Received: 28 January 2024 | Accepted: 17 March 2025

DOI: 10.1002/agj2.70057

Agronomy Journal

REVIEW

Crop Economics, Production, and Management

A review of double-crop soybean production in comparison to full-season system in the United States

Md. Rasel Parvej[1,2] | **David L. Holshouser**[3]

[1]Division of Plant Science and Technology & School of Natural Resources, University of Missouri, 208 Waters Hall, 1112 University Ave., Columbia, Missouri 65211, USA

[2]Department of Seed Science and Technology, Bangladesh Agricultural University, Mymensingh, Bangladesh

[3]Tidewater Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, Suffolk, Virginia, USA

Correspondence
Md. Rasel Parvej, Scott Research, Extension, and Education Center, Louisiana State University Agricultural Center, 212-A Macon Ridge Rd, Winnsboro, LA 71295, USA. Email: mrparvej@missouri.edu

Assigned to Associate Editor Henry Qu.

Contribution of the Virginia Tech Tidewater Agricultural Research and Extension Center received.

Funding information
Virginia Agricultural Experiment Station; National Institute of Food and Agriculture, US Department of Agriculture

Abstract

Soybean [*Glycine max* (L.) Merr.] after winter wheat (*Triticum aestivum* L.) is the most common double-cropping system in the United States, driven by the desire for increased cash flow and profits and bolstering global food security. Despite its popularity, double-cropping often results in a lower soybean yield compared to full-season systems, attributed to various factors. Maintaining wheat stubble height ≤30 cm during harvesting and planting soybean in between wheat rows minimizes some negative effects of wheat residue. Planting double-crop soybean immediately after wheat harvest is crucial, as late planting is the primary factor of diminished double-crop yield. Late planting results in a shorter soybean growing season, limiting the time available to develop an optimal leaf area index (LAI). Harvesting wheat at high moisture or planting early-maturing wheat cultivars with comparable yield potential can facilitate 7–10 days earlier soybean planting. Employing narrow rows (19 cm) during double-crop soybean planting ensures rapid attainment of optimum LAI (3.5–4.0) by the pod set stage, maximizing solar radiation interception and canopy photosynthesis. A 16 kg ha^{-1} starter N may enhance early vegetative growth, expediting optimal LAI achievement. Indeterminate soybean may be more appropriate for double-crop due to fewer branching habits, which reduces competition in narrow rows compared to determinate counterparts. Double-crop soybean in narrow rows requires higher seeding rates than full-season to maximize yield by optimizing LAI expeditiously. Additionally, double-crop soybean is more vulnerable to drought and insect–pest infestation or defoliation than full-season system. Therefore, managing double-crop soybean with the same diligence as full-season is imperative to maximize yield and profitability.

Plain Language Summary

Double-crop soybean is grown right after wheat is harvested and is a popular farming method in the United States because it helps farmers make more money and increase food production. But this system often leads to lower soybean yield than when soybean is planted alone for a full season. Planting soybean right after wheat harvest is

Abbreviations: LAI, leaf area index; MG, maturity group; R:FR, red to far-red; SCN, soybean cyst nematode.

important to avoid yield loss. Cutting wheat stubble short and planting between the rows can help. Using narrow rows and higher seeding rates helps soybean grow faster and catch more sunlight. Some nitrogen fertilizer at planting can boost early growth. Indeterminate soybean types may work better in narrow rows. Managing things like moisture, pests, and weeds is especially important for double-crop soybean because it is more sensitive to drought and insects. This study reviewed over 100 research articles to find the best ways to increase double-crop soybean yield and profit including changes in planting date, row spacing, fertilizer use, and water and pest control.

1 INTRODUCTION

In modern agriculture, double-cropping has emerged as a valuable practice for maximizing land productivity. Double-cropping involves cultivating and harvesting two successive crops on the same piece of land within a single year, constituting a form of multiple cropping where two or more crops are sequentially grown. Profitability remains a key determinant in the adoption of double-cropping systems, with variations based on regional climatic conditions, crop selection, and market demand. In the United States, soybean [*Glycine max* (L.) Merr.] prominently features in the double-cropping system, often cultivated during the summer following winter small-grain crops like wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), canola (*Brassica napus*), among others. The winter small-grain–soybean double-cropping system typically involves growing winter crops primarily for grain, occasionally for hay, silage, or grazing. In specific regions, soybean is double-cropped after the harvest of spring or early summer vegetables, such as snap beans (*Phaseolus vulgaris)*, or even after another soybean or corn crop within the same calendar year.

The most predominant double-cropping system in the United States is winter wheat followed by soybean (Gammans et al., 2025; Hansel et al., 2019; Kapusta, 1979; Moomaw & Powell, 1990; Okoli et al., 1984; Sanford et al., 1973; Schnitkey et al., 2022; Triplett, 1978), recognized for its adaptability to varied agro-climatic conditions. Wheat–soybean double-crop system has been widely adopted in certain regions of the United States, particularly in the Midwest and Southeast. This system allows for increased land productivity and resource efficiency but presents unique agronomic, environmental, and economic challenges compared to full-season soybean production. Understanding the comparative advantages and limitations of double-cropping versus full-season soybean systems is essential for optimizing soybean yields, maintaining soil health, and ensuring economic viability for producers (Egli & Cornelius, 2009; Mourtzinis & Conley, 2017).

A successful wheat–soybean double-cropping system requires careful timing and management. Wheat is typically planted from October to November and harvested for grain in June–July, and soybean is promptly planted post-wheat harvest. Soybean planting date is one of the most significant factors affecting yield potential. Studies indicate that delayed planting in double-crop systems often results in lower yields compared to full-season soybean production due to a shorter growing season, reduced light interception, and greater susceptibility to late-season weather stress (Hu & Wiatrak, 2012; Salmerón et al., 2016). Despite these limitations, soybean emerges as the preferred and dominant summer crop in double-cropping systems due to its photoperiod sensitivity and versatile days to maturity. Regardless of the planting date, double-crop soybean generally matures in late October through November before succumbing to frost damage. The popularity of wheat as a winter crop has surged, driven by its higher market price compared to alternatives like barley. The wheat–soybean double-cropping system has found success in different agro-climatic regions across the United States, and a similar practice is observed in several other countries worldwide, including Brazil, Argentina, China, and India.

The increasing popularity of double-cropping stems from its capacity to augment cash flow and profits while optimizing land, equipment, labor, and capital usage (Holshouser, 2014). Studies showed that double-cropping can enhance overall system productivity by utilizing otherwise fallow land, thereby improving resource use efficiency and total farm income (Balkcom et al., 2015; Kering et al., 2017). This practice contributes to enhanced soil physical, chemical, and biological properties by mitigating soil erosion, reducing water loss and nutrient leaching, and bolstering soil water-holding capacity, water infiltration, water-use efficiency, and soil organic matter content (DeLaune, 2018; Dorn et al., 2013; Farmaha et al., 2021; Kumar et al., 2021; Reddy et al., 2014). Some studies suggest that incorporating cover crops within a double-crop system can mitigate soil degradation risks while improving soil structure and microbial activity (Ashworth et al., 2018; J. Lee et al., 2019). Crucially, double-cropping plays a pivotal role in global food security, addressing the escalating needs of the world's growing population by augmenting overall food production from the same land area.

Despite its benefits, double-cropping presents agronomic and economic challenges. This system diminishes the yield and quality of the second crop (i.e., soybean) compared to full-season counterparts, primarily due to a compressed growing season (Hansel et al., 2019). For instance, while the optimal time for soybean planting is mid-April to mid-May, in the wheat–soybean double-cropping system, soybean is typically planted in late June to early July after wheat harvest, which reduces soybean growth, development, and yield by curtailing the total growing period. Moreover, late harvesting of double-crop soybean, resulting from delayed planting, leads to substantial yield loss attributed to heavy rainfall and frost in early November.

Economic viability remains a key concern for producers considering double-crop soybean production. Factors such as input costs, seed availability, and fluctuating market prices can influence the profitability of double-cropping systems compared to full-season soybean (Holshouser et al., 2006; Reiter et al., 2018). Additionally, weather variability, particularly in water-limited environments, can impact yield stability and financial returns (J. Zhang et al., 2016). While double-cropping presents several challenges, advancements in breeding, agronomic management, and precision agriculture technologies offer potential solutions to enhance system productivity and sustainability (Mourtzinis et al., 2019; Pittelkow et al., 2015).

Overall, double-cropping offers a unique opportunity to boost farm productivity, enhance soil health, and increase overall profitability. While wheat–soybean double-cropping remains the most dominant system in the United States, ongoing research and technological advancements will continue to refine best management practices. Addressing the agronomic, economic, and environmental challenges associated with double-cropping will be essential for optimizing soybean yields, improving sustainability, and ensuring economic viability for farmers. This comprehensive review aims to explore the environmental and crop management factors influencing soybean yield in the wheat–soybean double-cropping system, offering insights into best management practices to enhance double-crop soybean yield and profitability in the United States.

2 | IMPORTANCE OF DOUBLE-CROPPING

2.1 | Economic benefits

The double-cropping system stands out as a judicious and sustainable approach economically and environmentally. This system is widely adopted in various agricultural regions of the United States due to its potential to enhance farm profitability and land-use efficiency. The economic advantages of this system stem from increased revenue generation per unit of land, optimized resource use, and improved soil fertility. The economic viability of this system is notably evident in the additional revenue generated from the second crop. However, challenges such as increased production costs, dependency on favorable climatic conditions, and management complexities necessitate a careful comparison with the full-season soybean system.

Numerous studies conducted across diverse agro-climatic regions and soil textures consistently reveal that the wheat–soybean double-cropping system yields greater net returns than full-season soybean, despite the latter's higher yield (Browning, 2011; Caviness & Collins, 1985; Crabtree & Rupp, 1980; Farno et al., 2002; Kelley, 2003; Kyei-Boahen & Zhang, 2006; LeMahieu & Brinkman, 1990, 1991; Sanford, 1982; Sanford et al., 1986; R. A. Wesley, 1999; R. A. Wesley & Cooke, 1988; R. A. Wesley et al., 1988, 1994, 1995). A notable comparison by Kyei-Boahen and Zhang (2006) on clay loam soils in Stoneville, Missouri, demonstrated that although full-season soybean exhibited a yield advantage of 10%–40% over double-crop soybean, the wheat–soybean double-cropping system proved more profitable due to the supplementary revenue from wheat, contributing to over 60% of the combined net returns. Reiter et al. (2018) conducted an economic analysis of double-crop soybean production and concluded that, under favorable climatic conditions, net returns from the double-crop system can exceed those of a full-season soybean system.

The profitability of the double-cropping system hinges on factors such as the length of the growing season (location), crop management practices, and crop prices, particularly those of winter small grains. Reiter et al. (2018) found that when wheat and soybean prices are favorable, the double-crop system provides significantly higher gross margins compared to full-season soybean. Additionally, Kering et al. (2017) highlighted that the potential for revenue enhancement is maximized when appropriate agronomic practices, such as optimal planting dates and precision fertilization, are followed. R. Shrestha et al. (2021) further emphasized that the economic feasibility of the double-crop system is influenced by regional soil and weather conditions, with variations in N use efficiency and moisture availability playing key roles.

The financial viability of the double-cropping system depends on several crucial agronomic and economic factors. Research conducted by Moomaw and Powell (1990) in northeast Nebraska with a shorter growing season revealed that full-season soybean generated higher returns than double-crop soybean post-wheat harvest, especially when the latter was intended for forage. Studies in the Mid-South by R. A. Wesley and Cooke (1988) and R. A. Wesley et al. (1994, 1995) underscored that full-season irrigated soybean exhibited greater profitability than rainfed double-crop soybean. Further investigations into multiple double-cropping systems in the Mid-Atlantic region (Browning, 2011) demonstrated that the barley–soybean double-cropping system yielded comparable net returns, based on a barley price of \$0.122 kg^{-1} in 2010, to both full-season soybean and wheat–soybean double-cropping systems. Interestingly, with a barley price of \$0.153 kg^{-1}, the net returns of the barley–soybean double-cropping system surpassed those of full-season soybean and wheat–soybean double-cropping systems by \$108 and \$130 ha^{-1}, respectively.

While the wheat–soybean double-crop system offers higher revenue potential, it also entails increased input costs. These include expenses related to seed, fertilizers, pesticides, and additional field operations. J. Zhang et al. (2016) noted that higher input costs in the double-crop system can sometimes offset yield gains, particularly in years with suboptimal weather conditions. Additionally, wheat residue management and soil moisture depletion can affect soybean establishment and productivity, further influencing economic returns (Reddy et al., 2014). L. E. Lindsey et al. (2023) suggested that optimized planting densities and cultivar selection can mitigate these costs by improving yield potential and seed quality. Balkcom et al. (2015) emphasized that soil fertility management is crucial in double-cropping systems, as wheat depletes soil nutrients more than a full-season soybean crop. However, the inclusion of cover crops or conservation tillage can help mitigate these effects and reduce fertilizer costs in subsequent growing seasons. Moreover, Pittelkow et al. (2015) found that precision agriculture technologies, such as variable rate application and sensor-based fertilization, improve input efficiency and enhance economic returns in double-cropping systems.

Market price volatility for wheat and soybean plays a critical role in determining the economic feasibility of the double-crop system. Hu and Wiatrak (2012) examined price trends and concluded that while the double-crop system provides higher gross revenue potential, it is more sensitive to price fluctuations compared to the full-season soybean system. Insurance policies and government subsidies for wheat and soybean can help mitigate financial risks, as discussed by J. Zhang et al. (2016). Another key risk factor is climatic uncertainty, which can significantly impact yield stability and profitability. Mourtzinis et al. (2019) observed that extreme weather events such as drought and early frost can reduce soybean yield potential in double-crop systems. Conversely, in regions with reliable rainfall patterns and mild winters, the double-crop system has demonstrated consistent economic advantages over full-season soybean. R. Shrestha et al. (2021) and L. E. Lindsey et al. (2023) further emphasized the role of conservation management strategies in stabilizing double-crop yields under variable weather conditions.

The wheat–soybean double-crop system presents a viable economic alternative to the full-season soybean system, particularly when managed with optimal agronomic practices. While higher input costs and climatic risks exist, the potential for increased revenue per unit of land makes this system attractive to many producers. The wheat–soybean double-crop system offers smallholder farmers in developing nations an opportunity to diversify income sources from multiple harvests, reducing financial risk and ensuring economic stability. Future research should focus on improving risk management strategies, optimizing input use, and integrating advanced technologies to enhance the economic sustainability of double-cropping systems.

2.2 | Ecological benefits

The wheat–soybean double-cropping system presents numerous ecological advantages over full-season soybean monoculture. This system enhances soil health, improves water conservation, reduces greenhouse gas emissions, and supports biodiversity. By maintaining continuous soil cover, double-cropping mitigates soil erosion, nutrient runoff, and leaching, making it a valuable strategy for sustainable agriculture.

One of the primary ecological benefits of the wheat–soybean double-crop system is its positive impact on soil health. Continuous soil cover provided by the system prevents erosion and enhances soil organic matter content (Ashworth et al., 2018). Research by Balkcom et al. (2015) found that conservation tillage practices integrated with double-cropping improve soil aggregation, microbial diversity, and nutrient cycling. Furthermore, R. Shrestha et al. (2021) reported that wheat residue contributes to soil structure stability and increases organic carbon storage, reducing soil degradation compared to full-season soybean monoculture. Cover crops within the wheat–soybean sequence act as nutrient scavengers, reducing N leaching and improving P availability (J. Lee et al., 2019). Additionally, L. E. Lindsey et al. (2023) highlighted that N use efficiency improves due to the complementary effects of wheat residue decomposition and soybean biological N fixation, reducing reliance on synthetic fertilizers and minimizing N runoff into waterways.

Soil erosion, responsible for detaching and transporting soil sediments into aquatic ecosystems, often carries substantial amounts of organic matter, N, P, K, S, and other nutrients, thereby causing water pollution through eutrophication. Double-cropping plays a crucial role in maintaining soil cover, effectively reducing soil erosion and sediment transport (Dabney, 1998). Nitrate-N (NO_3-N), prone to surface runoff if not absorbed by plants, poses a threat to water quality, leading to pollution, decreased soil fertility, and productivity (Dabney et al., 2001; Scott et al., 1998). Additionally, nitrate-N can leach below the root zone into groundwater, further contributing to water pollution. The implementation of double-cropping acts as a cover crop, efficiently scavenging excess N (Dabney et al., 2001) and minimizing nutrient leaching (Dabney, 1998; Gill, 1997; Scott et al., 1998). L.

E. Lindsey et al. (2023) emphasized that soil cover during winter months minimizes surface runoff and erosion, leading to improved water quality in surrounding ecosystems. Winter crops like wheat, oat, and rye exhibit particular effectiveness in mitigating excess N compared to undesirable vegetation (Dabney, 1998). Moreover, the wheat–soybean double-crop system can reduce nutrient and sediment losses in agricultural runoff.

Effective water management is another ecological advantage of the wheat–soybean double-crop system. The presence of a winter wheat crop reduces soil evaporation and improves water infiltration rates, benefiting subsequent soybean crops (Reiter et al., 2018). J. Zhang et al. (2016) found that double-cropping systems contribute to greater soil water retention compared to full-season soybean systems, especially in regions susceptible to drought. L. E. Lindsey et al. (2023) noted that the increased root biomass in double-cropping systems further enhances soil water-holding capacity, supporting sustainable water management strategies in soybean production.

Double-cropping significantly enhances the addition of crop residue to the soils compared to mono-cropping, resulting in improved soil quality and fertility (Caviglia & Andrade, 2010; Caviglia et al., 2004, 2011). This improvement includes increased water infiltration (Dabney, 1998), enhanced water-holding capacity, and elevated soil organic matter content (Bellinder et al., 2004; Dabney, 1998; Dabney et al., 2001; Magdoff & Weil, 2004a, 2004b). Cover crops, even under conventional tillage systems, heighten water infiltration by mitigating soil particle detachment, preventing soil surface sealing, and creating additional macropores through root systems (Dabney, 1998). The introduction of soil organic matter, facilitated by winter wheat or cover crops, clearly influences soil physical, chemical, and biological properties (Reeves, 1997). This includes preventing soil compaction and erosion (Rhoton, 2000), enhancing bulk density, cation exchange capacity, pH, electrical conductivity, microbial biomass (Reeves, 1997), water-use efficiency (Weil & Magdoff, 2004), and nutrient cycling and availability for subsequent crops (Reeves, 1997; Weil & Magdoff, 2004). Magdoff and van Es (2000) emphasized that soils with low organic matter necessitate increased fertilizers, irrigation, and pesticides to achieve the same crop yield as soils with sufficient organic matter.

The wheat–soybean double-crop system plays a role in climate change mitigation by enhancing soil carbon sequestration. Research by Pittelkow et al. (2015) demonstrated that conservation tillage and double-cropping contribute to long-term soil carbon storage by increasing root and biomass inputs to the soil. Additionally, R. Shrestha et al. (2021) found that double-cropping reduced carbon dioxide emissions compared to full-season soybean systems due to greater biomass retention and reduced soil disturbance. Reduced greenhouse gas emissions in double-cropping systems are also associated with lower fertilizer application rates. Since soybean has the ability to fix atmospheric N, combining it with wheat in a double-cropping system reduces the need for synthetic N fertilizers, a significant source of nitrous oxide emissions (Ashworth et al., 2018). Consequently, the system helps to mitigate the environmental footprint of soybean production while maintaining high productivity levels.

Biodiversity conservation is another ecological benefit of the wheat–soybean double-crop system. Crop rotation and increased plant diversity contribute to a more resilient agroecosystem by supporting beneficial soil microorganisms and insect populations (J. Lee et al., 2019). According to Balkcom et al. (2015), double-cropping systems promote biological activity by reducing pest pressure and fostering habitat diversity for pollinators and predatory insects. Furthermore, integrating wheat into the rotation creates seasonal habitat for wildlife, particularly ground-nesting birds and small mammals. Research by L. E. Lindsey et al. (2023) found that wheat fields provide essential nesting and foraging habitats that are not available in full-season soybean monocultures, contributing to broader ecosystem health and biodiversity enhancement.

Double-cropping plays a pivotal role in diminishing some pest pressure by substituting susceptible host crops with non-susceptible ones (Anderson & Domsch, 1975). The growth and development of weeds can be curtailed by winter grain or cover crops, fostering competition for space, light, water, and nutrients. In the context of the wheat–soybean double-cropping system, delayed soybean planting may contribute to the reduction of soybean cyst nematode (SCN; *Heterodera glycines* Ichinohe) populations (Koenning & Anand, 1991). Additionally, wheat stubble retention and no-tillage practices have been reported to contribute to the suppression of SCN populations at harvest (Hershman & Bachi, 1995). These effects are likely attributed to multiple mechanisms, including the physical barrier provided by crop residues, alterations in soil microbial communities, and changes in soil structure that affect nematode movement and survival (S. Chen, 2007; Z. J. Grabau & Chen, 2016). No-tillage systems, in particular, have been shown to influence SCN dynamics by maintaining higher levels of organic matter and soil moisture, which can enhance populations of nematode-antagonistic microbes such as *Pochonia chlamydosporia* and *Purpureocillium lilacinum* (Hamid et al., 2017; Mauchline et al., 2013). Furthermore, wheat stubble can contribute to an unfavorable environment for SCN by modifying soil temperature and moisture conditions, potentially reducing hatching rates and juvenile nematode mobility (Pedersen et al., 2010; Workneh et al., 1999). Moreover, rotational systems incorporating wheat into a soybean-based cropping system have been suggested as a potential cultural management strategy for reducing SCN pressure, particularly when combined with

SCN-resistant soybean cultivars (Tylka & Marett, 2014). The presence of wheat residue may also enhance biological suppression of SCN by fostering beneficial soil organisms that compete with or prey upon nematodes (Bao et al., 2011). Thus, integrating wheat stubble retention and no-tillage practices into double-crop soybean systems not only supports soil conservation but also offers a viable approach for managing SCN populations, ultimately improving long-term soybean productivity in infested fields.

Overall, the wheat–soybean double-crop system offers several ecological advantages over the full-season soybean system. Improved soil health, enhanced water conservation, increased carbon sequestration, and greater biodiversity contribute to the sustainability of double-cropping systems. While economic considerations remain a primary driver of adoption, the ecological benefits of this system align with global efforts to promote sustainable agricultural practices. Future research should continue exploring best management practices to further optimize the environmental sustainability of wheat–soybean double-cropping.

2.3 | Global food security

Currently, the paramount scientific challenge revolves around ensuring food security, that is, addressing the imperative of nourishing the world's ever-expanding population through heightened crop production. With the global population steadily increasing and anticipated to reach approximately nine billion by 2050 (up from around 8.1 billion presently), there is a pressing need to double total food production. Compounding this challenge is the diminishing cultivable land, emphasizing the urgency to augment food output within existing land constraints. The double-cropping system, presenting the opportunity to cultivate two crops on the same piece of land within a single year, emerges as a strategic approach to elevate overall productivity per unit of land area (Gill, 1997). This could prove instrumental in meeting the escalating global food demand associated with population growth.

A comprehensive, long-term double-cropping study by Crabtree et al. (1990) in eastern Oklahoma demonstrated that a double-cropping system exhibits greater efficiency and sustainability in generating higher grain yield compared to mono-cropping. Several instances of double-cropping systems in the United States have demonstrated enhanced productivity compared to mono-cropping. Examples include wheat–soybean (Browning, 2011; Calvino et al., 2003; Caviglia et al., 2011; Heatherly & Elmore, 2004; Kyei-Boahen & Zhang, 2006; K. A. Nelson et al., 2011) and barley–soybean (Browning, 2011; Groover et al., 1989).

