, nitrogen absorption and accumulation in mung bean ‖ oat intercropping system. Journal of China Agricultural University 17(4):46-52.

Yin W (2017). Water competition and complementary utilization mechanism of wheat intercropping maize under alternating strip mulching of straw mulch. PhD Thesis, Gansu Agricultural University.

Zhang LZ, Van Der Werf W, Zhang SP, Li B, Spiertz J (2007). Growth, yield and quality of wheat and cotton in relay strip intercropping systems. Field Crops Research 103(3):178-188. *https://doi.org/10.1016/j.fcr.2007.06.002*

Zhang R, Liang H, Tian C, Zhang G (2000). Biological mechanism of controlling cotton aphid (Homoptera: aphididae) by the marginal alfalfa zone surrounding cotton field. Chinese Science Bulletin 45:355-358. *https://doi.org/10.1007/BF02909768*

Zhang SB, Liang KM, Guo J, Luo H (2016). Yield improvement by intercropping-viewed from a niche perspective. Fujian Journal of a Gricultural Sciences 31(9):1005-1012. *https://doi.org/10.19303/j.issn.1008-0384.2016.09.020*

Zhang W, Wei YX, Khan A, Lu JS, Xiong JL, Zhu SG, … Xiong Y (2023). Intercropped soybean boosts nitrogen benefits and amends nitrogen use pattern under plastic film mulching in the semiarid maize field. Field Crops Research 295:108881. *https://doi.org/10.1016/j.fcr.2023.108881*

Zhang WL (2021). Effects of maize on crop growth, water use and economic benefit. MSc Dissertation, Shihezi University.

Zhang X, Li Z, Siddique KH, Shayakhmetova A, Jia Z, Han Q (2020). Increasing maize production and preventing water deficits in semi-arid areas: a study matching fertilization with regional precipitation under mulch planting. Agricultural Water Management 241:106347. *https://doi.org/10.1016/j.agwat.2020.106347*

Zhao Y, Guo S, Zhu X, Zhang L, Long Y, Wan X, Wei X (2024). How maize-legume intercropping and rotation contribute to food security and environmental sustainability. Journal of Cleaner Production 434:140150. *https://doi.org/10.1016/j.jclepro.2023.140150*

Zheng BC, Zhou Y, Chen P, Zhang XN, Du Q, Yang H, … Yong TW (2022). Maize–legume intercropping promote N uptake through changing the root spatial distribution, legume nodulation capacity, and soil N availability. Journal of Integrative Agriculture 21(6):1755-1771. *https://doi.org/10.1016/S2095-3119(21)63730-9*

Zhou T, Du Y, Ahmed S, Liu T, Ren M, Liu W, Yang W (2016). Genotypic differences in phosphorus efficiency and the performance of physiological characteristics in response to low phosphorus stress of soybean in southwest of China. Frontiers in Plant Science 7:1776. *https://doi.org/10.3389/fpls.2016.01776*

Zhou T, Wang L, Sun X, Wang X, Pu T, Yang H, … Yang W (2021). Improved post-silking light interception increases yield and P-use efficiency of maize in maize/soybean relay strip intercropping. Field Crops Research 262:108054. *https://doi.org/10.1016/j.fcr.2020.108054*

Zhu SG, Cheng ZG, Batool A, Wang YB, Wang J, Zhou R, … Xiong YC (2022). Plant facilitation shifts along with soil moisture and phosphorus gradients via rhizosphere interaction in the maize-grass pea intercropping system. Ecological Indicators 139:108901. *https://doi.org/10.1016/j.ecolind.2022.108901*

Zi SH, Wu KX, Ouyang CR, Fan ZW, Yang YQ, Zhou F, Wu BZ (2019). Effects of root exudates of maize and potato on potato growth. Agricultural Research in the Arid Areas 37(2):88-94. *https://doi.org/10.7606/j.issn.1000-7601.2019.02.13*

Zou X, Liu Y, Huang M, Li F, Si T, Wang Y, … Shi P (2023). Rotational strip intercropping of maize and peanut enhances productivity by improving crop photosynthetic production and optimizing soil nutrients and bacterial communities. Field Crops Research 291:108770. *https://doi.org/10.1016/j.fcr.2022.108770*

Zou XX, Shi PX, Zhang CJ, Si T, Wang YF, Zhang XJ, … Wang ML (2021). Rotational strip intercropping of maize and peanuts has multiple benefits for agricultural production in the northern agropastoral ecotone region of China. European Journal of Agronomy 129:126304. *https://doi.org/10.1016/j.eja.2021.126304*

Zuazo VHD, Pleguezuelo CRR (2008). Soil-erosion and runoff prevention by plant covers. A review. Agronomy for Sustainable Development 28(1):65-86. *https://doi.org/10.1051/agro:2007062*

Zuo YM, Zhang FS (2003). Effects of peanut intercropping with different gramineous species and their intercropping model on iron nutrition of peanut. Scientia Agricultura Sinica 36(3):300-306. *https://doi.org/10.3321/j.issn:0578-1752.2003.03.012*

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