The wheat–soybean double-crop system is recognized for its ability to increase total crop output per unit of land. Reiter et al. (2018) found that double-cropping leads to a higher overall yield per hectare compared to a full-season soybean system, making it a viable strategy for addressing the rising global food demand. Similarly, Holshouser et al. (2006) reported that under favorable climatic conditions, the wheat–soybean system generates higher total grain production than a single-season soybean crop. In addition, L. E. Lindsey et al. (2023) emphasized that integrating wheat and soybean in a double-crop system allows for greater use of available growing seasons, reducing periods of fallow land. This approach is particularly relevant in densely populated regions where arable land is limited, enhancing food availability without further deforestation or land conversion.

Soybean is a key source of plant-based protein and essential nutrients, while wheat serves as a staple carbohydrate source for many populations. By integrating both crops in a double-cropping system, farmers contribute to a more balanced food supply, improving nutritional diversity (Ashworth et al., 2018). The combination of wheat and soybean addresses dietary needs by providing both macronutrients (proteins and carbohydrates) and micronutrients essential for human health. L. E. Lindsey et al. (2023) also emphasized that the increased crop output from double-cropping enhances food affordability by stabilizing supply chains and reducing dependency on single-crop production systems.

Climate variability is a significant challenge to global food security, and cropping systems must be adaptable to changing conditions. Pittelkow et al. (2015) highlighted that diversified cropping systems, including double-cropping, enhance resilience to climatic fluctuations by spreading risk across different growing seasons. Moreover, R. Shrestha et al. (2021) found that wheat residue left after harvest in a double-crop system improves soil moisture retention, reducing drought stress on the subsequent soybean crop. The ability to mitigate climate risks is particularly important in regions prone to extreme weather events. J. Zhang et al. (2016) observed that in water-limited environments, the wheat–soybean double-crop system benefits from improved soil structure and organic matter accumulation, leading to better water infiltration and retention. This advantage makes the system more sustainable in comparison to full-season soybean production, which is more vulnerable to mid-season droughts and extreme heat stress.

The wheat–soybean double-crop system presents a strategic advantage in addressing global food security challenges. By maximizing land efficiency, enhancing climate resilience, and contributing to nutritional and economic stability, this system provides a sustainable alternative to traditional full-season soybean cultivation. As global food demand continues to rise, further research and policy support are needed to optimize double-cropping practices, making them more accessible to farmers worldwide. Future advancements in breeding, agronomic practices, and precision agriculture will be instrumental in scaling up the benefits of the wheat–soybean double-crop system for global food security.

3 | DOUBLE-CROP SOYBEAN PRODUCTION IN THE UNITED STATES

Double-crop soybean cultivation is predominantly observed in the southeastern United States, facilitated by the region's extended growing season (Lewis, 1972; L. R. Nelson et al., 1977; Sanford et al., 1973; Worsham, 1974). The shorter growing season limits the double-cropping options in the northern region (K. D. Thelen & Leep, 2002). Double-cropping system is primarily practiced following winter wheat, with occasional instances of soybean cultivation succeeding winter barley (Camper et al., 1972) and canola (Porter, 1993, 1995; D. L. Thomas et al., 1990) in the southeastern Coastal Plain. In 2015, soybean cultivation covered approximately 34.5 million ha in the United States, with double-crop soybean accounting for 6% of the total soybean hectarage (USDA-NASS, 2015). Over the past three decades, from 1986 to 2015, the proportion of soybean hectarage dedicated to double-crop soybean averaged 7%, ranging from 3% in 2010 to 11% in 1989 and 1999 (USDA-NASS, 1990, 1995, 2000, 2005, 2010, 2015). However, this percentage is relatively low across the entire United States due to the Midwest (Iowa, Illinois, Indiana, North Dakota, Nebraska, and Ohio) housing half of the total soybean hectarage (16.9 million ha in 2015; USDA-NASS, 2015), where double-crop soybean is infrequently cultivated. In these regions, the growing season constraints and climate conditions make double-crop soybean production less feasible than full-season soybean cultivation (L. E. Lindsey et al., 2023; R. Shrestha et al., 2021).

From 1986 to 2015, the average proportion of double-crop soybean hectarage was 4% in Illinois, 3% in Indiana, and 1% in Ohio. Data for Iowa, Nebraska, and North Dakota were not available (Figure 1a; USDA-NASS, 1990, 1995, 2000, 2005, 2010, 2015). In the Mid-South (Tennessee, Kentucky, Arkansas, and Missouri), the percentage of double-crop soybean hectarage ranged from 10% to 32% (Figure 1b). In the deep South (Georgia, South Carolina, Florida, Alabama, Louisiana, and Mississippi), this range was 9%–46% (Figure 1c), and in the Mid-Atlantic region (Delaware, Virginia, Maryland, North Carolina, Pennsylvania, and New Jersey), it was 14%–45% (Figure 1d). Despite South Carolina and Georgia having 44%–46% of total soybean hectarage as double-crop soybean, the Mid-Atlantic states, particularly North Carolina, Virginia, Maryland, and Delaware, have been more enthusiastic about this production system, with around 41% of soybean land dedicated to double-crop soybean since 1986. However, there has been a recent decline in double-crop soybean hectarage across states (Figure 1), potentially attributed to lower wheat prices (USDA-ERS, 2016).

Comparing the average yields in 2014 or 2015, full-season and double-crop soybean yielded 4280 and 4099 kg ha^{-1}, respectively, in Arkansas; 4099 and 3655 kg ha^{-1} in Tennessee; 3984 and 3978 kg ha^{-1} in Georgia; 4609 and 4361 kg ha^{-1} in North Carolina; and 3487 and 3084 kg ha^{-1} in Virginia, based on official variety test publications from each state. Despite extension data indicating minimal differences in soybean yield between the two production systems, actual research data, as presented by Kyei-Boahen and Zhang (2006) from large plot research (44 m long × 2.5 m wide plots), suggested that full-season soybean yields were 10%–40% higher than double-crop soybean. The lower number of entries for double-crop soybean in official variety tests may contribute to a higher average yield, and regional variations, such as the rainfed production system in Virginia, could account for differences in soybean yields among states.

Several factors have limited the adoption of double-crop wheat–soybean production. One of the primary constraints has been the lack of crop insurance programs covering double-crop systems. Historically, farmers who adopted double-cropping faced greater financial risks due to potential weather-related losses and yield uncertainties. The absence of comprehensive insurance coverage discouraged many producers from adopting the system (RMA, 2023). However, recent policy changes and initiatives, such as the USDA Risk Management Agency's Double-Cropping Initiative, have expanded crop insurance options, providing better financial security for farmers engaged in double-cropping (RMA, 2023). In addition to insurance challenges, limited wheat markets have also played a role in reducing double-crop wheat–soybean adoption. In many Midwest states, the focus on corn-soybean rotations has led to reduced infrastructure and market demand for winter wheat, making it less attractive for farmers to incorporate wheat into their cropping systems (J. Zhang et al., 2016). Consequently, the profitability of wheat production influences the viability of the double-crop system, with fluctuating wheat prices affecting farmers' planting decisions (Reiter et al., 2018).

The adoption of the wheat–soybean double-crop system has been constrained by insurance limitations, wheat market dynamics, agronomic challenges, and climate variability. Recent policy developments and agronomic advancements are addressing some of these barriers, making double-cropping a more attractive option for US farmers. Future research and policy initiatives should focus on enhancing the sustainability and profitability of the system while ensuring its adaptability to diverse agricultural landscapes.

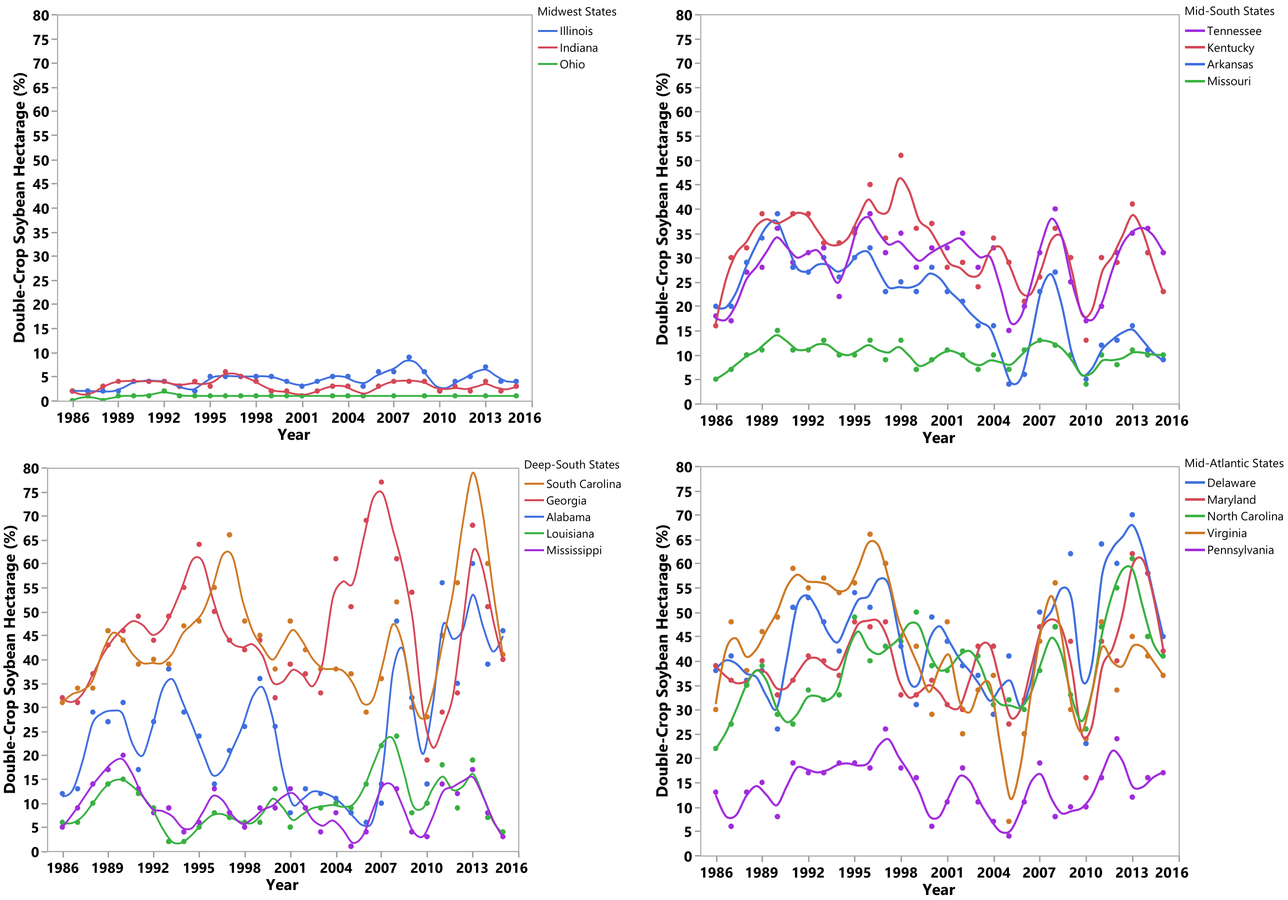

FIGURE 1 Percentage of soybean hectarage planted following another harvested crop for (a) Midwest, (b) Mid-South, (c) Deep-South, and (d) Mid-Atlantic states from 1986 to 2015

4 | FACTORS AFFECTING DOUBLE-CROP SOYBEAN YIELD AND QUALITY

4.1 | Wheat cultivar and harvest date

Double-crop soybean production is significantly influenced by the choice of wheat cultivar and the timing of wheat harvest. The ability to plant soybean earlier in the growing season is critical for optimizing yield and quality. The selection of an early-maturing wheat cultivar plays a crucial role in advancing soybean planting dates in double-cropping systems. Caviness and Collins (1985) highlighted the significance of an early wheat cultivar like Doublecrop, developed in Arkansas, which allows soybean planting approximately 5 days earlier. Their findings suggested that integrating early wheat planting with proper fertilization and high-moisture harvesting could further facilitate early double-crop soybean planting, thereby maximizing soybean yield potential. More recent research by Parvej et al. (2020a, 2020b) indicated that harvesting a high moisture content of around 20% (200 g H_2O kg^{-1} grain) in wheat grains facilitates a 7- to 15-day advancement in soybean planting within a double-cropping system. They also noted that wheat grain can be safely harvested at a moisture content of approximately 20%, but it is essential to dry the harvested grains promptly. The timely harvesting of wheat not only ensured early soybean establishment but also prevented excessive soil moisture depletion, which is crucial for subsequent soybean emergence and growth.

High-moisture wheat harvest has the potential to increase drying costs, as additional energy and time are required to reduce grain moisture to safe storage levels. Wheat harvested at higher moisture levels (above 18%) often necessitates artificial drying to prevent spoilage, mold growth, and quality deterioration (J. T. Edwards et al., 2012). The increased cost of drying depends on fuel prices, drying efficiency, and initial grain moisture content, which can add a significant expense to wheat production (Haque et al., 2014). However, this added cost can often be offset by a premium price for higher quality grain. High-moisture harvesting can help maintain better test weight, reduce shattering losses, and minimize preharvest sprouting, leading to improved grain quality and marketability (Hellevang, 2013; Parvej et al., 2020a; Paulsen & Hill, 2005). Kirleis et al. (1982) noted that soft red winter wheat achieves maximum test weight and grade at a moisture content of 30% or less (300 g H_2O kg^{-1} grain), maintaining acceptable milling quality at 30%–35% (300–350 g H_2O kg^{-1} grain) moisture content. Thus, while high-moisture wheat harvest may increase drying costs, the economic benefits from improved grain quality and higher soybean yields can compensate for these expenses, making it a viable management strategy in wheat–soybean double-cropping systems.

Parvej et al. (2020a, 2020b) emphasized that early wheat harvest allows soybean planting in the first week of June, leading to an overall increase in double-crop enterprise income. Additionally, Rucker et al. (2022) noted that early wheat harvest facilitates timely planting of double-crop soybean, which can significantly improve soybean yield potential by extending the growing season and avoiding late-season temperature and moisture stress. Alternate findings were observed in Ohio for soft red winter wheat. According to Alt et al. (2019), the choice of soft red winter wheat cultivars with appropriate agronomic traits significantly affected double-crop soybean planting windows and overall system profitability. Their study highlighted variations in grain quality, test weight, and harvest moisture levels that influenced the feasibility of early double-cropping in temperate climates.

In contrast, delayed wheat harvest, as demonstrated by Farrer et al. (2006), resulted in reduced wheat yield (up to 900 kg/ha) and test weight (up to 115 kg/m^3) when the harvest was delayed by 8–19 days from a moisture content of 13.5% (135 g H_2O kg^{-1} grain). Furthermore, the literature highlights that various wheat milling and baking qualities, including grain and flour falling number, clear flour percentage, grain deoxynivalenol (DON), and farinograph breakdown times, experience deterioration with delayed harvest (Farrer et al., 2006; Parvej et al., 2020a).

Overall, wheat cultivar selection and harvest timing are critical determinants of double-crop soybean success. Early-maturing wheat cultivars and high-moisture wheat harvesting practices enable earlier soybean planting, contributing to increased soybean yield potential and enhanced overall system profitability. Delayed wheat harvest, on the other hand, negatively impacts both wheat and soybean productivity. Future research should focus on optimizing cultivar selection and refining harvest management strategies to further enhance double-cropping sustainability in diverse agro-climatic conditions.

4.2 | Crop residues

Utilizing crop residues is a common practice to mitigate soil erosion, particularly in agricultural systems employing conservation tillage methods (Adams et al., 1970, 1973; Beaty & Giddens, 1962; Larson & Beale, 1961; Onstad & Otterby, 1979; Wischmeier, 1973). Researchers have proposed that a minimum of 2200 kg ha^{-1} crop residues on the soil surface is necessary for effective soil erosion control (Campbell et al., 1979; Langdale et al., 1979; Mannering & Meyer, 1963; Wischmeier, 1973). Despite these benefits, the use of crop residues in double-crop soybean production introduces certain drawbacks, including the potential inhibition of herbicide activity and allelopathic effects, which are elaborated below.

4.2.1 | Herbicide activity

Crop residues can pose a considerable impediment to the effectiveness of herbicides (J. L. Williams & Wicks, 1978; Witt, 1980). Banks and Robinson (1982) discovered that a quantity exceeding 2.2 Mg ha^{-1} of wheat residues can impede the activity of certain residual herbicides. In soybean fields covered with small-grain crop residues, Sanford et al. (1973) encountered challenges in weed control. The presence of crop residues hinders herbicides from reaching the soil surface, thereby diminishing herbicide efficiency (Reddy et al., 1995). Additionally, residues contribute to a decline in herbicide bioactivity due to herbicide sorption, resulting in suboptimal weed control (Locke et al., 2002; Reddy et al., 1995). Locke et al. (2002) observed increased herbicide sorption in the top 2-cm depth of no-till soils with residue cover than in conventionally tilled soils. Reddy et al. (1995) similarly reported higher herbicide sorption in fields covered with crop residues compared to those without residues, noting that herbicide sorption intensifies with the duration of residue decomposition.

The reduction in herbicide activity necessitates more frequent herbicide applications at higher rates, leading to increased crop production costs (Locke et al., 2002; Reddy et al., 1995). Moreover, it contributes to the development of weed resistance to herbicides, posing additional challenges to effective weed management strategies. This highlights the importance of carefully considering the presence and management of crop residues in herbicide applications to optimize weed control and minimize associated economic and resistance concerns.

4.2.2 | Allelopathy

The allelopathic impact of crop residues may sometimes overshadow the positive contributions of these residues in establishing and preserving soil quality. Allelopathy refers to the detrimental influence of one plant species, through the release of chemical substances (phytotoxins), on another species (Rice, 1984). This term has long been associated with crop residues left on the soil surface (Collison & Conn, 1925). The introduction of residue mulching in crop production has accentuated the issue of allelopathy (Rice, 1983). Guenzi and McCalla (1966a) observed higher concentrations of various phenolic compounds in mulched plots compared to plowed plots. Borner (1960) reported that residues from small-grain winter crops, such as wheat, barley, and oats, contain several phenolic compounds that exert allelopathic effects. Kimber (1973) discovered that phytochemicals extracted from wheat straw were less toxic than those extracted from barley, oats, and rye. Guenzi and McCalla (1966b) also extracted some phenolic acids from wheat straw that displayed phytotoxicity. These phenolic acids in wheat straw have been reported to hinder nutrient uptake, nodule formation, N_2 fixation by *Rhizobium* spp., and acetylene reduction in soybean (Rice, 1984). However, the extent of wheat straw phytotoxicity may vary with wheat cultivar (Collins & Caviness, 1978; Martin, 1985).

Several studies have demonstrated that residues from small-grain crops can impede soybean seed germination, seedling vigor, and overall crop growth due to allelopathy or phytotoxic reactions (Collison, 1925; Guenzi & McCalla, 1962; Herrin, 1984; Kimber, 1973; Norstadt & McCalla, 1968; Steinsiek, 1981). Wheat residue left on the soil surface has been shown to delay soybean emergence and reduce plant population by up to 150,000 plants ha^{-1} due to allelopathy and inadequate soil-seed contact (Hovermale et al., 1979; Sanford, 1982; Vyn et al., 1998). Stunted soybean seedling growth, accompanied by chlorosis in the presence of wheat stubbles, has been observed by Sanford (1982), Caviness et al. (1986), Hairston et al. (1987), and Vyn et al. (1998). The literature also documents a 16% higher soybean dry matter accumulation when the wheat straw is removed compared to incorporation or leaving it on the soil surface (Boquet & Walker, 1984; Hairston et al., 1987; Sanford, 1982; Vyn et al., 1998). Nevertheless, the degree of the adverse effect of crop residues depends on the frequency with which crop roots encounter residues producing phytotoxins since these toxins are not highly mobile in the soil (Rice, 1983), and their phytotoxic activity is localized around decomposed residues (Patrick et al., 1964). These findings suggest that double-crop soybean should be planted in between wheat rows to avoid or minimize phytotoxicity.

4.2.3 | Residue decomposition

The rate of residue decomposition is contingent upon the structural properties and quality of the residue, specifically its carbon-to-nitrogen (C/N) ratio. Gaillard et al. (2003) noted that wheat residue, characterized by high cellulose and hemicellulose content, undergoes microbial degradation at a slower pace. In general, a lower C/N ratio signifies higher residue quality, leading to an accelerated rate of decomposition. Wright and Hons (2004) found that wheat residue decomposes more gradually compared to residues from grain sorghum or soybean due to its elevated C/N ratio.

Crop residues with high C/N ratios demand more N for decomposition, resulting in the immobilization of soil N. Although slowly decomposing residues contribute to enhanced soil aggregation over time, the introduction of additional N during double-crop soybean production may expedite the decomposition of wheat straw. This, in turn, increases the availability of N for soybean seedlings by counteracting N immobilization. Moreover, the application of supplementary N can mitigate the allelopathic effects of crop residues, which inhibit processes such as nutrient uptake, nodule formation, and N_2 fixation (Rice, 1984). By enhancing N availability, additional N contributes to a more favorable environment for soybean growth, compensating for potential nutrient limitations imposed by residue decomposition dynamics.

4.3 | Crop residues management

The effective management of crop residues plays a pivotal role in establishing double-crop soybean and preserving soil quality. When a small grain crop yields 4036 kg ha^{-1}, it generates a residue volume ranging from 4036 to 8071 kg ha^{-1} (Caviness & Collins, 1985). If not handled appropriately, this residue can negatively impact the growth, development, and yield of double-crop soybean (Boquet & Walker, 1984; Sanford, 1982). A study by Hairston et al. (1987) observed inhibited soybean growth following wheat cultivation, attributing it to the substantial amount of wheat residues present. Several common residue management practices are detailed below.

4.3.1 | Wheat stubble height

Managing wheat stubble height is a critical component of the wheat–soybean double-cropping system, directly influencing weed suppression, soybean emergence, growth, and yield. While wheat stubble provides soil cover and erosion protection, excessive stubble height can create challenges such as reduced soybean emergence, shading effects, and difficulties in weed management. A balanced approach to stubble management is essential to maximize benefits while minimizing adverse impacts on subsequent soybean growth and yield.

Wheat stubble height is positively correlated with shading, providing an effective means of suppressing weed growth (Harwood & Bantilan, 1974). Shetty et al. (1982) established that increased stubble height results in better weed control, with 90% shading reducing up to 80% of dry matter accumulation in several weed species. Managing stubble height to achieve desired shading levels can significantly inhibit weed growth, enhancing the overall weed management strategy. For example, Begna et al. (2002) observed that shading resulted in a decrease in dry matter accumulation for redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), and velvetleaf (*Abutilon theophrasti* Medic.). However, the reduction was more pronounced for roots and reproductive structures than for shoots. Neeser et al. (1997) discovered that inducing artificial shading decreases tuber production in purple nutsedge (*Cyperus rotundus* L.) by diminishing the amount of photosynthetically active radiation.

The height of wheat stubble has a direct impact on soybean emergence, growth, and yield. Boquet and Walker (1984) investigated different stubble heights under a no-till double-cropping system, revealing that seedling emergence was highest in 15- and 23-cm stubbles. Excessive shading caused by tall stubble during the early vegetative period can adversely impact soybean branch formation. Acock and Acock (1987) demonstrated a negative correlation between branch node number and shading duration from VC to V6 stages (Fehr et al., 1971). Prolonged shading from tall stubble can hinder soybean growth during critical stages.

Light quality changes due to wheat stubble shading impact soybean growth. Research indicates that the red to far-red (R:FR) light ratio significantly influences soybean growth and development. A lower R:FR ratio, which can result from shading, such as that caused by high wheat stubble, has been shown to promote carbon assimilation in soybean seedlings by increasing their photosynthetic capacity. Specifically, a low R:FR ratio can enhance stem elongation and photosynthetic efficiency in soybean plants (F. Yang et al., 2020). While direct studies on the impact of wheat stubble-induced changes in the R:FR ratio on subsequent soybean crops are limited, existing evidence suggests that alterations in light quality due to shading can influence soybean growth responses. For instance, increased shading from earlier planting in narrow wheat rows has been observed to cause soybean plants to develop elongated internodes, leading to weaker plants (Hartschuh & Lindsey, 2025). Therefore, managing wheat stubble to optimize the R:FR ratio could be a potential strategy to enhance soybean performance in double-cropping systems.

The height of wheat stubble is linked to soybean yield. Over 2 years of wheat–soybean double-crop investigations, L. J. Grabau and Pfeiffer (1990) documented comparable soybean yields for stubble heights of 15 and 30 cm. However, the yield was greater with a 30-cm stubble height compared to no stubble (0 cm). In a separate study, Hovermale et al. (1979) identified the optimal soybean yield with a 20-cm stubble height, surpassing yields associated with 10-, 36-, and 41-cm stubble heights. Pod height is a crucial factor for harvest efficiency. Boquet and Walker (1984) recorded maximum soybean yield with stubble heights of ≤30 cm, while taller stubbles (38 and 46 cm) led to reduced yield due to the etiolation of young soybean plants, challenging herbicide application, lodging, and poor weed control.

Lower pod height is very crucial for reducing harvest loss because soybean pods that are <7.5 cm above the soil surface are difficult to harvest (J. T. Pearce, 2005). Hovermale et al. (1979) found that soybean lower pod height tends to increase with the increased stubble height. They also found lodging of double-crop soybean increases with the increased stubble height.

In conclusion, the most significant benefits of optimizing double-crop soybean yield under no-till conditions are achieved at a stubble height of ≤30 cm (Heatherly & Elmore, 2004; R. A. Wesley, 1999). Even wheat stubbles >30 cm in height provide little added advantage in soil surface protection from erosion and evaporation compared to stubbles that are shorter in height (Nielson et al., 2003), the most benefit of optimum wheat stubble height would be achieved if the additional wheat chaff during harvesting is spread uniformly on the soil surface (Holshouser, 2014). Therefore, managing wheat stubble height is a critical aspect of the wheat–soybean double-cropping system, influencing weed control, soybean growth, and overall crop yield. Balancing these factors ensures the optimization of double-crop soybean production under diverse conditions, including no-till systems.

4.3.2 | Wheat residue burning

The practice of burning wheat straw before soybean planting remains a contentious and environmentally questionable method in most regions of the United States. Although frowned upon, it persists in the Mid-South for wheat–soybean double-cropping (Frederick et al., 1998; Sanford, 1982). However, this burning practice carries significant ecological drawbacks discussed below.

Burning negatively influences soil carbon content, as evidenced by various studies (Biederbeck et al., 1980; Murphy et al., 2006; Prasad et al., 1999; Sanford, 1982; Wuest et al., 2005). Although some studies reported minimal differences in total soil carbon between burned and non-burned treatments (Brye et al., 2006; Chan & Heenan, 2005), the general consensus suggests a reduction in soil carbon due to burning. Wuest et al. (2005) suggested that since burning typically affects the top portion of the soil profile, a long-term burning study needs to be conducted to obtain a noticeable difference in soil carbon.

Burning induces a decline in soil nutrients, particularly N, P, and S. Biederbeck et al. (1980) observed that although burning rapidly converted organic N and P into inorganic forms, there was a failure to accumulate these nutrients in the soil profile over time. This suggests that the rapidly available inorganic N and P might be susceptible to loss mechanisms, including volatilization, leaching, runoff, or being carried away from the field as ashes by the wind. Murphy et al. (2006) noted higher leaching losses of NH_4^+, NO_3^-, and ortho-P in burned areas compared to non-burned areas. Caldwell et al. (2002) and Murphy et al. (2006) reported that the elevated temperatures from burning led to the emission of N and S gases, resulting in their loss through volatilization. Wuest et al. (2005) also documented soil N loss through burning. A 45-year study conducted by Rasmussen et al. (1980) on silt loam soils in Oregon determined that burning accelerates the rate of soil N loss. The continuous practice of burning may necessitate an increased soil N requirement in the long run.

The burning of residues creates an ash-bed effect that enhances soil pH and K concentration (Chan & Heenan, 2005). Sherman et al. (2005) observed an immediate 0.23 unit increase in soil pH after burning on grassland Ultisols in Maryland. However, after 1 year, they found no discernible difference in soil pH between burning and non-burning treatments. They explained that burning releases soluble cations that, upon hydrolysis, elevate soil pH. Conversely, Murphy et al. (2006) did not detect any impact of burning on soil pH, as well as on exchangeable Ca and Mg, in forest soils in Nevada.

Burning also has adverse effects on various physical and biological aspects of soil. The burning of crop residues has been reported to contribute to soil moisture loss through evaporation (Kelley & Sweeny, 1998; NeSmith et al., 1987; Verhulst et al., 2011). This exposes the soil, making it susceptible to erosion from both wind and rain (Wuest et al., 2005). Additionally, the burning process generates hydrophobic ash, leading to decreased water infiltration (J. Pikul & Zuzel, 1994; Rasmussen et al., 1980; Wuest et al., 2005), reduced hydraulic conductivity (Biederbeck et al., 1980), and compromised soil aggregate stability (Wuest et al., 2005), resulting in an overall deterioration of soil structure. Wuest et al. (2005) highlighted that residue burning significantly diminishes crucial components in the top 15 cm of the soil, such as glomalin (a fungal-secreted polysaccharide), basidiomycetes populations, and earthworms. These elements play pivotal roles in soil aggregation, organic matter formation, and carbon sequestration. The reduction in these factors can have long-term consequences for soil health and productivity. In addition to these soil-related impacts, burning also contributes to air pollution, reduces visibility for road traffic, and poses health hazards, particularly through the irritants present in the smoke emitted during burning, which can be particularly problematic for individuals with asthma and allergies (Caviness & Collins, 1985).

Despite numerous drawbacks, researchers have highlighted some positive effects associated with residue burning, particularly in terms of weed control and the yield of double-crop soybean. Wheat straw is commonly subjected to burning as a method of weed management and to prepare seedbeds for soybean planting. The burning process effectively eliminates many weeds, destroys numerous weed seeds present on the soil surface, reduces seedling diseases, facilitates soybean planting, and minimizes the allelopathic effects of wheat residues (Caviness & Collins, 1985; R. A. Wesley, 1999). Walsh and Newman (2007) noted that the elevated temperatures resulting from burning contribute to a decrease in the weed seed bank, thereby reducing weed infestations. Furthermore, studies conducted by Hairston et al. (1987) and Daniels and Scott (1991) revealed a higher germination rate of soybean seeds planted after residue burning. However, Cordell et al. (2007) found no significant effect of residue burning on soybean seed germination in a 2-year wheat–soybean double-crop study. Hairston et al. (1987) observed that wheat residue, whether incorporated or left on the soil surface, negatively impacted early-season soybean growth compared to the treatment involving residue burning. Sanford (1982) reported leaf yellowing in double-crop soybean when planted into unburned wheat residue as opposed to burned residue.

Residue burning has been associated with an increase in double-crop soybean yield in various studies (Boquet & Walker, 1984; Daniels & Scott, 1991; C. D. Elmore et al., 1995; Hairston et al., 1987; Heatherly et al., 1996; Sanford, 1982; R. A. Wesley & Cooke, 1988). However, conflicting results are found in other studies where no significant effect of burning on double-crop soybean yield was observed (Beale & Langdale, 1967; Cordell et al., 2007; NeSmith et al., 1987; Rasmussen & Rohde, 1988; Undersander & Reiger, 1985). Notably, the studies reporting higher yield and economic returns from residue burning were predominantly conducted on fine-textured soils, while those showing no effect were mostly conducted on coarse-textured soils. The positive impact of residue burning on fine-textured soil may be attributed to the minimal impact of wheat straw mulch on conserving soil moisture (Bond & Willis, 1971), water infiltration (Undersander & Reiger, 1985), and soil organic matter (Undersander & Reiger, 1985) compared to coarse-textured soils. Additionally, the benefits on fine-textured soils could arise from improved weed control, reduced allelopathic effects, minimized N immobilization, and the immediate availability of certain nutrients (Hairston et al., 1987). Daniels and Scott (1991) specifically identified a double-crop soybean yield advantage through wheat residue burning when residue interferes with herbicide activity. Although residue burning is not considered an ideal practice, it may be advisable in situations where soil surface residue consistently hampers maximum soybean yield, provided that soil fertility and erosion are not significant concerns, especially on fine-textured soils.

In conclusion, while residue burning might enhance certain aspects of crop management, it comes with significant environmental and soil health trade-offs. Sustainable alternatives and practices that mitigate these negative impacts should be explored and promoted.

4.3.3 | Wheat residue baling

Removal of wheat straw by bailing is an alternative approach to alleviate the negative impacts of shading, allelopathy, or straw burning in double-crop soybean. Various studies have shown that removing wheat straw can lead up to a 16% increase in soybean dry matter compared to incorporating or leaving the straw on the soil surface (Boquet & Walker, 1984; Hairston et al., 1987; Sanford, 1982; Vyn et al., 1998). Despite being a time-consuming process, some growers in the Mid-Atlantic region have deemed it a profitable practice, given reasonably good straw prices and market availability (J. T. Pearce, 2005). Wheat straw prices, often sought after by horse (*Equus caballus*) and mushroom (*Agaricus bisporus*) industries, were observed to range from \$86 to \$177 MT^{-1} in 2004 at a major hay and straw auction in New Holland, PA (MASS, 2004). Correspondingly, the yield of wheat straw typically falls within the range of 1.5–3.6 MT ha^{-1} (Engel et al., 2003). The removal of wheat straw through baling can yield additional gross income ranging from \$198 to \$475 ha^{-1}, considering an average straw price of \$132 MT^{-1}. However, before opting for wheat straw baling in double-crop soybean fields, it is crucial to consider the nutrient content and assess other physical, chemical, and biological benefits of wheat straw.

In a wheat–soybean double-crop system, the removal of P and K through the harvest of both wheat grain and straw, followed by soybean cultivation, can significantly deplete soil nutrient reserves. Wheat straw contains about 1.65 kg of P_2O_5 and 12.93 kg of K_2O per metric ton (algreatlakes.com). The combined removal of P and K from harvesting both wheat and soybean, especially when wheat straw is also removed, can lead to a rapid decline in soil nutrient levels. This nutrient drawdown may necessitate increased fertilizer applications to replenish soil reserves and maintain optimal conditions for subsequent crops. Failure to replace the extracted nutrients can result in reduced soil fertility, leading to lower crop yields over time.

Therefore, it's crucial for producers engaged in double-cropping systems to regularly monitor soil nutrient levels through testing and adjust fertilization practices accordingly. Applying fertilizers that account for the nutrient removal of both crops can help sustain soil health and productivity in the long term.

4.3.4 | Tillage

Tillage practices play a crucial role in influencing double-crop soybean yield by modulating soil physical, chemical, and biological properties. The two predominant tillage options for double-crop soybean production are no-tillage and conventional tillage. Conservation tillage, particularly no- or reduced-tillage, has gained widespread adoption, covering about two-thirds of soybean hectarage in the United States by 1997 (Padgitt et al., 2000). It has been recognized as a key approach to enhance soil carbon content and reduce CO_2 emissions in agricultural fields (Ellert & Janzen, 1999; Franzluebbers, 2010; Lal & Kimble, 1997; Morell et al., 2011; Sainju et al., 2008; Schlesinger & Andrews, 2000).

No-tillage practices contribute to an increase in macro-aggregate size (>2 mm) in the top 5-cm soil depth, promoting optimal root penetration and facilitating water and air movement into the soil. In contrast, conventional tillage accelerates the transformation of macro-aggregates into micro-aggregates (Six et al., 2000). Macro-aggregates play a pivotal role in preserving particulate organic matter by offering larger inter-aggregate pores, thus shielding it from rapid decomposition (Weil & Magdoff, 2004). Research by Rhoton (2000) demonstrated greater aggregate stability in no-tillage than conventional tillage in a 4-year wheat–soybean double-crop study, indicating that the positive impact on aggregate stability in no-tillage could counterbalance its potential negative effects on root penetration. Additionally, Rhoton observed higher soil organic matter content, exchangeable Ca, extractable P, Mn, and Zn under no-tillage, implying an improvement in soil fertility over time.

No-tillage allows for immediate soybean planting after wheat harvest, minimizing soil moisture loss—a critical factor in double-crop soybean production. Literature suggests that employing a no-tillage approach diminishes soil moisture losses in the seedbed germination zone, leading to improved stand establishment (Jeffers et al., 1973). Conversely, conventional tillage accelerates soil moisture loss through evaporation, potentially impeding soybean germination and emergence, especially in the absence of timely rainfall (Sanford, 1982). A wheat–soybean double-cropping investigation by NeSmith et al. (1987) demonstrated elevated soil water content under no-tillage or disking compared to the moldboard plow treatment in sandy clay loam soils. Diaz-Zorita et al. (2004) assessed the superior moisture-holding capacity of silt loam soils under no-tillage relative to soils subjected to periodic tillage. Their findings also indicated a saturated hydraulic conductivity of 16.4 mm h^{-1} in no-tillage, contrasting with 5.1 mm h^{-1} in conventional tillage. They concluded that the heightened moisture content and hydraulic conductivity in no-tillage were ascribed to increased macropore distribution and soil aggregate stability compared to conventional tillage.

No-tillage has demonstrated effectiveness in reducing soil erosion, as documented in studies by McGregor et al. (1975) and Langdale et al. (1979). However, the impact of no-tillage on runoff has shown inconsistency. T. W. Harper et al. (2008) observed an eightfold reduction in sediment load on silt loam soils under no-tillage compared to conventional tillage. Similarly, Langdale et al. (1979) recorded significantly lower sediment and runoff losses in sandy loam soils under no-tillage with double-cropping compared to conventionally tilled soils with mono-cropping. In contrast, Ghidey and Alberts (1998), in a 12-year evaluation on a silt loam soil with a 3%–3.5% slope, reported that no-tillage resulted in five to seven times lower soil erosion but 20% and 14% greater runoff than chisel plow and conventional tillage, respectively. Greater runoff and herbicide losses under no-tillage were also observed by Shipitalo et al. (1997) and Shipitalo and Owens (2006), leading to higher herbicide costs (Parsch et al., 2001).

Literature reveals varied responses regarding the impacts of tillage on double-crop soybean yield. Some studies, including those by Beale and Langdale (1967), NeSmith et al. (1987), R. A. Wesley et al. (1988), Heatherly et al. (1996), and Cordell et al. (2007), reported no significant effect of tillage on double-crop soybean yield in the southern United States. However, McGregor et al. (2006), after a 16-year investigation, noted that soybean yield with conventional tillage surpassed that with no-tillage for the initial 3 years but reversed over the subsequent 13 years. R. A. Wesley et al. (1988) found equivalent yields for conventional and no-tillage in irrigated systems, while in rainfed systems, conventional tillage outperformed no-tillage in a year with moderate temperatures but performed worse in the hottest year compared to no-tillage. Similarly, Tyler and Overton (1982) reported better seed quality, including less purple stain and wrinkling, for double-crop soybean with no-tillage in a dry year. These results suggest that the advantages of no-tillage, such as soil moisture conservation, may not manifest immediately after adoption but can positively impact soybean yield over time.

No-till farming also enhances soil fertility by improving soil structure, increasing organic matter content, and promoting beneficial microbial activity. One of the primary benefits of no-till is the reduction of soil erosion, which helps retain essential nutrients such as N, P, and K in the root zone, improving soil fertility over time (Lal, 2004). No-till systems also contribute to higher soil organic matter levels due to the reduced disturbance of crop residues, which enhances carbon sequestration and provides a steady nutrient release through mineralization (Six et al., 2000). Increased organic matter supports improved soil aggregation, enhancing water retention and nutrient availability, which is crucial for plant growth (Franzluebbers, 2010). Additionally, no-till systems foster a more diverse and active microbial community, including mycorrhizal fungi and N-fixing bacteria, which play key roles in nutrient cycling and soil fertility maintenance (Helgason et al., 2014). The improved microbial environment in no-till fields enhances enzymatic activities that facilitate the breakdown of organic residues and the release of essential nutrients (Mbuthia et al., 2015). Furthermore, studies have shown that no-till improves soil cation exchange capacity, allowing the soil to retain more nutrients and reduce leaching losses (Duiker & Beegle, 2006). Over time, the cumulative benefits of no-till lead to greater soil fertility, increased nutrient-use efficiency, and improved long-term sustainability of agricultural production systems. This makes no-till a key practice for maintaining soil health while reducing dependency on synthetic fertilizers.

Tillage also significantly influences weed infestation and population diversity, primarily employed for weed control purposes (Esbenshade et al., 2001a). Tillage serves to diminish weed seed germination by burying seeds deep within the soil profile, shielding them from light exposure and limiting gas diffusion (Benvenuti, 2003; Benvenuti & Macchia, 1998). Conversely, no-tillage practices augment weed species and population diversity as weeds accumulate on the soil surface, potentially diminishing soybean yield (Banks et al., 1985; Wicks & Sommerhalder, 1971). However, observations by Esbenshade et al. (2001a) in Pennsylvania revealed lower burcucumber (*Sicyos angulatus* L.) emergence under no-tillage than conventional tillage, attributing this to crop residue suppressing burcucumber emergence in no-tillage. Additionally, Reddy (2001a) documented that in a no-tillage system, crop residues exerted suppression on browntop millet [*Brachiaria ramosa* (L.) Stapf] density during the initial 3 weeks after planting, but this effect diminished in the subsequent 9 weeks. Importantly, it had no discernible impact on the densities of barnyardgrass [*Echnochloa crus-galli* (L.) Beauv.], prickly sida (*Sida spanosa* L.), and yellow nutsedge (*Cyperus esculentus* L.). These findings suggest that conventional tillage holds a distinct advantage in controlling weed species. However, the advent of herbicide-resistant soybean varieties, coupled with advanced herbicide technologies, has simplified weed control under no-tillage conditions.

In summary, while tillage can provide short-term benefits to double-crop soybean yield by improving weed control and soil aeration, it may have long-term drawbacks, such as soil degradation and increased erosion. In contrast, no-tillage promotes soil fertility, moisture retention, and erosion reduction, with potential long-term yield benefits. Additionally, no-till systems may facilitate an earlier planting date, further enhancing soybean establishment. However, the transition to no-till may present challenges, including shifts in weed diversity and a learning curve for optimal management.

4.4 | Planting date

The timing of planting has been extensively studied as a crucial factor influencing soybean growth, development, yield, and seed quality (Rahman et al., 2005; Q. Y. Zhang et al., 2010). Cartter and Hartwig (1963) emphasized that the planting date holds greater significance than any other individual cultural practice for achieving successful soybean production. Numerous studies have consistently demonstrated that delayed planting, occurring from late May to July, adversely impacts soybean yield potential in both irrigated and rainfed conditions (Barreiro & Godsey, 2013; Bastidas et al., 2008; Beatty et al., 1982; J. E. Board & Hall, 1984; Boquet et al., 1982; Bowers, 1995; T. E. Carter & Boerma, 1979; G. Chen & Wiatrak, 2010; De Bruin & Pedersen, 2008b; J. T. Edwards et al., 2003; Egli & Bruening, 2000; Egli

& Cornelius, 2009; Heatherly, 1988; Heatherly, 1996; Heatherly & Spurlock, 1999; Kane et al., 1997; Oplinger & Philbrook, 1992; Parker et al., 1981; Parvez et al., 1989; Popp et al., 2002).

For full-season soybean, the optimal planting window typically spans from late March to mid-May, contingent on the location and soybean maturity group (MG). Late planting from mid-May to early June has been associated with a reduction in soybean yield, with estimates ranging from 0.09% to 1.69% per day (Salmerón et al., 2016). Egli and Cornelius (2009) conducted a comprehensive review of planting date studies under rainfed conditions, revealing a rapid decline in soybean yield when planted after specific dates: May 30 in the Midwest (Iowa, Illinois, Indiana, North Dakota, Nebraska, and Ohio), May 27 in the deep South (Alabama, Florida, Georgia, Louisiana, Mississippi, and South Carolina), and June 7 in the Midsouth (Arkansas, Kentucky, Missouri, and Tennessee). Recent studies have further elucidated the impact of planting dates on soybean yields across various regions in the United States. Mourtzinis et al. (2017) conducted comprehensive analyses revealing that delayed soybean planting results in significant yield reductions, with the rate of loss varying by region and environmental conditions. Their findings indicate that for each day planting is postponed beyond early May, soybean yields can decrease substantially, underscoring the importance of timely planting to maximize yield potential. Similarly, Schmitz and Kandel (2021) examined the effects of planting date, seeding rate, relative maturity, and row spacing on soybean yield and found that planting date had the greatest influence on yield potential. Meanwhile, Morris et al. (2021) studied interactions between planting date, MG, and seeding rate in North Carolina, demonstrating that earlier planting dates consistently produced higher yields, with later planting dates requiring higher seeding rates to compensate for shorter growing seasons. Further analysis by Mourtzinis and Conley (2023) explored the economic impact of planting order decisions, finding that prioritizing soybean planting over corn can maximize farm gross revenue in certain conditions. Their study underscores the broader financial implications of planting date decisions beyond just yield potential, highlighting the importance of optimizing planting schedules for both crops. These studies collectively highlight the necessity for region-specific planting strategies to optimize soybean yields, taking into account local climate conditions, economic factors, and the associated risks of delayed planting.

Within the framework of the wheat–soybean double-cropping system, the timeframe deemed optimal for soybean planting is typically from early June to mid-June. However, achieving planting within this timeframe poses significant challenges due to high rainfall and delays in wheat maturity in certain years, particularly in southern Illinois, Kentucky, Tennessee, and Arkansas, where seasonal weather variability can impact field conditions and planting schedules. Literature underscores that late planting is a primary factor contributing to reduced yield in double-crop soybean (J. E. Board & Harville, 1996; Holshouser, 2014; Parker et al., 1981). Boerma and Ashley (1982) demonstrated that delaying double-crop soybean planting by 5–10 weeks beyond the normal mid-June schedule resulted in a substantial yield reduction. Also, they found that delayed planting from early July to late July led to an average seed yield reduction of 36 kg ha^{-1} day^{-1} in Georgia. Holshouser (2014) noted a similar yield reduction of 34 kg ha^{-1} day^{-1} in Virginia for double-crop soybean planted after mid-June. Further investigations by Jeffers et al. (1973) and Beuerlein (2004) indicated that delaying double-crop soybean planting after June 15 in Ohio could lead to yield reductions of up to 470 kg ha^{-1} week^{-1} (67 kg ha^{-1} day^{-1}).

The yield decline in late-planted double-crop soybean can be attributed to various factors. Inadequate vegetative growth, due to shorter growing seasons, is a primary limiting factor for yield (Ball et al., 2000b; Barreiro & Godsey, 2013; Boerma & Ashley, 1982; T. E. Carter & Boerma, 1979; Caviglia et al., 2011; Herbert & Litchfield, 1984; Holshouser, 2014; B. P. Jones et al., 2003). Holshouser (2014) emphasized that inadequate vegetative growth, particularly in terms of leaf area index (LAI), is a key constraint for late-planted double-crop soybean. He clarified that late-planted soybean (late June to early July) lacks sufficient time to achieve an optimal LAI. This limitation hampers their capacity to optimize light interception, leading to diminished dry matter production and ultimately resulting in lower yields.

Soybean LAI exhibits a positive correlation with soybean seed yield, as documented by B. P. Jones (2002). Several studies have indicated that the yield of late-planted soybean tends to increase with higher LAI values (J. E. Board et al., 1992; J. E. Board & Harville, 1993; Hunt et al., 1994; B. P. Jones et al., 2003; Wells, 1991). Malone et al. (2002) indicated a linear increase in yield with the rise of LAI up to 3.5–4.0 at the R4–R5 stages for both full-season and double-crop soybean, after which the yield plateaus. Literature suggests that soybean typically requires a vegetative period ranging from 42 to 58 days, contingent upon environmental conditions (Boquet et al., 1983; Hartwig, 1970; Huxley et al., 1976; Huxley & Summerfield, 1974; Nagata, 1960; J. F. Thomas & Raper, 1977; Van Schaik & Probst, 1958), to attain an LAI of 3.0 (Constable, 1977). However, late-planted soybean often faces challenges in achieving the critical LAI range of 3.5–4.0, as outlined by J. E. Board and Harville (1992), essential for optimal radiation interception. This deficiency in LAI negatively impacts photosynthesis and, consequently, leads to reduced yields.

Early flowering, induced by a shorter photoperiod, has also been identified as a contributing factor to reduced late-planted soybean yield (Bastidas et al., 2008; J. E. Board, 1985; J. E.

Board & Hall, 1984; Hartwig, 1954; Pedersen & Lauer, 2004). Late planting has been associated with a reduction in the duration of key soybean growth stages, including vegetative, flowering, pod set, and seed-filling periods (G. Chen & Wiatrak, 2010; Egli, 2011; Egli & Bruening, 2000; Purcell et al., 2002). This shortened timeline from emergence to R5 stages, resulting from late planting, guides to insufficient vegetative growth (Egli & Bruening, 2000; Egli et al., 1987; Kane et al., 1997; Purcell et al., 2002), thereby compromising crop growth rate and dry matter accumulation, ultimately impacting soybean yield maximization (J. E. Board et al., 1999). Purcell et al. (2002) highlighted that the reduced vegetative period in late-planted soybean is a consequence of the combined influence of photoperiod and temperature. A temperature and photoperiod interaction study by J. E. Board and Hall (1984) demonstrated that warmer temperatures (27˚C) with a short photoperiod significantly reduce the days to first flowering compared to cold temperatures (21˚C) with a long photoperiod. H. W. Johnson et al. (1960) also observed a direct impact of late planting dates on altering the duration of soybean developmental stages in response to changes in photoperiod. The reduced photoperiod, resulting from late planting, shortens the length of the seed-filling period (R4–R7; Morandi et al., 1988), which is positively correlated ($r = 0.51$) with soybean yield (Dunphy et al., 1979). Other research has indicated that soybean yield is directly linked to solar radiation levels and/or assimilate supply during pod set to seed-filling (R3–R7) periods (Duncan, 1986; Hardman & Brun, 1971; Schou et al., 1978; H. M. Taylor et al., 1982). Drought stress during the period from mid-July to late August coinciding with the reproductive stages has been highlighted as another significant factor leading to reduced yields, particularly in the southeastern United States (Morrison & Rabb, 1996). These literatures suggest that the early onset and duration of reproductive stages coincide with unfavorable conditions, including reduced photoperiod and decreased precipitation during the later stages of the growing season contribute to the overall yield reduction of late-planted soybean after wheat.

The reduced rates of dry matter accumulation, particularly during critical stages like flowering, pod set (Egli & Bruening, 2000), and seed-filling (Calvino et al., 2003) periods, also contribute to the yield reduction. Parvez et al. (1989) found a lower level of dry matter accumulation for soybean planted in July compared to those planted in May. Literature has documented that the diminished yield in soybean planted in July is attributed to reduced branch development (J. E. Board, 1985; J. E. Board & Hall, 1984; Hartwig, 1954). Settimi and Board (1988) observed that a lower photoperiod during late planting directly hinders branch formation at the lower main-stem nodes and indirectly diminishes potential sites for branch formation at the upper main-stem nodes by inducing early flowering. Additionally, J. E. Board and Settimi (1986) explained that a short photoperiod during late planting dates diminishes branch development by compressing the time between R1 and R5 stages, crucial stages for most branch development.

The decline in yield for late-planted double-crop soybean is also linked to reduced plant height (Bastidas et al., 2008; Ouattara & Weaver, 1995; Wilcox & Frankenberger, 1987), nodes per plant (Bastidas et al., 2008; Beatty et al., 1982; O. G. Carter, 1974; T. E. Carter & Boerma, 1979; Caviness & Smith, 1959; Constable, 1977; Leffel, 1961; Pedersen & Lauer, 2004; Weiss, 1950), pods per plant (Anderson & Vasilas, 1985; R. W. Elmore, 1990), pods per square meter (J. E. Board et al., 1999; Pedersen & Lauer, 2004; Robinson et al., 2009), reproductive pods per node (J. E. Board et al., 1999), seeds per square meter (J. E. Board et al., 1992; J. E. Board & Harville, 1992; Calvino et al., 2003; Egli, 1975; Egli & Bruening, 2000; Egli et al., 1987; Guffy et al., 1983; P. G. Jones & Laing, 1978; Pedersen & Lauer, 2004), and seed weight (Calvino et al., 2003). Ouattara and Weaver (1995) reported that the reduction in the lowest pod height is another issue in late-planted soybean, causing harvest yield losses and, consequently, reduced seed yield. This problem is more pronounced in a determinate soybean growth habit compared to an indeterminate soybean growth habit.

Soybean seed number per hectare is directly linked to plant population, pods per plant, and seeds per pod, with seed number exhibiting a high correlation with soybean seed yield (J. E. Board et al., 2003; Kahlon et al., 2011). The decline in seed number during late planting dates has been ascribed to reduced air temperature (Calvino et al., 2003) and diminished solar radiation interception during flowering and early pod set (J. E. Board et al., 1992; J. E. Board & Harville, 1992; Egli & Bruening, 2000; Egli et al., 1987). Several researchers have proposed that radiation interception during flowering and early pod set serves as a pivotal factor in determining soybean seed number (Egli & Bruening, 2000; Kantolic et al., 2013; Liu et al., 2010; H. M. Taylor et al., 1982). Late planting also leads to heightened soybean seed protein concentration but reduced seed oil concentration (Kane et al., 1997; Pendleton & Hartwig, 1973; Robinson et al., 2009).

Overall, the literature strongly indicates that the reduction in soybean yield during late planting dates results from the combined impacts of reduced air temperature and a shorter growing season, leading to early flowering and lower LAI, thereby reducing radiation interception, dry matter accumulation, and yield component production. Drought stress during mid-July to late August, coinciding with flowering and early pod set stages, also poses a challenge for diminished soybean yield, especially under rainfed production systems.

4.5 | Row spacing

Row spacing represents a critical management factor significantly influencing soybean growth and yield. Traditionally, soybean has been cultivated with row spacings ranging from

19 to 100 cm. However, there is a growing trend toward adopting narrow row spacing due to its associated enhancement in yield potential (R. R. Johnson, 1987). Numerous studies have consistently reported an increase in soybean yield when planted in narrower row spacing as opposed to wider configurations (Ablett et al., 1984; Beuerlein, 1988; J. E. Board et al., 1990; J. E. Board & Harville, 1994; Boquet, 1990; Boquet et al., 1982; Cooper, 1977; Costa et al., 1980; Devlin et al., 1995; Egli, 1994; R. W. Elmore, 1998; Ethredge et al., 1989; Heatherly, 1988; Heatherly et al., 2002; R. R. Johnson, 1987; Kratochvil et al., 2004; Lehman & Lambert, 1960; Lueschen et al., 1992; Mickelson & Renner, 1997; K. A. Nelson & Renner, 1998; Oriade et al., 1997; Parvez et al., 1989; Swanton et al., 1998; H. M. Taylor et al., 1982; A. K. Walker & Fioritto, 1984).

Research conducted in the southern United States has consistently shown higher soybean yields when planted in rows ranging from 25 to 50 cm compared to wider configurations of 95–100 cm (Frans, 1959; P. E. Smith, 1952; C. Williams et al., 1970; Noor, 1973). Similarly, studies in the northern United States have revealed increased soybean yields in 50-cm rows compared to 102-cm rows in Minnesota (Lehman & Lambert, 1960), 17-cm rows compared to 50- or 75-cm rows in Illinois (Cooper, 1977), and 27-cm rows compared to 76-cm rows in Wisconsin (Costa et al., 1980). C. D. Lee (2006) consistently observed a yield increase in soybean planted in 38-cm rows compared to 76-cm rows. Lambert & Lowenberg-DeBoer (2003) reported that planting soybean in 19-cm rows with a grain drill is more economically viable, resulting in a 4.8% yield increase compared to planting in 38-cm wide rows in corn-soybean rotations in the North-Central United States. Cox and Cherney (2011) recently found a negative linear response of soybean biomass, LAI, yield components, and seed yield to row spacings of 19, 38, and 76 cm, producing 598, 554, and 497 g biomass m^{-2}; 3.64, 3.47, and 3.16 LAI; 2272, 2230, and 2072 seeds m^{-2}; and 3.37, 3.12, and 2.86 Mg yield ha^{-1}, respectively.

Yield advantages from narrow-row production become more pronounced with delayed planting dates. Most of the research mentioned above was conducted under optimal planting dates for full-season soybean. Existing literature shows that narrow row spacing is particularly advantageous when soybean is planted later than the optimal dates, typically in May (Akhanda et al., 1976; Beatty et al., 1982; Boquet, 1990; Parker et al., 1981; Parvez et al., 1989). Interestingly, the yield increase in narrow rows compared to wide rows is more pronounced during delayed planting in mid-June compared to planting at optimum times (J. E. Board et al., 1990; Boerma & Ashley, 1982; Boquet et al., 1982). Holshouser et al. (2006) reported that double-crop soybean, planted from early June to early July, benefits from narrow row spacing to maximize yield. Narrow row spacing has also been shown to enhance soybean yield in early soybean production systems, such as those in April (Beatty et al., 1982; Boquet et al., 1982).

The enhanced soybean yield in narrow row spacing can be attributed to several factors, including more uniform plant spacing, rapid leaf area development leading to faster canopy closure, increased radiation interception, higher crop growth rate, and elevated plant survival rates (Andrade et al., 2002; J. E. Board et al., 1992; Boquet, 1990; Bowers et al., 2000; Bullock et al., 1998; Dalley et al., 2004; Ethredge et al., 1989; Heatherly, 1988; Heatherly & Elmore, 2004; Herbert & Litchfield, 1984; Holshouser & Whittaker, 2002; Oriade et al., 1997; Reddy, 2002; Shibles & Weber, 1965; H. M. Taylor et al., 1982; E. R. Walker et al., 2010; Wells et al., 1993). Early-season canopy development is considered a primary advantage of reduced row spacing, a benefit observed not only in soybean but also in other crops such as cotton (*Gossypium hirsutum* L.) and corn (Culpepper & York, 2000; Esbenshade et al., 2001b; Heitholt et al., 1992; Reddy, 2001b; Tharp & Kells, 2001).

The literature indicates that the growth rate and yield of soybean depend on the amount of solar radiation intercepted during both early vegetative and reproductive stages (Shibles & Weber, 1966; Wells, 1991). Narrow row spacing helps the rapid achievement of the desired LAI, ensuring the interception of the maximum amount of solar radiation (R. H. Shaw & Weber, 1967). Shibles and Weber (1966) emphasized that an LAI of ≥3.2 by full bloom (R2) is necessary to intercept 95% of incident radiation and produce 95% of maximum dry matter. Additionally, J. E. Board and Harville (1992) and Westgate (1999) highlighted that 95% light interception with an LAI of 3.5 or 4.0 serves as a reliable measure of soybean yield potential, as both are associated with canopy closure and maximum canopy photosynthesis. Bullock et al. (1998) and Andrade et al. (2002) emphasized the correlation between a greater LAI, higher light interception, increased crop growth rate, enhanced dry matter accumulation, and, ultimately, elevated crop yield. Narrow row spacing also ensures greater availability of soil moisture through swift canopy closure, optimal soil nutrient access due to uniform root distribution, and improved competition with weeds for soil resources (Pires et al., 2000; H. M. Taylor, 1980; A. L. Thomas et al., 1998). All these factors are crucial for achieving maximum crop yield.

While several studies have consistently highlighted the advantages of narrow row spacing in increasing soybean yield, there are a few exceptions where no yield benefit was reported (Alessi & Power, 1982; Beatty et al., 1982; Caviness, 1966; Hartwig, 1957; H. M. Taylor, 1980). In a comprehensive investigation by Kratochvil et al. (2004) involving 48 cultivar-row spacing comparisons for both full-season and double-crop soybean, it was found that soybean in 19-cm row spacing yielded the same or more than those in 38-cm row spacing. Similarly, Bertram and Pedersen (2004) conducted a comparison of soybean yields in 19-, 38-, and 76-cm row spacing in Wisconsin. They ranked soybean yield with 19- and 38-cm rows being superior to 76-cm rows in central and northern Wisconsin, while in southern Wisconsin, 38-cm rows were more advantageous than 19-cm rows, with 76-cm rows ranking the lowest. Pedersen and Lauer (2004) further contributed to the understanding of inconsistent yield responses to row spacing by ranking soybean yield with 19-cm rows being superior to both 38- and 76-cm rows in 1998 and 1999, 38-cm rows being superior to 19-cm rows in 2000, and both 38- and 76-cm rows being superior to 19-cm rows in 2001. The variability in yield response is attributed to different cultural practices and environmental conditions. Janovicek et al. (2006) investigated soybean yield in various row spacings (19-, 38-, 57-, and 76-cm) under no-tillage and moldboard plow systems in Ontario, Canada. They ranked soybean yield with 19- and 38-cm rows being superior to 57- and 76-cm rows under the no-tillage system and 19-cm rows being superior to 38-, 57-, and 76-cm rows under the moldboard plow system.

Holshouser et al. (2006) reported that soybean with 19-cm rows tends to produce a similar yield when planted with a standard drill and a higher yield when planted with a precision drill compared to soybean planted with a vacuum meter planter in 38-cm rows. Hanna et al. (2008) observed a 9% higher soybean yield in 19-cm rows compared to 38-cm rows in the absence of wheel-traffic damage. In the presence of wheel-traffic damage associated with pesticide application, there was no yield difference between 19- and 38-cm rows, indicating the potential benefits of narrow row spacing in mitigating such damage. Holshouser and Taylor (2008) investigated soybean yield loss due to wheel-traffic damage at the R4 stage in 19-, 38-, and 76- or 91-cm row spacing for both full-season and double-crop soybean in the Mid-Atlantic region. They reported that, in the absence of wheel traffic, both full-season and double-crop soybean with 19- and 38-cm rows yielded similarly but more than soybean with 76- or 91-cm rows under rainfed conditions. There was no yield difference among row spacings under irrigated conditions. In the presence of wheel-traffic damage, both full-season and double-crop soybean yielded equally or more when planted in 19-cm rows compared to 38- or 91-cm rows under rainfed conditions, except for 1 year with double-crop soybean. The results were the opposite for irrigated conditions, where soybean yielded more in 76-cm rows than in 19- and 38-cm rows. The lower yield in 19-cm rows in 1 year was attributed to hot and dry conditions, resulting in low compensation for yield loss from neighboring rows.

Drought stress has been consistently identified as a factor diminishing the soybean yield benefits associated with narrow row spacing in several studies (Alessi & Power, 1982; Devlin et al., 1995; R. W. Elmore, 1998; Epler & Staggenborg, 2008; Heatherly, 1988; Heitholt et al., 2005; H. M. Taylor, 1980). H. M. Taylor (1980) observed that soybean yield remained similar across row spacings of 25-, 50-, 75-, and 100-cm in a year with below-average rainfall. However, it inclined to increase with reducing row spacing in a year with average rainfall, reaching 17% higher yields in 25-cm rows compared to 100-cm rows in a year with above-average rainfall. Alessi and Power (1982) as well as Boquet et al. (1982) reported lower soybean yields in narrower rows than in wider rows under conditions of extreme moisture stress. Devlin et al. (1995) demonstrated that soybean planted in 20-cm rows yielded higher than those in 76-cm rows at high-yielding sites (>3.3 Mg ha^{-1}) with no water stress, but this trend reversed under water deficit (drought) conditions. Similar findings were reported by Graterol et al. (1996). The literature suggests that the diminished soybean yield in narrow rows during very dry years can be attributed to the rapid utilization of soil moisture during the vegetative stage, which is more pronounced in narrower row spacing than wider row spacing (Alessi & Power, 1982; Heatherly & Elmore, 2004; H. M. Taylor, 1980; Van Doren & Reicosky, 1987). This results in low water availability during reproductive stages, particularly under rainfed conditions.

In summary, while narrow row spacing offers a definite yield advantage over wider rows, especially for late-planted soybean, the extent of this yield benefit is subject to variations influenced by factors such as planting equipment, wheel-traffic damage, and the water stress associated with rainfall distribution patterns.

4.6 | Soybean maturity groups

Soybean MG indicates the duration of the soybean growing season, with MG numbers ranging from 000 to X based on the length of the growth cycle. Typically, soybean with lower MG numbers are cultivated in the northern United States, while those with higher MG numbers are preferred in the southern United States, primarily due to differences in day length (L. X. Zhang et al., 2007). L. Zhang et al. (2004) highlighted that lower MG numbers correspond to shorter growing cycles. For instance, MG III, IV, and V soybeans require an average of 114, 127, and 141 days, respectively, to reach maturity. Additionally, they observed that the duration of the growth cycle for each MG can vary based on the planting date.

Proper cultivar selection has the potential to boost soybean yield at late planting by 29%–276% (J. E. Board, 2002). Farmers commonly inquire about the most suitable MG for double-crop soybean production, but the response is contingent on various factors. The interaction of soybean MG with elements such as planting date and environmental conditions plays a crucial role. Although several studies have highlighted the dependence of the ideal MG on soybean planting date (Boquet, 1998; T. E. Carter & Boerma, 1979; G. Chen & Wiatrak, 2010; Egli & Bruening, 2000; Egli

& Cornelius, 2009; Heatherly, 1996; Heatherly & Spurlock, 1999; D. R. Johnson & Major, 1979; Kane et al., 1997; Salmerón et al., 2014), none have specifically assessed this interaction under a double-cropping system. Consequently, most extension recommendations for soybean MGs in double-cropping systems rely on their performance in full-season cropping systems. Despite both systems differing significantly in terms of seedbed conditions and growing season duration, conventional recommendations may not account for the unique conditions favoring one MG over another in the double-cropping system.

Existing research, primarily conducted within a full-season system, indicates that soybean yield in the southern United States generally sees an increase with MG III–V during April planting and with V–VII during May and June planting (Egli & Cornelius, 2009; Heatherly, 1999a; Heatherly & Elmore, 2004). However, this interaction between planting date and MG does not hold true in the northern United States (Kane et al., 1997). J. E. Board (2002) observed that in Louisiana, late-planted soybean yield increases with MG from V through VII. Caviness and Thomas (1979) reported that in Arkansas, MG V outperformed MG VI and VII when planted from May 15 to June 15. Conversely, Heatherly and Elmore (2004) found in Mississippi that MG VI and VII cultivars outperformed MG V when planted after May 31 under rainfed conditions. In a Mississippi wheat–soybean double-cropping system, Kyei-Boahen and Zhang (2006) determined that late MG IV provided the maximum yield and net return across three planting dates (May 21, May 28, and June 6). L. X. Zhang (2004) suggested that in Mississippi, MG III and IV can achieve competitive yields when planted late (after May) compared to optimum planting (April–May). G. Chen and Wiatrak (2010) noted that in South Carolina, the yield-maximizing planting dates were mid-May for MG IV and early May to mid-June for MG V cultivars.

Recent studies in the Midwest further emphasize the relationship between soybean planting date, MG, and yield potential. Mourtzinis et al. (2017) found that across multiple locations in the northern United States, delaying soybean planting beyond early May resulted in significant yield reductions, with the magnitude of decline dependent on MG and temperature. Their results align with Schmitz and Kandel (2021), who reported that later-planted soybean in North Dakota exhibited reduced yield potential across all MGs, reinforcing the importance of timely planting in northern climates. Morris et al. (2021) also highlighted that optimal planting dates in North Carolina varied based on MG selection, suggesting that regional environmental conditions play a crucial role in yield optimization. Additionally, Mourtzinis and Conley (2023) demonstrated the economic implications of planting date decisions, emphasizing that prioritizing earlier planting and selecting the appropriate MG can significantly impact farm profitability in the Midwest and northern United States.

Furthermore, Salmerón et al. (2015) assessed the interaction between soybean MG and planting date across 10 locations in Texas, Arkansas, Louisiana, Missouri, Mississippi, and Tennessee for 2 years. They found that soybean planted in May–June decreased yield by 7% for MG III, 12% for MG IV, 18% for MG V, and 11% for MG VI compared to soybean planted in March–April. They also reported stable soybean yield for MG IV and V with an 80% probability of achieving >3.0 Mg ha^{-1} when planted from March 20 to April 31, depending on location and year, and for MG III and IV with a 62% probability of achieving >3.0 Mg ha^{-1} when planted from May 3 to July 17. The literature suggests that the yield-optimizing planting date not only depends on soybean MG but also on regional environmental conditions (G. Chen & Wiatrak, 2010; Egli & Cornelius, 2009; Mourtzinis & Conley, 2023; Mourtzinis et al., 2017; Schmitz & Kandel, 2021). Literature also suggests that while the interaction between MG and planting date varies across the southern and northern United States, planting early remains a fundamental strategy for maximizing yield, particularly in Midwestern states like Illinois, Iowa, Wisconsin, and North Dakota. The specific MG selection should be tailored to regional growing conditions, temperature trends, and economic considerations to optimize soybean production.

The interaction between soybean MG and planting date may exhibit variations under irrigated and rainfed conditions, as plants do not undergo drought stress under irrigated settings. Hence, comprehending the interaction between MG and planting date is crucial, particularly under rainfed conditions. In the southeastern United States, drought stress from mid-July to late August is a significant impediment to the yield of late-planted rainfed soybean (Morrison & Rabb, 1996). Late-maturing cultivars (MG V and VI) are often recommended for late planting or double-crop soybean to mitigate the impact of late-summer drought stress under rainfed conditions (Ashlock, Klerk, et al., 1998; Ashlock, Mayhew, et al., 1998). This recommendation stems from the alignment of the seed-filling period of late-maturing cultivars with substantial rainfall and mild temperatures during September (Purcell et al., 2003). Moreover, the duration of reproductive developmental stages at late planting may be more adversely affected for early-maturing cultivars than for late-maturing ones (Abel, 1961). However, G. Chen and Wiatrak (2010) reported a more significant reduction in the duration of the flowering period for MG V through VIII compared to MG IV when planted late. J. E. Board and Hall (1984) observed that warm temperatures (27˚C) with a short photoperiod decrease the days to first flowering more for MG VI and VII cultivars than for MG V cultivars. Consequently, selecting an appropriate MG for a double-cropping system poses challenges due to the limited research on double-cropping systems and the variability in environmental conditions across years and latitudes. The choice of MGs for the double-cropping system in a specific geographical location or state should be grounded in their performance under the same system and agro-climatological conditions, and this area necessitates further research.

4.7 | Soybean growth habits

Soybean with MG ≤ IV typically exhibits an indeterminate growth habit, while those with MG ≥ V display a determinate growth habit, although exceptions exist. The key distinction lies in the fact that indeterminate soybean continues main-stem elongation after flowering, whereas determinate soybean ceases main-stem elongation either at or shortly after flowering (Bernard, 1972; Hoeft et al., 2000). Determinate soybean is typically shorter, has fewer main-stem nodes but more branches, and demonstrates lower susceptibility to lodging compared to indeterminate soybean (Beaver et al., 1985; Cooper, 1985; Egli & Leggett, 1973; Foley et al., 1986; Gai et al., 1984; Hicks et al., 1969; Ouattara & Weaver, 1994; Wilcox & Frankenberger, 1987). Although the yield potentials of determinate and indeterminate soybean are generally comparable (Ouattara & Weaver, 1994; Parvej et al., 2015), these two growth habits are known to respond differently to narrow versus wide row spacing (R. W. Elmore, 1998).

The consistency of soybean yield increases in narrow row spacing is generally lower in the southern United States compared to the northern United States (Beatty et al., 1982; Boquet et al., 1982; Hartwig, 1957; Hodges et al., 1983; Parvez et al., 1989; R. L. Smith, 1968; R. L. Smith & Hinson, 1969). This discrepancy is primarily attributed to the prevalent use of determinate soybean varieties in the southern United States, as noted by R. R. Johnson (1987). Determinate soybean typically achieve canopy closure by the flowering or pod set stage due to extensive branching, potentially limiting the benefits derived from narrow row spacing (R. R. Johnson, 1987). Given that narrower rows facilitate faster canopy closure and indeterminate soybean, characterized by less branching, do not naturally achieve canopy closure by the pod set period, Parvez et al. (1989) proposed the hypothesis that indeterminate soybean would derive greater benefits from narrow row cultivation compared to determinate soybean.

Recent studies have continued to explore the impact of row spacing on soybean yields, with a focus on both indeterminate and determinate cultivars. While earlier research indicated that indeterminate soybean exhibits a yield increase of 10%–50% in narrow rows compared to wider rows, irrespective of the planting date (Cooper, 1971, 1977; Cooper & Lambert, 1965; Lehman & Lambert, 1960; Moraghan, 1970; Pendleton et al., 1960), more recent findings present a nuanced perspective. For instance, a study by De Bruin and Pedersen (2008a) found no significant yield differences between narrow and wide-row configurations in certain conditions. Similarly, research by Andrade et al. (2019) indicated that while experimental data often showed a consistent yield advantage for narrow rows, data from producer fields did not always reflect this benefit. These discrepancies suggest that the effectiveness of narrow row spacing may depend on specific environmental factors, management practices, and regional conditions. Therefore, while narrow row spacing has the potential to enhance soybean yields, its success is not universal and should be evaluated within the context of local agronomic conditions.

Although determinate soybean has also shown positive responses to narrow rows when planted after mid-June (Akhanda et al., 1976; Beatty et al., 1982; Boerma & Ashley, 1982; Boquet et al., 1982; Parvez et al., 1989), existing literature indicates that determinate soybean may experience a reduction in yield due to a lower number of fertile nodes, branches, pods, and seeds plant^{-1} when planted late (J. E. Board, 1985; J. E. Board & Settimi, 1986; Boquet et al., 1982; Leffel, 1961; Osler & Cartter, 1954). Duncan (1986) observed that reduced competition during the vegetative stage leads to increased soybean yield, attributed to enhanced dry matter and pod production that efficiently utilizes photosynthates from intercepted light. This implies that in a double-cropping system with narrow row (19 cm) cultivation, determinate soybean may exhibit greater competition due to extensive branching, potentially resulting in yield loss compared to indeterminate soybean. However, limited research has investigated the yield response of indeterminate and determinate soybean to narrow versus wide row spacing in a double-cropping system, necessitating further exploration in this area.

4.8 | Seeding rate and plant population

The cost of soybean seeds has experienced a significant increase over the past few decades. In 1996, the expense was approximately \$27 ha^{-1}; by 2015, it had escalated to \$150 ha^{-1} (USDA-NASS, 2016). This upward trend has continued, with recent data indicating that in 2021, the average seed cost for US soybean producers was about \$156 ha^{-1} (USDA-ERS, 2022). This rise in seed costs can be attributed to several factors, including the adoption of genetically engineered seed varieties and advancements in seed technologies. Consequently, determining an economically optimal seeding rate to attain a plant population that maximizes soybean yield has become a prominent agronomic objective (Ball et al., 2000a; J. E. Board & Kahlon, 2013; De Bruin & Pedersen, 2008a).

Soybean possesses a distinctive ability to compensate for seed yield loss at reduced plant populations by increasing the number of branches, pods plant^{-1}, and seeds pod^{-1} (J. Board, 2000; J. E. Board et al., 1999; J. E. Board & Kahlon, 2013; Carpenter & Board, 1997; Cox et al., 2010; Egli, 1988; Egli & Bruening, 2006; Epler & Staggenberg, 2008; Koger, 2009; Wells, 1991, 1993). Notably, literature has documented similar yields for full-season soybean at 620,000 seeds ha^{-1} compared to a 40% reduction in South Carolina (Norsworthy & Frederick, 2002) and 432,300 seeds ha^{-1} with a 20% reduction in Maryland (Kratochvil et al., 2004). Bowen and Schapaugh (1989) found no yield response in full-season soybean at seeding rates of 128,000, 259,000, and 385,000 seeds ha^{-1} in Kansas. Similar results were reported for the Texas Gulf Coast by Grichar (2007). Other studies have indicated that full-season soybean requires 200,000–350,000 uniformly distributed plants ha^{-1} for optimal yield (Beuerlein, 1988; R. W. Elmore, 1991, 1998; Heatherly & Elmore, 2004; Weber et al., 1966; Wiggans, 1939). Overall, influenced by environmental and crop management factors, the literature suggests that the optimum plant population for maximizing soybean yield ranges from 300,000 to 500,000 plants ha^{-1} (Costa et al., 1980; Egli, 1988; Leffel & Barber, 1961; Lehman & Lambert, 1960; Lueschen & Hicks, 1977; Parks et al., 1982; Wells, 1991).

Many studies have explored the response of full-season soybean yield to seeding rates (J. Board, 2000; Cooper, 1977; J. T. Edwards & Purcell, 2005; Egli, 1988; Ethredge et al., 1989; Parvez et al., 1989; Shibles & Weber, 1966). Generally, soybean yield exhibits a positive linear-plateau or quadratic relationship with seeding rate or plant population (Ablett et al., 1984; Cox & Cherney, 2011; Devlin et al., 1995; J. T. Edwards & Purcell, 2005; Holshouser & Whittaker, 2002; Oplinger & Philbrook, 1992; N. M. Thompson et al., 2015). For instance, Blumenthal et al. (1988), examining soybean yield in response to plant populations of 50,000, 100,000, 200,000, and 400,000 plants ha^{-1}, observed an increase in soybean yield up to 200,000 plants ha^{-1}, beyond which it declined. Bruns and Young (2012) assessed full-season soybean yield across seeding rates ranging from 200,000 to 500,000 seeds ha^{-1} and identified the maximum yield at 400,000 seeds ha^{-1}. In a study by Cox and Cherney (2011), soybean yield increased by 7% with a seeding rate increase from 321,000 to 420,000 seeds ha^{-1} but decreased by 4% with a further increase to 469,000 seeds ha^{-1}.

Literature indicates that an excessive plant population can reduce soybean yield by diminishing individual plant leaf area, thus decreasing light interception efficiency (J. Board, 2000; J. T. Edwards et al., 2005; Purcell et al., 2002). G. Chen and Wiatrak (2011) demonstrated that both LAI and normalized difference vegetation index (NDVI) either decline or exhibit minimal increases with a seeding rate above 272,000 seeds ha^{-1}. Plant NDVI is commonly used to monitor plant growth and vegetation cover, and soybean yield is closely correlated with NDVI at the pod-set stage (Ma et al., 2001). Another factor contributing to reduced seed yield at excessive plant populations is lodging (Costa et al., 1980; Noor & Caviness, 1980; Weber & Fehr, 1966). High plant population heightens competitive stress (Bowen & Schapaugh, 1989), plant height, and plant mortality (Cooper & Lambert, 1971), leading to yield loss through lodging (Cooper, 1981; Ethredge et al., 1989; Mancuso & Caviness, 1991; Weber & Fehr, 1966). Tall soybean plants are particularly susceptible to lodging under heavy rainfall and strong winds (J. Board, 2001). However, reports of soybean yield decline due to excessive plant population are mainly derived from research conducted under full-season cropping systems.

Research on double-crop soybean yield response to the seeding rate or plant population is limited in the existing literature. The available evidence indicates that late-planted double-crop soybean necessitates a higher seeding rate or plant population to maximize yield compared to early-planted full-season soybean (Beuerlein, 1988; Whigham et al., 2000). Previous recommendations from Cooperative Extension specialists in the Mid-Atlantic region suggest seeding rates ranging from 247,000 to 432,000 live seeds ha^{-1} for full-season soybean and 445,000 to 556,000 live seeds ha^{-1} for double-crop soybean (Kratochvil et al., 2004). C. D. Lee et al. (2008) observed that soybean planted in May require a population of 108,000–232,000 plants ha^{-1} for optimal yield, while those planted in June require a range of 238,000–282,000 plants ha^{-1}.

Recent recommendations from Cooperative Extension specialists in the Mid-Atlantic region have adjusted soybean seeding rates to reflect advancements in seed technology and agronomic practices (Whaley et al., 2018). For full-season soybean production, seeding rates now range from approximately 197,000–345,000 live seeds ha^{-1} (80,000–140,000 seeds ac^{-1}), depending on soil productivity and expected yield potential. Fields with higher yield potential may require lower seeding rates, while less productive soils may benefit from higher rates. For double-crop soybean systems, seeding rates are typically increased to account for the shortened growing season and to ensure adequate canopy closure. L. Lindsey and Richer (2021) suggest planting between 200,000 and 250,000 seeds ac^{-1} (approximately 494,000–617,500 seeds ha^{-1}) to achieve optimal yields for double-crop soybean. These adjustments aim to balance seed costs with agronomic benefits, optimizing plant populations for both full-season and double-crop soybean systems.

Holshouser and Jones (2003) demonstrated a linear or curvilinear increase in double-crop soybean LAI and seed yield with an increase in plant population. Similar findings were reported by Devlin et al. (1995) for the seed yield of soybean planted in June. Data from Kratochvil et al. (2004) suggested that the yield of double-crop soybean tends to rise with increasing seeding rate, while full-season soybean exhibits inconsistent responses to seeding rate. Based on these results, soybean yield response to seeding rate may differ for double-crop soybean compared to full-season soybean, underscoring the need for further research on this topic.

Recent studies have further examined the maturity timelines of full-season and double-crop soybean systems.

Typically, double-crop soybean is planted 30–45 days later than full-season soybean, as they follow the harvest of a preceding crop, such as winter wheat (Lofton et al., 2020). This delayed planting results in a correspondingly later maturation period for double-crop soybean. The exact difference in maturation time between full-season and double-crop soybean can vary based on regional climate conditions, soybean MG selection, and specific management practices. Therefore, while double-crop soybean generally matures several weeks later than their full-season counterparts, the precise duration can differ depending on these factors.

According to Kratochvil et al. (2004), the difference in maturity contributes to the lower seeding rate required for full-season soybean compared to double-crop soybean. The extended growth period allows full-season soybean to achieve the desired LAI at a reduced seeding rate. Another factor influencing the higher yield of full-season soybean at a reduced seeding rate is the enhanced seed-soil contact in fields with no or minimal crop residues, resulting in improved emergence and stand establishment (Barker et al., 2005; Specht et al., 2014). These factors shed light on the inconsistent yield response of full-season soybean to seeding rates. In contrast, a low seeding rate for late-planted soybean may limit vegetative growth due to shorter growing seasons, potentially leading to reduced seed yield (Ball et al., 2000b; Calvino et al., 2003; G. Chen & Wiatrak, 2011). Full-season soybean, benefiting from a longer growing season, can maintain high yields even at reduced seeding rates by allowing plants to develop an optimal LAI (Popp et al., 2006). Ball et al. (2000b) demonstrated that double-crop soybean, despite having a shorter growing season, can achieve a desirable LAI of 3.5–4.0 with an increased plant population from 300,000 to 600,000 plants ha^{-1}. Malone et al. (2002) reported that both full-season and double-crop soybean experiences decreased yields when LAI falls below 3.5–4.0 at the R4–R5 stages.

The optimal seeding rate for both full-season and double-crop soybean is influenced by various factors, including soil and environmental conditions, row spacing, MG, and soybean growth habits. Soybean generally requires a higher plant population to maximize yield in adverse growing conditions compared to favorable conditions (Wells, 1991, 1993). Under optimal soil conditions, Heatherly and Elmore (2004) recommended a seeding rate of 300,000–370,000 viable seeds ha^{-1}, but this rate should be increased by 50% under poor soil conditions. Holshouser and Whittaker (2002) reported that soybean may need three times more plants ha^{-1} (208,000 vs. 600,000 plants ha^{-1}) for maximum yield in Virginia under drought conditions compared to situations with sufficient soil moisture. Norsworthy & Frederick (2002) suggested that the soybean seeding rate could be reduced from the recommended rate without sacrificing yields, but only under conditions of adequate soil moisture. Conversely, Devlin et al. (1995) reported that soybean yield and plant height exhibited positive responses to seeding rate under high-yielding conditions but not under low moisture conditions. Williamson (1974) observed lower yields for a seeding rate of 356,000 plants ha^{-1} compared to <267,000 plants ha^{-1} in dry years with moisture stress. In drought conditions, the competition for limited soil moisture may intensify as plant population increases, leading to a reduction in seed yield (Alessi & Power, 1982; R. W. Elmore, 1998).

Row spacing stands out as another critical factor influencing the optimal plant population or seeding rate for achieving maximum soybean yield (J. E. Board et al., 1990; J. E. Board & Harville, 1994; Boquet, 1990; Bullock et al., 1998; Egli, 1994; Oplinger & Philbrook, 1992; Parvez et al., 1989; Weber et al., 1966). Herbert and Litchfield (1984) highlighted that in narrow row (25 cm) plantings, a higher seeding rate of 800,000 seeds ha^{-1} resulted in elevated LAI and dry matter compared to a lower seeding rate of 250,000 seeds ha^{-1}. According to De Bruin and Pedersen (2008b), soybean requires 194,000–290,800 plants ha^{-1} in 38-cm row spacing and 157,300–211,800 plants ha^{-1} in 76-cm row spacing to achieve maximum yield. Bertram and Pedersen (2004) recommended seeding rates of 556,000, 432,000, and 309,000 seeds ha^{-1} for 19-, 38-, and 76-cm row spacing in Wisconsin. Studies by Weber et al. (1966) and Oplinger and Philbrook (1992) indicated that full-season soybean necessitates a higher seeding rate in narrow row spacing compared to wider row spacing for maximizing yield. However, Timmons et al. (1967) reported that soybean with wide row spacing requires more seeds to maximize yield than soybean with narrow row spacing. The literature also documented no interaction between seeding rate and row spacing for full-season soybean yield (Ablett et al., 1991; Beuerlein, 1988; Cooper, 1977). For the late-planted soybean, Boquet (1990), when comparing late-planted soybean yield in 50-cm versus 100-cm row spacing, determined that soybean with 50- and 100-cm row spacing maximize yield at 380,000 and 130,000 plants ha^{-1}, respectively, when planted in June, and at 51 and 26 plants m^{-2} when planted in July. Devlin et al. (1995) illustrated that late-planted soybean yield increases linearly for 20-cm row spacing and curvilinearly for 76-cm row spacing with an increase in seeding rate.

The optimal seeding rate or plant population varies across soybean MG and growth habits. Popp et al. (2006) identified an economically optimum plant population of 110,000 plants ha^{-1} for MG IV and 490,000 plants ha^{-1} for MG II when planted as a full-season crop. G. Chen and Wiatrak (2011) determined an optimum seeding rate of 255,000 seeds ha^{-1} for MG V as full-season soybean, and 228,200 and 342,500 seeds ha^{-1} for MG VII and VIII, respectively, as double-crop soybean. Holshouser and Jones (2003) reported that double-crop soybean, planted in late June or early July, requires 741,000 plants ha^{-1} for MG III cultivars and 370,500 plants ha^{-1} for MG V cultivars to maximize yield. Beuerlein (1988) observed that indeterminate soybean, such as Williams, did not respond to the seeding rate, while determinate soybean, like Sprite, increased yield with an increase in the seeding rate up to 741,000 seeds ha^{-1}. Similar results were reported by R. W. Elmore (1998). Ablett et al. (1991) demonstrated that indeterminate soybean yielded similarly at seeding rates of 395,000 and 790,000 seeds ha^{-1}, but determinate soybean yielded more at 395,000 seeds ha^{-1}. This outcome suggests that determinate soybean may lead to more competition at a high seeding rate due to its high branching ability, especially when planted early. Literature suggests that reducing the seeding rate for early maturing indeterminate cultivars may not be feasible at most planting dates due to limited branching ability and a short vegetative period, constraining the attainment of optimum LAI (Akhter & Sneller, 1996). Conversely, a reduction in the seeding rate for early-planted late-maturing determinate cultivars is possible without affecting seed yield due to prolonged vegetative growth (Norsworthy & Frederick, 2002). However, for late-planted soybean, a low seeding rate for late-maturing determinate cultivars (MG VII and VIII) may not be possible due to yield loss from the short growing period (Ball et al., 2000b; Calvino et al., 2003; G. Chen & Wiatrak, 2011).

In summary, existing literature indicates that double-crop soybean exhibits distinct responses to seeding rates and necessitates a higher number of seeds to optimize yield when compared to full-season soybean. Consequently, reducing the seeding rate for double-crop soybean may not be a viable strategy. Employing a higher seeding rate, coupled with the appropriate MG in narrow row spacing, can facilitate swift canopy development, enhancing solar radiation interception and potentially mitigating yield losses associated with late planting in double-crop soybean. However, there is a dearth of information in the literature regarding the optimal seeding rate or plant population for double-crop soybean under various agronomic factors, including narrow versus wide rows, early versus late MG, determinate versus indeterminate varieties, and irrigated versus rainfed conditions. Given that the seeding rate for full-season soybean varies with latitude, future research and recommendations for double-crop soybean should be tailored to specific states or broader geographic regions, such as the Midwest, Mid-South, deep-South, and Mid-Atlantic.

4.9 | Soil fertility

4.9.1 | Nitrogen management

Nitrogen stands out as the most crucial nutrient in crop production, with soybean having a greater demand for N than any other nutrient. Soybean needs varying amounts of N to achieve specific grain yields, requiring 166, 251, 323, and 408 kg N ha^{-1} to produce 1680, 2688, 3696, and 4704 kg of grain ha^{-1}, respectively (equivalent to 87–99 kg N ha^{-1} Mg^{-1} grain; IPNI, 2011). Soybean meets this substantial N requirement through symbiotic N_2 fixation facilitated by *Rhizobia* bacteria, specifically *Bradyrhizobium japonicum*, which converts atmospheric N_2 into plant-available N (Beuerlein, 2004; Bezdicek et al., 1978; Bhangoo & Albritton, 1976; T. G. Patterson & LaRue, 1983). Nevertheless, the efficacy of N_2 fixation depends on the population of *B. japonicum* (K. Thelen & Schulz, 2009) and the availability of soil nitrate-N (NO_3-N; J. E. Harper, 1987).

The abundance of *B. japonicum* population is influenced by factors such as cropping system, plant population density, soil temperature, soil water content, organic matter, soil texture, and soil pH (Abendroth & Elmore, 2006; Albrecht et al., 1984; Bacanamwo & Purcell, 1999; Beuerlein, 2004; De Bruin et al., 2010; Furseth et al., 2012; Graham, 1992; Hiltbold et al., 1980; Schulz & Thelen, 2008; Seneviratne et al., 2000). To ensure symbiotic N_2 fixation, the application of *B. japonicum* inoculants is recommended for soils that have not been previously cropped to soybean (De Bruin et al., 2010; Furseth et al., 2012; Hiltbold et al., 1980; Schulz & Thelen, 2008) as well as for soils that are coarse in texture with low organic matter and nonoptimal pH and have been flooded recently (Abendroth & Elmore, 2006; Pedersen, 2004). It is observed in the literature that the application of bacterial inoculants is unlikely to boost soybean yield in soils where soybean has been cultivated in the last 5 years and *B. japonicum* populations are already present (Beuerlein, 2005; De Bruin et al., 2010; Furseth et al., 2012; Hiltbold et al., 1980; Schulz & Thelen, 2008).

The literature indicates that soybean N_2 fixation can contribute 25%–50% of the total N accumulated during the growing season under fertile soil conditions (J. E. Harper, 1987) and 80%–94% under conditions of low soil NO_3-N and sufficient soil moisture conditions (J. E. Harper, 1987; Mastrodomenico & Purcell, 2012). In situations of low soil N, soybean has demonstrated the ability to fix enough N to produce 4.5–5.0 Mg of grain ha^{-1} (Purcell, 2014; Salvagiotti et al., 2008), suggesting that additional N may not be necessary to achieve satisfactory yields (<5.0 Mg ha^{-1}). However, various studies have shown a positive response of full-season soybean to N fertilization across a broad range of yield goals (Afza et al., 1987; Al-Ithawi et al., 1980; Bhangoo & Albritton, 1976; Eaglesham et al., 1983; Ham et al., 1975; Lamb et al., 1990; Purcell & King, 1996; Sorensen & Penas, 1978; Touchton & Rickerl, 1986; T. L. Wesley et al., 1998; Wood et al., 1993), although others reported no response (Beard & Hoover, 1971; de Mooy et al., 1973; Deibert et al., 1979; Gutierrez-Boem et al., 2004; Sij et al., 1979; Slater et al., 1991; Welch et al., 1973) or even a negative response (Peterson & Varvel, 1989). The lack of response or negative response of soybean yield to fertilizer N may be attributed to reduced nodule formation, nodule mass, and N_2 fixation resulting from high levels of fertilizer N or residual soil NO_3-N (Bhangoo & Albritton, 1976; Ham et al., 1975; Purcell, 2014; Weber, 1966; Yoneyama et al., 1985; Yoshida, 1979).

The literature suggests that the potential for soybean yield increase due to N fertilization becomes apparent when the yield surpasses 4.0 Mg ha^{-1}, soil NO_3-N is below 56 kg ha^{-1} in the top 61-cm soil depth, the soil pH is below 7.5, and irrigation is provided (Scharf & Wiebold, 2003). Positive yield responses to fertilizer-N have been documented in full-season soybean on soils with less than 90 kg NO_3-N ha^{-1} (Lamb et al., 1990) and with low pH and organic matter (Sorensen & Penas, 1978). Purcell and King (1996) reported that N fertilization increased soybean yield under water stress conditions that limited biological N_2 fixation. Hesterman & Isleib (1991) found no soybean yield response to fertilizer-N on clay soils but observed a yield increment of 460 kg ha^{-1} on sandy loam soils. The study by Sorensen and Penas (1978) highlighted that soil temperature, moisture, and pH influence soybean yield response to fertilizer-N on silty clay loam soils. In a study conducted in a high-yielding environment in Mr. Kip Cullers' field in Missouri and another in Fayetteville, AR, in 2013, Van Roekel (2015) reported maximum soybean yields of 7953 kg ha^{-1} (118 bushel ac^{-1}) and 7794 kg ha^{-1} (116 bushel ac^{-1}), respectively. In the Fayetteville study, a high-yielding environment was established by applying a total of 781 kg N, 305 kg P, 631 kg K, 90 kg S, and 31 kg Mg ha^{-1} as poultry litter and inorganic fertilizer before planting, along with 178 kg N, 40 kg K, and 11 kg S ha^{-1} as inorganic fertilizer and 625 mm irrigation during the crop growing season. For both studies, Purcell (2014) highlighted that over 90% of the total accumulated N in both studies came from poultry litter and/or inorganic fertilizer, with less than 10% from biological N_2 fixation. While emphasizing that a single management factor cannot maximize soybean yield, Purcell indicated that soybean may need the total amount of N from inorganic N sources to maximize a yield of ≥6719 kg ha^{-1} (100 bushel ac^{-1}). He concluded that achieving an additive benefit from supplemental N to increase soybean yield might be challenging unless N_2 fixation is limited by stress and ineffective *B. japonicum* populations.

The literature suggests that N_2 fixation in soybean initiates around the V2–V3 stages (Wani et al., 1995), reaches its peak shortly after blooming, and experiences a rapid decline during the seed-filling period (Gomes & Sodek, 1987; Lawn & Brun, 1974; Thibodeau & Jaworski, 1975). Alternatively, it may continue at a high rate until the late seed-filling period (Denison & Sinclair, 1985; Hanway & Weber, 1971; Leffel et al., 1992; D. R. Nelson et al., 1983; A. N. Nelson & Weaver, 1980; Spaeth & Sinclair, 1983; Weber, 1966; Zapata et al., 1987). Bergersen (1958) observed nodulation only at 9 days after soybean emergence, while Hardy et al. (1971) noted nodulation at 14 days after planting, specifically under optimal soil moisture and temperature conditions. Both researchers suggested that a small amount of preplant N would be beneficial for early-season soybean growth. A similar recommendation was made by Shibles (1998) for soils low in organic matter.

The response of soybean yield to fertilizer-N may vary between double-crop and full-season soybean production systems. Although limited research has been conducted on the double-crop soybean yield response to fertilizer-N, existing literature consistently indicates a positive impact of N fertilization on late-planted soybean (K. A. Dillon, 2014). Starling et al. (1998, 2000; Hairston et al., 1987; Starling et al., 1998, 2000; R. S. Taylor et al., 2005) observed that soybean with starter N (50 kg N ha^{-1} as ammonium-nitrate, NH_4NO_3) exhibited a yield increase of up to 14% and R1 dry matter accumulation of up to 25% on sandy loam soils compared to soybean without starter N. R. S. Taylor et al. (2005) assessed the yield and R1 dry matter of double-crop soybean across five broadcast N rates (0, 25, 50, 75, and 100 kg N ha^{-1} as NH_4NO_3) with three planting dates (mid-June, late June, and mid-July) on fine sandy loam soil with less than 8 kg NO_3-N ha^{-1}. Their findings revealed that, regardless of planting date, soybean yield and dry matter accumulation at the R1 stage increased up to 75 kg N ha^{-1} and then tended to decrease. K. A. Dillon (2014) reported similar results, demonstrating that double-crop soybean with a starter N of 16 kg N ha^{-1} increased yield by 5% compared to the no N control, and there was no significant difference in yield among soybean with 0, 31, 47, and 63 kg N ha^{-1}. In fact, soybean with 63 kg N ha^{-1} in his study yielded numerically lower than soybean with any other starter N. Similarly, Reese and Buss (1992) did not observe a yield benefit from the application of 56 kg N ha^{-1} at planting or at flowering. J. L. Pikul et al. (2001) also reported a positive soybean yield response to low starter N of <15 kg N ha^{-1} in 9 of 11 years. Hairston et al. (1987) reported similar results for 28 kg ha^{-1} preplant N. All these studies on late-planted soybean suggest that when the N supply from soil residual N and biological N_2 fixation is limited, double-crop soybean may benefit from a small amount of starter N for rapid early-season growth, as insufficient vegetative growth is one of the vital reasons for the decrease in double-crop soybean yield (Ball et al., 2000b). The reduction in yield of double-crop soybean with high starter N may be attributed to the same factors causing reduced nodule formation and N_2 fixation at high fertilizer-N rates or soil NO_3-N availability (Bhangoo & Albritton, 1976; Ham et al., 1975; Purcell, 2014; Weber, 1966; Yoneyama et al., 1985; Yoshida, 1979).

Since soybean N_2 fixation peaks around the blooming stage, additional fertilizer-N during the reproductive stages may not be necessary to maximize yield. Several studies have shown an increase in soybean yield from fertilizer-N applied at planting or emergence, but no yield improvement was recorded from fertilizer-N applied at the mid-pod fill stage (Bly et al., 1998; Riedell et al., 1998; Woodard et al., 1998). This suggests that foliar N application during the reproductive stage may not be an effective option for increasing soybean yield. Another reason is that foliar feeding does not allow farmers to apply enough N to enhance soybean yield significantly. Purcell (2014) calculated that the application of 4 L ha^{-1} foliar fertilizer-N containing 20% N provides approximately 0.8 kg N ha^{-1} (0.08 g N m^{-2}). This amount is considerably low compared to the typical daily N accumulation rate of 0.4–0.6 g N m^{-2} day^{-1} required to induce any significant yield change. Additionally, a high rate of foliar fertilizer-N may lead to leaf burn due to a high salt index (Parker & Boswell, 1980).

In summary, full-season soybean may not necessitate additional N to achieve satisfactory yields under conditions of sufficient soil moisture and low soil nitrate-N (NO_3-N). The application of small to moderately high amounts of fertilizer-N may not yield any incremental benefits in enhancing the overall yield of full-season soybean, unless growth conditions constrain natural N_2 fixation. However, achieving the highest soybean yield (≥6719 kg ha^{-1}) might require the complete substitution of the biological N source (N_2 fixation) with a substantial amount of inorganic N, in conjunction with other essential nutrients and irrigation. In contrast, because of the shorter growing season of double-crop soybean and the delayed onset of N_2 fixation until 9 days after soybean emergence, a small amount of starter N could boost early-season growth, facilitating rapid canopy closure, optimal solar radiation interception, and, consequently, an increase in soybean yield. Nevertheless, given the inadequate number of research assessing the response of double-crop soybean to starter N, further research is warranted to confirm the consistency of yield improvement from starter N and, if affirmed, to identify the optimal starter N rate for maximizing yield.

4.9.2 | Phosphorus and potassium management

Soybean has been shown to exhibit positive responses to both P and K fertilization in various studies (Borges & Mallarino, 2000, 2003; Dodd & Mallarino, 2005; Haq & Mallarino, 2005; Mallarino et al., 2009; Parvej et al., 2018; A. S. Williams et al., 2018). But the extent of the positive yield response to P and K fertilization is dependent upon the soil-test P and K concentrations, respectively. Numerous studies have documented an increase in soybean yield due to P and K fertilization in soils with very low or low nutrient availability, typically ranging from <15 to 21 mg P kg^{-1} (Bray-P1 or Mehlich-3 extractants; Bharati et al., 1986; Borges & Mallarino, 2000, 2003; de Mooy et al., 1973; Dodd & Mallarino, 2005; Haq & Mallarino, 2005; Mallarino et al., 1991; Mallarino et al., 2009; Randall et al., 1997; Rehm, 1986; Webb et al., 1992; Wittry & Mallarino, 2004) and <90 to 130 mg K kg^{-1} (NH_4AOc or Mehlich-3 extractants; Bharati et al., 1986; Borges & Mallarino, 2000, 2003; de Mooy et al., 1973; Grove et al., 1987; Haq & Mallarino, 2005; Jeffers et al., 1982; Rehm et al., 1995; Yin & Vyn, 2002a, 2003). Soybean's response to P and K fertilization is minimal or absent in soils with medium nutrient availabilities (Grove et al., 1987; Rehm, 1986) and unexpected in soils with high or very high nutrient availabilities (Bharati et al., 1986; Borges & Mallarino, 2000; Buah et al., 2000; de Mooy et al., 1973; Rehm, 1986; Yin & Vyn, 2002a). However, it's worth noting that none of the cited research except Parvej et al. (2018) has evaluated soybean yield responses to P and K fertilization under a double-cropping system.

In the wheat–soybean double-cropping system, farmers typically apply P and K fertilizers before planting wheat, aiming to fulfill the nutrient requirements of both crops. Similarly, in a 2-year corn–soybean rotation in the Midwest, the entire P and K amounts for both crops are typically applied before planting corn. These practices enable farmers to streamline operations, saving time and reducing fertilizer application costs for soybean. In the Midwest corn–soybean production system, existing literature presents varying responses of soybean yield to the timing of P and K applications (Buah et al., 2000; Mallarino et al., 2009; Yin & Vyn, 2002a, 2002b). However, no recent peer-reviewed articles were found that specifically investigated the effects of P and K application timing on soybean yield in the wheat–soybean double-cropping system. Research conducted in the 1980s on sandy to loamy sand soils in Georgia and Virginia indicated that the timing of P and K application does not significantly impact double-crop soybean yield (Elwali & Gascho, 1985; Evanylo, 1991; Touchton et al., 1982). The most recent extension publication, focusing on silt loam soils in Arkansas (Slaton et al., 2012, 2013), reported similar results for P in 2011 and 2012 and for K in 2012; however, in 2011, a significant interaction between K application rate and timing was also reported. These findings suggest that the timing of P fertilizer application may not influence double-crop soybean yield in the wheat–soybean system, but there might be room for further investigation regarding K application timing. G. D. Jones et al. (1977) demonstrated that soybean is more responsive to K fertilization than P.

Most double-crop soybean following winter wheat are cultivated using no-tillage practices, a method that has been the subject of various studies highlighting P and K stratification in the topsoil (Cruse et al., 1983; Fernández et al., 2008; Griffith et al., 1977; Houx et al., 2011; Karathanasis & Wells, 1990; Karlen et al., 1991; Ketchenson, 1980; Mackay et al., 1987; Mallarino & Borges, 2006; Moncrief & Schulte, 1982; Rehm et al., 1995; Shear & Moschler, 1969; Timmons, 1982; Vyn & Janovicek, 2001). All these studies were conducted on fine-textured soils, ranging from silt loam to clay, and consistently showed significant P stratification compared to K.

However, research by Elwali and Gascho (1985) and Evanylo (1991) on coarse-textured soils, specifically sand to loamy sand, revealed either no or less stratification of K across soil profiles. Soil-test K data from both studies suggested that K leached down into the soil profile. Evanylo (1991) concluded that the absence of double-crop soybean yield response to K fertilization rate and timing on loamy sand was linked to leaching and the accumulation of K below a 46-cm soil depth. He proposed that the availability of soil K below the 46-cm depth in coarse-textured soil should be accounted for when calculating the optimum fertilizer rate for soybean. This idea finds support in the literature, which indicates that soybean taproots can utilize soil reserves differently, extracting more K from the B horizon in coastal plain soils compared to corn fibrous roots (Heckman & Kamprath, 1995; Woodruff & Parks, 1980).

The application of K in split or in-season intervals may offer a viable strategy to enhance soybean yield by minimizing K loss in soils susceptible to leaching. Kolar and Grewal (1994) conducted an assessment of soybean yield with split K applications on loamy sand, observing higher soybean yields when K was applied in two (half at preplant and half at flowering) or three (one-third at preplant, one-third at flowering, and one-third at pod development) splits compared to soybean receiving all preplant K. Another contemporary method involves foliar application of K in soybean to address in-season K deficiencies and potentially boost yield by enhancing K uptake efficiency. K. A. Nelson et al. (2005) demonstrated that late-planted soybean yields on silt loam could increase by up to 834 kg ha^{-1} through foliar K application at V4, R1–R2, and R3–R4 stages compared to soybean without K application. However, soybean yield increase from preplant K application was substantially higher than any foliar feeding at different growth stages. The conclusion drawn was that foliar K application cannot replace preplant K in enhancing soybean yield but can serve as a supplementary option to mitigate yield losses under conditions limiting K uptake from the soil. Currently, there is a lack of studies evaluating double-crop soybean yield responses to split or foliar K application, highlighting the need for further research on this subject.

Determining K deficiency before applying in-season K is crucial to assess the potential benefits of K application. Soybean K deficiency is commonly diagnosed using the critical K concentration in the uppermost recently mature trifoliolate leaf at the R2 stage (Bell et al., 1995; Hanway & Johnson, 1985; Mills & Jones, 1996; Sabbe et al., 2000; Slaton et al., 2010). A recent study by Parvej et al. (2016) established critical K concentrations in both petiole and trifoliolate leaves across the reproductive growth stages (R2–R6) of soybean. However, none of the cited studies developed critical tissue-K concentrations specifically for double-crop soybean. Coale and Grove (1991) noted numerically higher K concentrations in the leaf and statistically higher K concentrations in the petiole at the R1 and R5 stages of double-crop soybean compared to full-season, despite full-season soybean exhibiting greater total dry matter and K accumulation. These results suggest the elevated tissue-K concentration in double-crop soybean may be attributed to a lesser dilution effect than in full-season soybean. Consequently, critical tissue-K concentrations at specific growth stages may differ for double-crop and full-season soybean, necessitating further investigation into this aspect.

In conclusion, fertilization with P and K for double-crop soybean following winter wheat should align with established critical soil-test concentrations designed for full-season soybean. Fertilizers should be applied in soils with P and K concentrations below or at critical levels. Although there is literature addressing the effect of P and K application timing on soybean yield, specific investigations within the wheat–soybean double-cropping system are warranted. Adjustments in total fertilizer amounts are necessary if P and K are applied for both wheat and soybean. Further research is essential for the wheat–soybean double-cropping system to determine optimal nutrient management practices, particularly concerning split applications of P and/or K for wheat and soybean, as well as in-season P and/or K fertilization for double-crop soybean.

4.10 | Water management

Adequate soil moisture throughout the growing season is essential for achieving optimal soybean yields. In the context of double-crop soybean production, soil moisture plays a pivotal role (Pendleton & Hartwig, 1973), and drought conditions pose a significant challenge in nonirrigated systems, often leading to the failure of double-cropping endeavors (J. E. Dillon & McKibben, 1972). Drought can result in complete crop failure for double-crop soybean (Malcom, 1980) following winter wheat. Although early-season drought adversely affects seed germination and stand establishment, its impact is less pronounced in double-crop than in full-season soybean (Coale & Grove, 1990). However, planting double-crop soybean in excessively dry soil may lead to approximately 90% failure in seed germination and emergence (Swearingin, 1973). Drought stress during the soybean growing season can also diminish the germination capacity of harvested seeds (Heatherly, 1993). G. W. Thomas (1989) emphasized that insufficient soil moisture can result in a 50% reduction in double-crop soybean yield in Kentucky.

Soybean typically yields higher under irrigated conditions than under rainfed conditions. For example, irrigated soybean demonstrated a remarkable 62% higher yield than rainfed soybean in 2006 (USDA-NASS, 2007). Over the period from 1972 to 2003 in Arkansas, irrigated soybean exhibited an average yield of 2.5 Mg ha^{-1}, significantly surpassing the average yield of 1.5 Mg ha^{-1} for rainfed soybean (Egli, 2008). However, there is a notable absence of research in the last two decades specifically investigating the impact of irrigation on double-crop soybean production. In a study conducted on clay soil in Mississippi, R. A. Wesley et al. (1991) reported substantial yield differences between irrigated and rainfed soybean. Averaged across a 6-year period, irrigated soybean demonstrated a 130% and 252% increase in yield compared to rainfed soybean under full-season (2.78 vs. 1.21 Mg ha^{-1}) and double-cropping (2.18 vs. 0.62 Mg ha^{-1}) systems, respectively. Another study, conducted over a 3-year period by Daniels & Scott (1991) on silt loam soils in Arkansas, revealed a 41% higher yield for double-crop soybean under irrigation compared to nonirrigated treatments. Boerma and Ashley (1982) observed significant yield benefits from irrigation for soybean planted in different time frames. They found that irrigation increased yield by 355% for soybean planted in late June or early July and by 115% for soybean planted in late July or early August, particularly on sandy loam soils. These findings collectively emphasize the importance of irrigation for successful double-crop soybean production, highlighting the considerable challenge of achieving significant yield increases under rainfed conditions.

Soybean yield response to irrigation is primarily influenced by factors such as rainfall, soybean growth stage, and soil texture. Numerous studies have documented an increase in soybean yield with irrigation, particularly in regions characterized by arid climates and erratic rainfall patterns (Al-Ithawi et al., 1980; Ashley & Ethridge, 1978; Bachelor & Scott, 1979; Boerma & Ashley, 1982; Brady et al., 1974; Heatherly, 1985; Heatherly & Elmore, 1986, 1988; Hunt et al., 1981; Lutz & Jones, 1975; Mahler & Wollum, 1981; Matson, 1964; McKibben & Oldham, 1973; Mederski et al., 1973; Miller & Beard, 1967; Momen et al., 1979; Ramseur et al., 1984; Reicosky & Deaton, 1979; Stutte & Weiland, 1980). In the wheat–soybean double-cropping system, high-yielding wheat cultivars absorb substantial water, leaving the soil dry for soybean growth (Bauer et al., 1989; Sanford & Hairston, 1984). This can potentially hinder soybean growth, but the extent of the impact is contingent on the distribution of rainfall during the soybean growing season (Daniels & Scott, 1991). R. C. Pearce et al. (1993) noted that soybean yield is more influenced by the quantity and distribution of rainfall throughout the growing season rather than the soil moisture at the time of planting. Crabtree et al. (1990) reported that double-crop soybean yields can be comparable to full-season soybean in years with favorable rainfall distribution from June to September. After analyzing 49 years of soybean yield and rainfall data in Illinois, Runge and Odell (1960) concluded that maximum soybean yield occurs in years with evenly distributed above-average rainfall during the late vegetative, flowering, and seed-filling periods. These findings underscore the significance of irrigation scheduling or rainfall distribution during specific growth stages for successful soybean production.

The seed-filling period stands out as the most critical stage for soybean yield reduction due to water stress, with irrigation during seed-filling proving more beneficial than at any other stage (Constable & Hearn, 1978; Doss et al., 1974; McCauley, 1981; Pendleton & Hartwig, 1973; Salter & Goode, 1967; Sionit & Kramer, 1977; J. A. Thompson, 1977). Rogers and Thurlow (1970) identified a high correlation between soybean yield and rainfall during the seed-filling period. Research indicates that the reduction in soybean yield from water stress during pod set (R3–R4) and seed-filling (R5–R6) stages is associated with decreased pod and seed numbers, as well as reduced seed size and weight (Andriani et al., 1991; Ashley & Ethridge, 1978; Brevedan & Egli, 2003; De Souza et al., 1997; Dusek et al., 1971; Egli et al., 1983; Korte, Specht, et al., 1983; Meckel et al., 1984; Momen et al., 1979; R. H. Shaw & Laing, 1966; Sionit & Kramer, 1977; Smiciklas et al., 1989; Snyder et al., 1982; Vieira et al., 1992). The diminished seed size resulting from moisture stress during seed-filling is attributed to the shortened seed-filling period (De Souza et al., 1997; Desclaux & Roumet, 1996; Egli & Bruening, 2004; Meckel et al., 1984; Smiciklas et al., 1989; Westgate et al., 1989) and the acceleration of leaf senescence (Ashley & Ethridge, 1978; Brevedan & Egli, 2003; De Souza et al., 1997). Consequently, irrigation during the pod set to seed-filling periods (R3–R6) emerges as the most effective water management practice for enhancing soybean yield (Kadhem et al., 1985a, 1985b; Korte, Specht, et al., 1983; Korte, Williams, et al., 1983).

The literature presents varied perspectives on the impact of water stress during the flowering (R1–R2) stage compared to the pod set (R3–R4) and seed-filling (R5–R6) stages on soybean yield. Some researchers have asserted that water stress during flowering can lead to yield losses comparable to those at later developmental stages (Ashley & Ethridge, 1978; Runge & Odell, 1960; Shipley & Regier, 1968; Somerhalder & Schleusener, 1960; L. M. Thompson, 1970). Conversely, others have contended that water stress during flowering is less critical for reducing soybean yield than stress during pod set and seed-filling stages (McCauley, 1981), as soybean typically experiences over 50% flower abortion under normal conditions (Brevedan et al., 1978). Even in cases with a high incidence of aborted flowers, soybean can compensate for yield reduction by increasing seeds pod^{-1} and individual seed weight (Momen et al., 1979; Rathore et al., 1981; R. H. Shaw & Laing, 1966; Sionit & Kramer, 1977). However, excessive flower abortion can lead to substantial yield losses (Ashley & Ethridge, 1978; Burnside & Colville, 1964; Dusek et al., 1971; McCauley, 1981; Salter & Goode, 1967; Somerhalder & Schleusener, 1960). Water stress during vegetative stages is considered less critical for yield reduction (Doss et al., 1974; McCauley, 1981), although irrigation during late vegetative stages has been shown to increase vegetative dry matter

(Ashley et al., 1978). In summary, the literature suggests that severe water stress at any growth stage of soybean can result in significant yield reduction (Doss et al., 1974; Sionit & Kramer, 1977).

The water requirement for optimal soybean yield is influenced by soil texture. Fine-textured soils typically exhibit better water-holding capacity than coarse-textured soils, providing more sustained water availability during the growing season. Popp et al. (2000) observed higher soybean yields in clay soils compared to silt-loam soils under rainfed conditions in eastern Arkansas, attributing the difference to the superior water-holding capacity of clay soils. Verkler et al. (2009) suggested that soybean in fine-textured soils may demand less irrigation for maximum yield compared to those in coarse-textured soils. However, soils prone to crusting with low water-holding capacity and compromised water infiltration may need more frequent irrigation, albeit with less water per irrigation (Heatherly & Elmore, 2004).

The management practices of crop residue, such as tillage and burning, also play a role in influencing irrigation needs. Verkler et al. (2009) noted that no-till soils with non-burned residue exhibit slower drying compared to conventionally tilled soils with burned residue, implying that no-tillage practices might reduce irrigation requirements. Dao (1993) observed higher volumetric water contents in the top 120-cm soil depth for no-till soils than conventionally tilled soils. Additionally, Amuri and Brye (2008) reported that non-burning combined with no-tillage practices enhances soil moisture-holding capacity. Existing literature also suggests that irrigation proves more effective in maximizing soybean yield under specific management practices, such as narrow row spacing, higher plant population, optimal fertilization, suitable cultivars, and Rhizobia inoculation (Brown & Perkins, 1979; Gerlow & Mullins, 1960; Mahler & Wollum, 1981; McKibben & Oldham, 1973; Mederski & Jeffers, 1973).

Although irrigation is essential for maximizing soybean yield, its economic feasibility may vary from year to year. In a 6-year study on silty clay in Arkansas, Parsch et al. (2001) found that full-season rainfed soybean often yields a higher return compared to full-season irrigated soybean. However, Heatherly (1999b) reported consistent profitability with irrigation in soybean production in the southern United States. Additionally, with groundwater levels depleting, water is becoming an increasingly scarce resource. Scott et al. (1998) highlighted that the available groundwater in the Alluvial Aquifer in Arkansas is projected to be depleted by 2050. Hence, the judicious application of irrigation water is crucial for ensuring sustainable agriculture and achieving maximum economic returns. In summary, optimal soybean yield may not necessitate continuous irrigation throughout the growing season, and improved agronomic management practices along with accurate weather forecasting may help reduce irrigation needs. However, there is limited or virtually no research on irrigation timing specifically for double-crop soybean.

4.11 | Pest management

4.11.1 | Weed

Weeds pose a significant threat to soybean yield by engaging in competition (Coble et al., 1981; Dewell et al., 2003; Grey, 2007; Harrison et al., 1985; Knake & Slife, 1962; Vail & Oliver, 1993). Weed management is believed to be more manageable in double-crop soybean due to the presence of small-grain residue, the use of residual herbicides in small-grain cultivation, no-tillage practices, and narrow-row configurations compared to full-season soybean (Holshouser, 2014; Vangessel et al., 2001). Existing literature indicates that small-grain residues can significantly suppress weed growth through shading (Harwood & Bantilan, 1974; Shetty et al., 1982), although they may reduce herbicide effectiveness by absorbing and preventing herbicides from reaching the soil surface (Locke et al., 2002; Reddy et al., 1995). Rainfall after preplant herbicide application can enhance weed control by washing herbicides off residues, and innovative approaches, such as mounting the spray bar under the combine, may help postharvest herbicides reach small weed populations during harvesting (Minor & Wiebold, 1998). Crop residues left on the soil surface inhibit weed germination and growth by limiting light penetration and through allelopathic and mulching effects (Bellinder et al., 2004; Fischer et al., 2002; Lewis, 1985; Liebl & Worsham, 1983; Liebman & Davis, 2000; A. Shrestha et al., 2002). Maintaining a higher stubble height during wheat harvesting minimizes weed leaf area removal, enabling herbicides to target more exposed weed leaf areas and ensuring more effective control (Holshouser, 2014).

No-tillage and narrow-row planting represent prevalent practices in double-crop soybean production, both acknowledged for their efficacy in weed control by suppressing weed growth (Amuri et al., 2010; Burnside & Colville, 1964; Dewell et al., 2003; Légère & Shreiber, 1989; Mickelson & Renner, 1997; Peters et al., 1965; D. R. Shaw & Rainero, 1990; Wax & Pendleton, 1968). D. R. Shaw and Rainero (1990) reported enhanced control of sicklepod (*Cassia obtusifolia* L.) in double-crop versus full-season soybean and in no-till compared to tilled soybean. Furthermore, narrow row spacing has been acknowledged as a viable approach for weed management, enhancing crop competitiveness against weeds and diminishing light penetration to the soil surface by facilitating swift canopy closure (Bradley, 2006; Teasdale, 1995). Narrow row spacing accelerates canopy closure by 1 week (Teasdale, 1995), curbing weed growth even without herbicide application (Mickelson & Renner, 1997; K. A. Nelson & Renner, 1998; Teasdale, 1995; Yelverton & Coble, 1991). The literature indicates that the effectiveness of weed control with a specific herbicide increases as row spacing decreases due to rapid canopy closure (Burnside & Colville, 1964; Légère & Schreiber, 1989; Mickelson & Renner, 1997; K. A. Nelson & Renner, 1999; Peters et al., 1965). Although some studies noted higher input costs due to a 20%–45% increase in seed requirement for narrow versus wide rows (Bertram & Pedersen, 2004; Kratochvil et al., 2004), soybean with narrow row spacing yields greater economic returns due to higher yields, even under similar weed management systems (Mickelson & Renner, 1997; K. A. Nelson & Renner, 1999; Oriade et al., 1997) or in the absence of weeds (Shibles & Weber, 1966; Patterson et al., 1988).

The timing of herbicide application plays a crucial role in effective weed control. Traditionally, both preemergence (burn down) and postemergence herbicides have been employed for weed management in double-crop soybean (McHarry & Kapuśta, 1979; Sims & Guethle, 1992; Triplett, 1978). However, the economic aspect of weed control has led some farmers to rely solely on postemergence herbicides, particularly for double-crop soybean (Krausz & Young, 2001; Stoller et al., 1993). Sims and Guethle (1992) highlighted the superior weed control provided by postemergence herbicides in double-crop soybean compared to preemergence herbicides alone. C. D. Elmore et al. (1995) reported that postemergence weed control was sufficient to maximize double-crop soybean yield in 2 out of 3 years of their study. In a postemergence herbicide program, the selection of an appropriate herbicide considers factors such as weed height, crop growth stage, soybean yield potential (DeFelice et al., 1989; Devlin et al., 1991; Monks et al., 1993), and the type of weed species present in the field (Krausz & Young, 2001).

While Holshouser (2014) suggested applying postemergence herbicides in double-crop soybean before weeds reach 10 cm tall, Dewell et al. (2003) found that optimal weed control in no-till double-crop soybean was achieved through postemergence herbicide treatment when weeds were 10–20 cm tall. Dewell et al. (2003) explained that the improved control at 10- to 20-cm tall weeds may result from the absence of late-emerging weeds during this period. Vangessel et al. (2001) noted that postemergence glyphosate herbicide can be applied over a wide window in double-crop soybean. However, delaying glyphosate application beyond the label recommendations for large morning glories (*Ipomoea* spp.) can lead to poor weed control and herbicide resistance issues (Jordan et al., 1997; Payne & Oliver, 2000). Moreover, farmers may hesitate to apply postemergence herbicides in double-crop soybean to avoid injuring the crop, as there might not be sufficient time for recovery from such injury (Krausz & Young, 2001; Vidrine et al., 1993).

In the wheat–soybean double-cropping system, achieving a weed-free seedbed is crucial for maximizing soybean yield. The use of burndown herbicides plays a key role in attaining weed-free conditions. Ferguson et al. (2008) emphasized that burndown herbicides, such as glyphosate or paraquat, enable the planting of double-crop soybean in weed-free environments. Additionally, applying residual herbicides before wheat harvest can effectively control weed populations that typically emerge after soybean planting (McHarry & Kapuśta, 1979; Triplett, 1978). In evaluating herbicide application timings, Higgins et al. (1988) compared fully tilled wheat early preplant applications with preemergence applications at soybean planting. They found that early preplant applications were more effective in controlling Pennsylvania smartweed (*Polygonum pensyvanicum* L.) compared to preemergence applications. Soybean yields were 26%–103% greater with early preplant herbicide in 1 of 3 years but were similar between the two treatments in the other 2 years. Bradley et al. (2004) observed enhanced control of trumpet creeper (*Campsis radicans*) in double-crop soybean with a combination of pre- and postemergence herbicides compared to preemergence herbicides alone. Grey (2007) reported superior control of tall morningglory (*Ipomoea purpurea*), sicklepod, large crabgrass (*Digitaria sanguinalis*), and Florida beggarweed (*Desmodium tortuosum*) in double-crop soybean when using both preemergence residual herbicide and postemergence glyphosate, compared to using pre- or postemergence herbicides alone. Furthermore, combining preemergence residual herbicide with postemergence glyphosate increased 380 kg ha^{-1} of soybean yield. These findings suggest that the use of both pre- and postemergence herbicides is a more effective option for weed control in double-crop soybean. Holshouser (2014) concluded that the optimal weed management philosophy for achieving maximum double-crop soybean yield is to “start clean and stay clean.”

4.11.2 | Insect

Double-crop soybean typically experiences minimal issues from soil insects and early-season pests like thrips (*Thrips tabaci* Linde) due to their rapid seedling emergence and early-season growth (Holshouser, 2014). However, certain leaf-feeding insects, such as green cloverworm (*Plathypena scabra* F.), soybean looper (*Pseudoplusia includes* Walker), velvetbean caterpillar (*Anticarsia gemmatalis* Hübner), bean leaf beetles (*Cerotoma trifurcate* Forster), beet armyworm (*Spodoptera exigua* Hübner), and Mexican bean beetle (*Epilachna varivestis* Mulsant), pose a significant threat to double-crop soybean, primarily because of their smaller canopy compared to full-season soybean. Defoliation is known to decrease soybean leaf area (Ostlie, 1984) and has a linear negative impact on soybean yield (Browde et al., 1994; Grymes et al., 1999; Nolting & Edwards, 1989).

Defoliation during the vegetative stage generally does not affect soybean yield (McAvoy, 1977), but severe defoliation

(50%), especially around the V3 stage, can lead to a reduction in soybean yield by up to 14% (Poston & Pedigo, 1976). Fehr et al. (1977) highlighted that the highest soybean yield loss occurs due to defoliation during the R4 and R5 stages. G. D. Thomas et al. (1974) identified R5 and R6 as critical defoliating stages, indicating that soybean plants can tolerate only 6% defoliation before experiencing yield loss. However, Talekar and Lee (1988) found that the R3 and R4 stages are the most sensitive to defoliation.

Defoliation decreases soybean leaf area crucial for optimal photosynthesis and soybean yield. Given that an LAI of 3.5–4.0 during the R2–R4 stages is necessary for maximizing soybean yield potential (J. E. Board & Harville, 1992; Higley, 1992; Westgate, 1999), double-crop soybean with an LAI within this range lacks additional layers of leaves to withstand insect feeding. In contrast, full-season soybean with an LAI of 6.0 possess two extra leaf layers, providing some resilience to insect-induced defoliation (Holshouser, 2014). Malone et al. (2002) conducted a 3-year assessment of the sensitivity of both full-season and double-crop soybean to manual and natural defoliation, establishing a correlation between LAI and soybean yield under various conditions. Their findings indicated a linear increase in yields for both full-season and double-crop soybean with rising LAI, reaching optimal levels between 3.5 and 4.5 during the R4–R5 stages, except for 1 year's yield in full-season soybean. The absence of a correlation in that particular year was attributed to an LAI exceeding 4.5 at the R4 stage, even under high defoliation treatment. Moreover, they observed that natural insect defoliation had no discernible impact on the yield of double-crop soybean with an LAI surpassing 4.0 from the R3 to R6 stages. They concluded that double-crop soybean, maintaining an LAI above the critical threshold (3.5–4.0) during the R3–R6 stages, exhibit tolerance to defoliating insect infestations. These results emphasize the significance of soybean LAI during mid-reproductive stages as a valuable tool for making informed management decisions against defoliating insect pests.

Double-crop soybean is typically planted later than their full-season counterparts. Joshi (1980) highlighted the heightened sensitivity of late-planted soybean to pod damage inflicted by corn earworms compared to their early-planted counterparts. Additionally, Herbert and Toews (2011) observed that the delayed planting of double-crop soybean leads to a significantly increased stink bug population during pod and seed development stages compared to full-season soybean. According to Holshouser (2014), the pod and seed developmental stages (R3–R5) of double-crop soybean align with the migration of corn earworms from corn fields, coinciding with the period when most full-season soybean reaches the more resistant R6 or advanced stages.

Holshouser further noted that stink bugs, which feed on developing seeds at the R5 stage, can cause more damage in double-crop soybean than in their full-season counterparts for the same reason. He emphasized the importance of scouting during the R4–R5 stages of double-crop soybean as a crucial management approach against pod and seed feeders, suggesting the use of insecticides only when pest levels reach the economic threshold.

Pod- and seed-feeding insects form another significant threat to double-crop soybean. Notable pod feeders in this category include the corn earworm (*Helicoverpa zea*) and various stink bugs such as the redbanded stink bug (*Piezodorus guildinii*), green stink bug (*Nezara viridula*), brown stink bug (*Euschistus servus*), and brown marmorated stink bug (*Halyomorpha halys*). These insects can induce pod drop or flattening, a critical component of soybean yield directly impacting overall production (J. E. Board et al., 2003; Kahlon et al., 2011; Parvej et al., 2015). Research by Singer et al. (2004) established a positive linear correlation between soybean pod removal and seed yield reduction. Similarly, Proulx and Naeve (2009) reported that pod removal ranging from 20% to 70% resulted in a yield reduction of 12%–52% compared to a no-pod-removal treatment. These findings underscore the significant impact even minimal pod removal can have on soybean yield. However, it's essential to note that both studies conducted by Singer et al. (2004) and Proulx and Naeve (2009) focused on full-season soybean, leaving the specific impact on double-crop soybean yield unknown.

4.11.3 | Diseases

Soybean is susceptible to over 30 fungal diseases in the United States (Hartman et al., 1999; Li & Yang, 2009; McGee, 1992). Notably, Cercospora leaf blight (*Cercospora kikuchii*), frogeye leaf spot (*Cercospora sojina*), aerial blight (*Rhizoctonia solani*), pod and stem blight (*Diaporthe phaseolorum* var. sojae), and anthracnose (*Colletotrichum truncatum*) are prevalent in the southern United States (Schneider et al., 2007), where double-cropping of soybean is common. Cercospora leaf blight, in particular, stands out as the most widespread and damaging foliar disease in the Mid-South, ranking as the second most prominent disease in the Mid-Atlantic states (Mehl & Phipps, 2013). The moderate optimum temperature (25˚C) during the growing season and the ability to transmit through seeds make this disease more prominent throughout the United States (Li & Yang, 2009).

In addition to these foliar diseases, white mold (*Sclerotinia sclerotiorum*) is another significant fungal pathogen affecting soybean production, particularly in regions with high humidity and dense canopy conditions. The risk of white mold increases during flowering, as the fungus primarily infects through senescing flowers that provide a nutrient source for pathogen establishment (Grau & Radke, 1984; D. S. Mueller et al., 2004). Tighter canopy structures create a microclimate with reduced airflow and increased moisture retention, favoring *S. sclerotiorum* development (Boland &

Hall, 1987). Under these conditions, prolonged leaf wetness and high relative humidity (>90%) can enhance the release and germination of ascospores, leading to a higher incidence of disease (Willbur et al., 2019). Consequently, in environments with frequent rainfall or irrigation during the reproductive stages, white mold can become a severe yield-limiting factor in soybean production.

Holshouser (2014) noted that Cercospora blight and frogeye leaf spots typically emerge later in the growing season, particularly during the pod (R3) to seed (R5) developmental stages when soybean is more susceptible to disease. Double-crop soybean may be more vulnerable to yield loss from foliar diseases compared to full-season soybean because the optimal weather conditions for disease development—specifically, relative humidity exceeding 95% for 10–12 h daily and temperatures ranging from 20 to 25°C for at least two consecutive days—readily occur during the pod and seed developmental stages of double-crop soybean. However, Holshouser highlighted that double-crop soybean is less vulnerable to seedling diseases due to their rapid emergence under warm soil temperatures in June and July. Furthermore, he indicated that anthracnose and Phomopsis seed decay (*Diaporthe/Phomopsis* spp.), which can compromise seed quality, present a diminished threat to double-crop soybean. This is attributed to their later maturation in the year when temperatures are lower, impeding the development of these diseases.

Utilizing resistant cultivars stands out as the most effective and economical method for managing soybean diseases (Schneider et al., 2007). Despite this, late-season soybean diseases are often addressed by farmers through the application of fungicides (Levy, 2005; Miles et al., 2007; Sinclair & Hartman, 1995; Yorinori et al., 2005) and cultural practices (Schneider et al., 2007), primarily because of the limited availability of disease-resistant cultivars (Dorrance et al., 2004; Li & Yang, 2009). However, soybean exhibits inconsistent responses to foliar fungicides, and the enhanced disease control achieved through fungicide application doesn't always correlate with yield preservation (K. A. Dillon, 2014; Phipps & Telenko, 2011; Schneider et al., 2007). Literature reveals varied results in terms of soybean response to fungicide application, with documented positive yield responses in Ohio (Cruz et al., 2010), Illinois, Florida, and Georgia (T. A. Mueller et al., 2006), and Virginia (Phipps et al., 2010). Conversely, no response was observed in Indiana (Hanna et al., 2006) and North Dakota (T. A. Mueller et al., 2006), while inconsistent responses were noted in Missouri (Bradley & Sweets, 2008) and Illinois (Pataky & Lim, 1981). K. A. Dillon (2014) specifically identified positive yield responses to foliar fungicides in double-crop soybean at four of six sites for MG IV cultivars and at three of six sites for MG V cultivars. The lack of a consistent yield response to fungicides was attributed to the absence of diseases and unfavorable weather conditions for disease development (Bradley & Sweets, 2008; Pataky & Lim, 1981; Phipps & Telenko, 2011; Swoboda & Pedersen, 2009), underscoring the critical importance of fungicide application timing for effective soybean disease control and maximizing yield.

The ideal timing for fungicide application to achieve maximum soybean yield depends on factors such as the time of disease infection, disease intensity, rate of disease development, environmental conditions, and the soybean LAI and developmental stages (Bradley & Sweets, 2008; K. A. Dillon, 2014; Holshouser, 2014; T. A. Mueller et al., 2009; X. B. Yang & Robertson, 2007). While literature indicates that the most effective fungicide application timing spans from early-flowering (R1) through seed-filling (R5) periods (Cruz et al., 2010; Miles et al., 2007; T. A. Mueller et al., 2006; Padgett et al., 2006; A. Tenuta et al., 2007), a common practice involves a single fungicide application between R3 and R5 stages (Schneider et al., 2007). Studies demonstrating positive yield responses to fungicides emphasize the effectiveness of applications at the R3 (K. A. Dillon, 2014; Dorrance et al., 2010; Miles et al., 2007), R4 (K. A. Nelson et al., 2010), or R5 (K. A. Dillon, 2014) stages compared to other growth stages. This suggests that the optimal fungicide application timing can vary based on geographical location, year, and prevailing weather conditions. Holshouser (2014) emphasizes that excessively early, late, or frequent fungicide applications are not effective for disease control and maximizing economic yield. Both K. A. Dillon (2014) and Holshouser (2014) highlight that the likelihood of disease development is reduced when the canopy is not fully closed (LAI 3.5–4.0). Holshouser (2014) concludes that fungicides with dual modes of action should be applied at a reproductive growth stage, usually at or after R3, if environmental conditions favor disease development beyond that growth stage.

4.11.4 | Nematode

SCN is recognized as a significant threat to soybean crops in both the United States and Canada (Long & Todd, 2001; M. Tenuta & Tenuta, 2015). The SCN is recognized as the most damaging pathogen to soybean crops, causing more than twice the yield losses of any other soybean disease (Bradley et al., 2021). Financially, SCN is estimated to cost US soybean producers between $1.0 and $1.5 billion annually (Chowdhury et al., 2022). The SCN is known to induce "yellow dwarf" and often results in the occurrence of "sudden death syndrome" in soybean plants (MTD, 2010; M. Tenuta & Tenuta, 2015). The management of SCN has been a subject of extensive research in various regions of the United States. Strategies such as no-tillage practices (Hershman & Bachi, 1995; Koenning et al., 1995; Tyler et al., 1987), wheat stubble management (Hershman & Bachi, 1995), adjustment of soybean planting dates (Koenning & Anand, 1991), crop rotation with nonhost crops (Anand et al., 1995; Dabney et al., 1988; J. H. Edwards et al., 1988; Francl & Dropkin, 1986; Howard et al., 1998; Koenning et al., 1993, 1995; Ross, 1962; Sasser & Uzzell, 1991; Schmitt, 1991; Young et al., 1986), and the utilization of resistant cultivars (Hartwig et al., 1987; Wallace et al., 1995) have been investigated. In the context of the wheat–soybean double-cropping system, soybean is typically planted later in the year (June through July) into wheat stubble under no-tillage conditions. Scientific literature suggests that practices such as no-tillage (Hershman & Bachi, 1995; Koenning et al., 1995), delayed planting (Koenning & Anand, 1991), and the presence of wheat stubble (Baird & Bernard, 1984; Hershman & Bachi, 1995) can contribute to the reduction of SCN populations. Hershman and Bachi (1995) observed that in the absence of wheat residues, SCN populations may rise to a level where SCN-susceptible soybean cultivars are not recommended for planting once every 4–6 years. However, Hershman (2009) emphasized that wheat stubble may not provide sufficient protection against soybean yield loss in fields where SCN populations exceed the damage threshold (>500 eggs kg^{-1} of soil) at soybean planting.

In a standard double-cropping system, encompassing three crops—corn, wheat, and soybean—over a 2-year cycle, corn and wheat serve as nonhost crops for SCN (Holshouser et al., 2011). The rotation of soybean with corn has been documented to reduce SCN populations (Howard et al., 1998; Long & Todd, 2001). Existing literature indicates that the improvement in soybean yield resulting from rotation with nonhost crops is linked to the decrease in SCN populations (Anand et al., 1995; Dabney et al., 1988; J. H. Edwards et al., 1988). Rotating with nonhost crops for 2–3 years is documented to reduce SCN populations to levels that may not adversely affect SCN-susceptible soybean cultivars (Francl & Dropkin, 1986; Koenning et al., 1993, 1995; Ross, 1962; Sasser & Uzzell, 1991; Schmitt, 1991). These findings suggest that a long-term double-cropping system (corn–wheat–soybean) may exert less SCN pressure compared to soybean–soybean or corn–soybean monoculture. However, optimal management practices for fields with SCN populations surpassing the damage threshold at planting involve the use of SCN-resistant soybean cultivars and/or nematicide seed treatments (Holshouser et al., 2011). Additionally, weed removal is advocated as a management practice for SCN, as certain weeds such as chickweed (Stellaria media) and henbit (Lamium amplexicaule) act as alternative hosts for SCN (Hershman, 2011; W. G. Johnson et al., 2008; MTD, 2010).

5 | SUMMARY AND CONCLUSIONS

This paper aimed to comprehensively review published research on double-cropping systems in the United States, with a focus on identifying critical management factors impacting soybean yield in wheat–soybean double-cropping systems. A thorough analysis of approximately 700 articles, including over 100 double-crop studies across states, was conducted. This study identified key factors influencing double-crop soybean yield, encompassing wheat cultivar and harvest date, allelopathy of wheat residue, wheat residue management, soybean planting date, row spacing, MG, growth habit, seeding rate, soil fertility, irrigation, and pest management. Table 1 provides a summative table highlighting the key recommendations along with their justifications for double-crop soybean production in the United States.

While wheat residue plays a crucial role in controlling soil erosion and maintaining soil quality, it was found to have adverse effects on double-crop soybean yield due to allelopathy and herbicide activity inhibition, issues with light quality, and nutrient tie-up during mineralization. Various residue management practices were explored, with the most effective approach being identified as no-tillage, maintaining wheat stubble height ≤30 cm, and uniformly spreading additional wheat chaff during harvesting.

The planting date emerged as a critical factor, with late planting identified as the primary yield-limiting factor for double-crop soybean. Delayed planting after mid-June led to a substantial reduction in seed yield, primarily attributed to a shorter growing season. To mitigate these negative effects, the paper recommends immediate soybean planting after wheat harvest, with early wheat harvest at high moisture facilitating early soybean planting and reducing yield loss.

Narrow row spacing (19 cm) was highlighted as a significant agronomic practice to minimize double-crop yield loss, with a potential yield increase of up to 18%. Equidistant plant spacing is essential for maximizing the benefits of narrow-row culture. The choice of a suitable MG for a double-cropping system remains challenging, but soybean with indeterminate growth habits is suggested to be more suitable for narrow rows.

Seeding rate was identified as a consistent influencer of double-crop soybean yield, with higher seeding rates or plant populations required compared to early-planted full-season soybean. Fertilizer-N responsiveness was noted, with a small amount of starter N enhancing early-season vegetative growth and canopy closure. Limited information was available regarding double-crop soybean yield response to P and K application timing, although soybean was found to be more responsive to K fertilization.

Drought emerged as a significant challenge in nonirrigated production systems, potentially leading to complete double-crop soybean failure. Efficient water management through irrigation was emphasized, with a focus on the critical seed-filling period. Herbicide application timing for weed control, the use of resistant cultivars, and judicious

TABLE 1 A summative table highlights the key recommendations and their justifications for double-crop soybean production.

Recommendation	Justification
No-tillage with a 30-cm wheat stubble height and uniform chaff distribution	Addresses allelopathy, herbicide inhibition, light quality issues, and nutrient tie-up
Immediate soybean planting after wheat harvest	Mitigates yield loss from late planting and short growing season
Early wheat harvest at high moisture to facilitate early soybean planting	Reduces yield loss by ensuring longer growing season
Narrow row spacing (19 cm) to increase yield up to 18%	Improves light interception and canopy closure, reducing yield loss
Use of indeterminate growth habit soybean for narrow rows	Maximizes benefits of narrow rows by maintaining extended vegetative growth
Higher seeding rates for double-crop soybean compared to full-season soybean	Higher plant populations compensate for shorter growing season
Small amount of starter N to enhance early-season vegetative growth	Promotes early canopy closure and vegetative growth
Emphasis on K fertilization for double-crop soybean	Soybean found to be more responsive to K fertilization based on soil-test K concentration
Efficient water management through irrigation, especially during seed filling	Critical for preventing drought-induced yield loss in nonirrigated systems
Optimized herbicide timing, resistant cultivars, and judicious insecticide/fungicide use	Essential for integrated pest management to maximize yield
Need for extensive double-crop research with modern high-yielding cultivars	Existing studies based on older cultivars; modern research needed
Return on investment studies evaluating yield gains, implementation costs, and break-even yields	Ensures economic feasibility of recommended management practices

application of insecticides and fungicides were deemed crucial for maximizing double-crop soybean yield.

In conclusion, this study acknowledged the scarcity of information on the agronomic management of modern high-yielding herbicide-resistant cultivars in double-cropping systems. Most research was conducted using conventional soybean cultivars during the 1970s to 1990s, and extension recommendations were often based on observations or research under simulated conditions. The paper highlighted the need for extensive double-crop research across diverse geographical regions, emphasizing areas such as early wheat harvest, early maturing wheat cultivar development, wheat stubble management, optimal MG and growth habit, seeding rate optimization, and precise N and K application timing under both irrigated and rainfed production systems. Irrigation work is also needed, as well as comprehensive return on investment studies evaluating yield gains and cost of implementation to develop break-even yield assessments.

AUTHOR CONTRIBUTIONS

Md. Rasel Parvej: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; software; validation; visualization; writing—original draft; writing—review and editing. **David L. Holshouser**: Conceptualization; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; writing—original draft; writing—review and editing.

ACKNOWLEDGMENTS

The authors would like to thank Mike Ellis, Billy Taylor, Collin Hoy, Jake Doiron, Matthew Wilkins, and Ed Seymore for their support. The funding for this work was provided in part by the Virginia Agricultural Experiment Station and the Hatch Program of the National Institute of Food and Agriculture, US Department of Agriculture.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ORCID

Md. Rasel Parvej https://orcid.org/0000-0002-6614-4037
David L. Holshouser https://orcid.org/0000-0002-8177-7414

REFERENCES

Abel, G. H. (1961). Response of soybeans to dates of planting in the Imperial Valley of California. *Agronomy Journal*, *53*, 95–98. https://doi.org/10.2134/agronj1961.00021962005300020010x

Abendroth, L., & Elmore, R. (2006). *Soybean inoculation: Applying the facts to your field* (NebGuide G1622). University of Nebraska.

Ablett, G. R., Beversdorf, W. D., & Dirks, V. A. (1991). Row width and seeding rate performance of indeterminate, semideterminate, and determinate soybean. *Journal of Production Agriculture*, *4*, 391–395. https://doi.org/10.2134/jpa1991.0391

Ablett, G. R., Schleihauf, J. C., & Mclaren, A. D. (1984). Effect of row width and population on soybean yield in southwestern Ontario. *Canadian Journal of Plant Science*, *64*, 9–15.

Acock, B., & Acock, M. C. (1987). Periodic shading and the location and timing of branches in soybean. *Agronomy Journal*, *79*, 949–952. https://doi.org/10.2134/agronj1987.00021962007900060001x

Adams, W. E., Morris, H. D., & Dawson, R. N. (1970). Effect of cropping systems and nitrogen levels on corn (*Zea mays*) yields in the Southern Piedmont region. *Agronomy Journal*, *62*, 655–659. https://doi.org/10.2134/agronj1970.00021962006200050033x

Adams, W. E., Morris, H. D., Giddens, J., Dawson, R. N., & Langdale, G. W. (1973). Tillage and fertilization of corn grown on lespedeza sod. *Agronomy Journal*, *65*, 653–655. https://doi.org/10.2134/agronj1973.00021962006500040037x

Afza, R., Hardarson, G., Zapata, F., & Danso, S. K. A. (1987). Effects of delayed soil and foliar N fertilization on yield and N2 fixation of soybean. *Plant and Soil*, *97*, 361–368. https://doi.org/10.1007/BF02383226

Akhanda, A. M., Prine, G. M., & Hinson, K. (1976). Influence of genotypes and row width on late-planted soybeans in Florida. *Proceedings of the Soil and Crop Science Society of Florida*, *35*, 21–25.

Akhter, M., & Sneller, C. H. (1996). Yield and yield components of early maturing soybean genotypes in the Mid-South. *Crop Science*, *36*, 877–882. https://doi.org/10.2135/cropsci1996.0011183X0036000400010x

Albrecht, S. L., Bennett, J. M., & Boote, K. J. (1984). Relationship of nitrogenase activity to plant water stress in field grown soybeans. *Field Crops Research*, *8*, 61–71. https://doi.org/10.1016/0378-4290(84)90052-2

Alessi, J., & Power, J. F. (1982). Effects of plant and row spacing on dryland soybean yield and water-use efficiency. *Agronomy Journal*, *74*, 851–854. https://doi.org/10.2134/agronj1982.00021962007400050019x

Al-Ithawi, B., Deibert, E. J., & Olson, R. A. (1980). Applied N and moisture level effects on yield, depth of root activity and nutrient uptake by soybean. *Agronomy Journal*, *72*, 827–832. https://doi.org/10.2134/agronj1980.00021962007200050031x

Alt, D., Lindsey, L. E., & Lentz, E. (2019). Double-crop soybean response to wheat management in the Midwest. *Crop, Forage & Turfgrass Management*, *5*(1), 190001. https://doi.org/10.2134/cftm2019.01.0001

Amuri, N., & Brye, K. R. (2008). Residue management practice effects on soil penetration resistance in a wheat – soybean double-crop production system. *Soil Science*, *173*, 779–791. https://doi.org/10.1097/SS.0b013e31818a54b4

Amuri, N., Brye, K. R., Gbur, E. E., Oliver, D., & Kelley, J. (2010). Weed populations as affected by residue management practices in a wheat – soybean double-crop production system. *Weed Science*, *58*, 234–243. https://doi.org/10.1614/WS-09-088.1

Anand, S. C., Koenning, S. R., & Sharma, S. B. (1995). Effect of temporal deployment of different sources of resistance to soybean cyst nematode. *Journal of Production Agriculture*, *8*, 119–123. https://doi.org/10.2134/jpa1995.0119

Anderson, J., & Domsch, K. (1975). Measurement of bacterial and fungal contributions to respiration of selected agricultural and forest soils. *Canadian Journal of Microbiology*, *21*, 314–322. https://doi.org/10.1139/m75-045

Anderson, L. R., & Vasilas, B. L. (1985). Effects of planting date on two soybean cultivars: Seasonal dry matter accumulation and seed yield. *Crop Science*, *25*, 999–1004. https://doi.org/10.2135/cropsci1985.0011183X002500060024x

Andrade, F. H., Calvino, P., Cirilo, A., & Barbieri, P. (2002). Yield responses to narrow rows depend on increased radiation interception. *Agronomy Journal*, *94*, 975–980. https://doi.org/10.2134/agronj2002.9750

Andrade, J. F., Rattalino Edreira, J. I., Mourtzinis, S., Conley, S. P., Ciampitti, I. A., Dunphy, J. E., Gaska, J. M., Glewen, K., Holshouser, D. L., Kandel, H. J., Kyveryga, P., Lee, C. D., Licht, M. A., Lindsey, L. E., Mcclure, M. A., Naeve, S., Nafziger, E. D., Orlowski, J. M., Ross, J., … Grassini, P. (2019). Assessing the influence of row spacing on soybean yield using experimental and producer survey data. *Field Crops Research*, *230*, 98–106. https://doi.org/10.1016/j.fcr.2018.10.014

Andriani, J. M., Andrade, F. H., Suero, E. E., & Dardanelli, J. L. (1991). Water deficits during reproductive growth of soybeans: I. Their effects on dry-matter accumulation, seed yield and its components. *Agronomie*, *11*, 737–746. https://doi.org/10.1051/agro:19910904

Ashley, D. A., & Ethridge, W. J. (1978). Irrigation effects on vegetative and reproductive development of three soybean cultivars. *Agronomy Journal*, *70*, 467–471. https://doi.org/10.2134/agronj1978.00021962007000030026x

Ashlock, L., Klerk, R., Huitink, G., Keisling, T. C., & Vories, E. D. (1998). Planting practices. In *Arkansas soybean handbook* (MP 197, pp. 35–41). Arkansas Cooperative Extension Service. https://www.uaex.uada.edu/publications/mp-197.aspx

Ashlock, L., Mayhew, W., Windham, T., Keisling, T. C., Klerk, R., Beaty, D., & Lorenz, G. (1998). Production systems and economics. In *Arkansas soybean handbook* (MP 197, pp. 115–121). Arkansas Cooperative Extension Service.

Ashworth, A. J., Allen, F. L., Tyler, D. D., & Taylor, A. M. (2018). Cover crops in double-crop soybean systems: Impacts on soil properties and soybean yield. *Agronomy Journal*, *110*(5), 1795–1803. https://doi.org/10.2134/agronj2017.12.0732

Bacanamwo, M., & Purcell, L. (1999). Soybean dry matter and N accumulation responses to flooding stress, N sources and hypoxia. *Journal of Experimental Botany*, *50*, 689–696. https://doi.org/10.1093/jxb/50.334.689

Bachelor, J. T., & Scott, H. D. (1979). Effects of irrigation on nitrogen and potassium uptake by soybeans. *Arkansas Farm Research*, *28*, 5.

Baird, S. M., & Bernard, E. C. (1984). Nematode population and community dynamics in soybean-wheat cropping and tillage regimes. *Journal of Nematology*, *16*, 379–386.

Balkcom, K. S., Schomberg, H. H., & Reeves, D. W. (2015). Enhancing double-crop soybean production with cover crops and conservation tillage. *Soil Science Society of America Journal*, *79*(2), 564–573. https://doi.org/10.2136/sssaj2014.09.0386

Ball, R. A., Purcell, L. C., & Vories, E. D. (2000a). Optimizing soybean plant population for a short-season production system in the southern USA. *Crop Science*, *40*, 757–764. https://doi.org/10.2135/cropsci2000.403757x

Ball, R. A., Purcell, L. C., & Vories, E. D. (2000b). Short-season soybean yield compensation in response to population and water regime. *Crop Science*, *40*, 1070–1078. https://doi.org/10.2135/cropsci2000.4041070x

Banks, P. A., & Robinson, E. L. (1982). The influence of straw mulch on the soil reception and persistence of metribuzin. *Weed Science*, *30*, 164–168. https://doi.org/10.1017/S0043174500062263

Banks, P. A., Tripp, T. N., Wells, J. W., & Hammel, J. E. (1985). Effect of tillage on sicklepod (*Cassia obstusifolia*) interference with soybeans (*Glycine max*) and soil water use. *Weed Science*, *34*, 143–149. https://doi.org/10.1017/S0043174500026618

Bao, Y., Neher, D. A., & Chen, S. Y. (2011). Population responses of soybean cyst nematode and its antagonists to tillage. *Applied Soil Ecology*, *47*(1), 77–83. https://doi.org/10.1016/j.apsoil.2010.12.003

Barker, D., Beuerlein, J., Dorrance, A., Eckert, D., Eisley, B., Hammond, R., Lentz, E., Lipps, P., Loux, M., Mullen, R., Sulc, M., Thomison, P., & Watson, M. (2005). *Ohio agronomy guide* (14th ed., Bulletin 472). Ohio State University Extension. http://extension.agron.iastate.edu

Barreiro, A. S., & Godsey, C. B. (2013). Soybean yield as affected by planting date and maturity group in the Southern Plains. *Crop Management*, *12*(1), 1–7. https://doi.org/10.1094/CM-2012-0150-RS

Bastidas, A. M., Setiyono, T. D., Dobermann, A., Cassman, K. G., Elmore, R. W., Graef, G. L., & Specht, J. E. (2008). Soybean sowing date: The vegetative, reproductive, and agronomic impacts. *Crop Science*, *48*, 727–740.

Bauer, A., Black, A. L., & Frank, A. B. (1989). *Soil water use by plant development stage of spring and winter wheat* (Experimental Station Bulletin 519). North Dakota State University.

Beale, O. W., & Langdale, G. W. (1967). Tillage and residue management practices for soybean production in a soybean-small grain rotation. *Agronomy Journal*, *59*, 31–33. https://doi.org/10.2134/agronj1967.00021962005900010009x

Beard, B. H., & Hoover, R. M. (1971). Effect of nitrogen and nodulation on yield of irrigated soybean. *Agronomy Journal*, *63*, 815–816. https://doi.org/10.2134/agronj1971.00021962006300050051x

Beatty, K. D., Eldridge, I. L., & Simpson, A. M., Jr. (1982). Soybean response to different planting patterns and dates. *Agronomy Journal*, *74*, 859–862. https://doi.org/10.2134/agronj1982.00021962007400050021x

Beaty, E. R., & Giddens, J. (1962). Effect of various methods of seedbed preparation and cultivation on yields of corn grown following rye. *Agronomy Journal*, *54*, 431–432. https://doi.org/10.2134/agronj1962.00021962005400050018x

Beaver, J. S., Cooper, R. L., & Martin, R. J. (1985). Dry matter accumulation and seed yield of determinate and indeterminate soybeans. *Agronomy Journal*, *77*, 675–679. https://doi.org/10.2134/agronj1985.00021962007700050004x

Begna, S. H., Dwyer, L. M., Cloutier, D., Assemat, L., DiTommaso, A., Zhou, X., Prithiviraj, B., & Smith, D. L. (2002). Decoupling of light intensity effects on the growth and development of C3 and C4 weeds species through sucrose supplementation. *Journal of Experimental Botany*, *53*, 1935–1940.

Bell, P. F., Hallmark, W. B., Sabbe, W. E., & Dombeck, D. G. (1995). Diagnosing nutrient deficiencies in soybean, using M-DRIS and critical nutrient level procedures. *Agronomy Journal*, *87*, 859–865. https://doi.org/10.2134/agronj1995.00021962008700050013x

Bellinder, R. R., Dillard, H. R., & Shah, D. A. (2004). Weed seedbank community responses to crop rotation schemes. *Crop Protection*, *23*, 95–101.

Benvenuti, S. (2003). Soil texture involvement in germination and emergence of buried weed seeds. *Agronomy Journal*, *95*, 191–198. https://doi.org/10.2134/agronj2003.1910

Benvenuti, S., & Macchia, M. (1998). Phytochrome-mediated germination control of *Datura stramonium* L. seeds after seed burial. *Weed Research*, *38*, 199–206. https://doi.org/10.1046/j.1365-3180.1998.00086.x

Bergersen, F. J. (1958). The bacterial component of soybean root nodules; changes in respiratory activity, cell dry weight and nucleic acid content with increasing nodule age. *Journal of General Microbiology*, *19*, 312–323. https://doi.org/10.1099/00221287-19-2-312

Bernard, R. L. (1972). Two genes affecting stem termination in soybeans. *Crop Science*, *12*, 235–239. https://doi.org/10.2135/cropsci1972.0011183X001200020028x

Bertram, M. G., & Pedersen, P. (2004). Adjusting management practices using glyphosate-resistant soybean cultivars. *Agronomy Journal*, *96*, 462–468. https://doi.org/10.2134/agronj2004.4620

Beuerlein, J. (2004). *Soybean inoculation; its science, use, and performance*. The Ohio State University Extension. http://agcrops.osu.edu/soybean/documents/SoybeanInoculation.pdf

Beuerlein, J. (2005). *2005 Ohio inoculation study*. The Ohio State University Extension. http://agcrops.osu.edu/specialists/soybean/current-research-projects/2005SoyInoculationReport.pdf/view

Beuerlein, J. E. (1988). Yield of indeterminate and determinate semidwarf soybean for several planting dates, row spacing, and seeding rates. *Journal of Production Agriculture*, *1*, 300–303. https://doi.org/10.2134/jpa1988.0300

Bezdicek, D. F., Evans, D. W., Abede, B., & Witters, R. W. (1978). Evaluation of peat and granular inoculums for soybean yield and N fixation under irrigation. *Agronomy Journal*, *70*, 865–868. https://doi.org/10.2134/agronj1978.00021962007000050037x

Bhangoo, M. S., & Albritton, D. J. (1976). Nodulating and non-nodulating Lee soybean isolines response to applied nitrogen. *Agronomy Journal*, *68*, 642–645. https://doi.org/10.2134/agronj1976.00021962006800040027x

Bharati, M. P., Whigham, D. K., & Voss, R. D. (1986). Soybean response to tillage and nitrogen, phosphorus, and potassium fertilization. *Agronomy Journal*, *78*, 947–950. https://doi.org/10.2134/agronj1986.00021962007800060002x

Biederbeck, V. O., Campbell, C. A., Bowren, K. E., Schnitzer, M., & McIver, R. N. (1980). Effect of burning cereal straw on soil properties and grain yields in Saskatchewan. *Soil Science Society of America Journal*, *44*, 103–111. https://doi.org/10.2136/sssaj1980.03615995004400010022x

Blumenthal, M. J., Quach, V. P., & Searle, P. G. (1988). Effect of soybean population density on soybean yield, nitrogen accumulation and residual nitrogen. *Australian Journal of Experimental Research*, *28*, 99–106. https://doi.org/10.1071/EA9880099

Bly, A., Woodard, H. J., & Winther, D. (1998). *Nitrogen application timing and rate effects on soybean grain parameters at Aurora SD in 1998* (Soil/Water Research, 1997 Progress Report, SOIL PR 97-35). Department of Plant Science, Agricultural Experiment Station, South Dakota State University.

Board, J. (2000). Light interception efficiency and light quality affect yield compensation of soybean at low plant populations. *Crop Science*, *40*, 1285–1294. https://doi.org/10.2135/cropsci2000.4051285x

Board, J. (2001). Reduced lodging for soybean in low plant population is related to light quality. *Crop Science*, *41*, 379–384. https://doi.org/10.2135/cropsci2001.412379x

Board, J. E. (1985). Yield components associated with soybean yield reductions at nonoptimal planting dates. *Agronomy Journal*, *77*, 135–140. https://doi.org/10.2134/agronj1985.00021962007700010032x

Board, J. E. (2002). A regression model to predict soybean cultivar yield performance at late planting dates. *Agronomy Journal*, *94*, 483–492. https://doi.org/10.2134/agronj2002.4830

Board, J. E., & Hall, W. (1984). Premature flowering in soybean yield reductions at nonoptimal planting dates as influenced by temperature and photoperiod. *Agronomy Journal*, *76*, 700–704. https://doi.org/10.2134/agronj1984.00021962007600040043x

Board, J. E., & Harville, B. G. (1992). Explanations for greater light interception in narrow- vs. wide-row soybean. *Crop Science*, *32*, 198–202. https://doi.org/10.2135/cropsci1992.0011183X003200010041x

Board, J. E., & Harville, B. G. (1993). Soybean yield component responses to a light interception gradient during the reproductive period. *Crop Science*, *33*, 772–777. https://doi.org/10.2135/cropsci1993.0011183X003300040028x

Board, J. E., & Harville, B. G. (1994). A criteria for acceptance of narrow-row culture in soybean. *Agronomy Journal*, *86*, 1103–1106. https://doi.org/10.2134/agronj1994.00021962008600060033x

Board, J. E., & Harville, B. G. (1996). Growth dynamics during the vegetative period affects yield of narrow-row, late-planted soybean. *Agronomy Journal*, *88*, 567–572. https://doi.org/10.2134/agronj1996.00021962008800040012x

Board, J. E., Harville, B. G., & Saxton, A. M. (1990). Narrow-row seed yield enhancement in determinate soybean. *Agronomy Journal*, *82*, 64–68. https://doi.org/10.2134/agronj1990.00021962008200010014x

Board, J. E., & Kahlon, C. S. (2013). Morphological responses to low plant population differ between soybean genotypes. *Crop Science*, *53*, 1109–1119. https://doi.org/10.2135/cropsci2012.04.0255

Board, J. E., Kamal, M., & Harville, B. G. (1992). Temporal importance of greater light interception to increased yield in narrow-row soybean. *Agronomy Journal*, *84*, 575–579. https://doi.org/10.2134/agronj1992.00021962008400040006x

Board, J. E., Kang, M. S., & Bodrero, M. L. (2003). Yield components as indirect selection criteria for late-planted soybean cultivars. *Agronomy Journal*, *95*, 420–429. https://doi.org/10.2134/agronj2003.4200

Board, J. E., Kang, M. S., & Harville, B. G. (1999). Path analyses of the yield formation process for late-planted soybean. *Agronomy Journal*, *91*, 128–135. https://doi.org/10.2134/agronj1999.00021962009100010020x

Board, J. E., & Settimi, J. R. (1986). Photoperiod effect before and after flowering on branch development in determinate soybean. *Agronomy Journal*, *78*, 995–1002. https://doi.org/10.2134/agronj1986.00021962007800060013x

Boerma, H. R., & Ashley, D. A. (1982). Irrigation, row spacing and genotype effects on late and ultra-planted soybean. *Agronomy Journal*, *74*, 995–999. https://doi.org/10.2134/agronj1982.00021962007400060015x

Boland, G. J., & Hall, R. (1987). Epidemiology of *Sclerotinia* stem rot of soybean in Ontario. *Phytopathology*, *77*(9), 1191–1196. https://doi.org/10.1094/Phyto-77-1191

Bond, J. J., & Willis, W. O. (1971). Soil water evaporation: Long term drying as influenced by surface residue and evaporative potential. *Soil Science Society of America*, *35*, 984–987. https://doi.org/10.2136/sssaj1971.03615995003500060036x

Boquet, D. J. (1990). Plant population density and row spacing effects on soybean at post-optimal planting dates. *Agronomy Journal*, *82*, 59–64. https://doi.org/10.2134/agronj1990.00021962008200010013x

Boquet, D. J. (1998). Yield and risk utilizing short-season soybean production in the mid-southern USA. *Crop Science*, *38*, 1004–1011. https://doi.org/10.2135/cropsci1998.0011183X003800040020x

Boquet, D. J., Koonce, K. L., & Walker, D. M. (1982). Selected determinate soybean cultivar yield responses to row spacings and planting dates. *Agronomy Journal*, *74*, 136–138. https://doi.org/10.2134/agronj1982.00021962007400010035x

Boquet, D. J., Koonce, K. L., & Walker, D. M. (1983). *Row spacing and planting date effect on yield and growth responses of soybeans* (Bulletin No. 754). Louisiana Agricultural Experiment Station.

Boquet, D. J., & Walker, D. M. (1984). *Wheat – soybean double-cropping: Stubble management, tillage, row spacing and irrigation* (Bulletin No. 706). Louisiana Agricultural Experiment Station.

Borges, R., & Mallarino, A. P. (2000). Grain yield, early growth, and nutrient uptake of no-till soybean as affected by phosphorus and potassium placement. *Agronomy Journal*, *92*, 380–388. https://doi.org/10.2134/agronj2000.922380x

Borges, R., & Mallarino, A. P. (2003). Broadcast and deep-band placement of phosphorus and potassium for soybean managed with ridge tillage. *Soil Science Society of America Journal*, *67*, 1920–1927. https://doi.org/10.2136/sssaj2003.1920

Borner, H. (1960). Liberation of organic substances from higher plants and their role in the soil sickness problem. *Botanical Review*, *26*, 393–424.

Bowen, C. R., & Schapaugh, W. T. (1989). Relationship among charcoal rot infection, yield, and stability estimates in soybean blends. *Crop Science*, *29*, 42–46. https://doi.org/10.2135/cropsci1989.0011183X002900010009x

Bowers, G. R. (1995). An early soybean production system for drought avoidance. *Journal of Production Agriculture*, *8*, 112–119. https://doi.org/10.2134/jpa1995.fpage

Bowers, G. R., Rabb, J. L., Ashlock, L. O., & Santini, J. B. (2000). Row spacing in the early soybean production system. *Agronomy Journal*, *92*, 524–531. https://doi.org/10.2134/agronj2000.923524x

Bradley, C. A., Hartman, G. L., & Mehl, H. L. (2021). Soybean yield loss estimates due to diseases in the United States and Ontario, Canada from 2015-2019. *Plant Health Progress*, *22*(4), 483–495. https://doi.org/10.1094/PHP-01-21-0013-RS

Bradley, K. W. (2006). A review of the effects of row spacing on weed management in corn and soybean. *Crop Management*, *5*, 1–10. https://doi.org/10.1094/CM-2006-0227-02-RV

Bradley, K. W., Hagood, E. S., Jr., & Davis, P. H. (2004). Trumpetcreeper (*Campsis radicans*) control in double-crop glyphosate-resistant soybean with glyphosate and conventional herbicide systems. *Weed Technology*, *18*, 298–303. https://doi.org/10.1614/WT-03-050R1

Bradley, K. W., & Sweets, L. E. (2008). Influence of glyphosate and fungicide coapplications on weed control, spray penetration, soybean response, and yield in glyphosate-resistant soybean. *Agronomy Journal*, *100*, 1360–1365. https://doi.org/10.2134/agronj2007.0329

Brady, R. A., Stone, L. R., Nickell, C. D., & Powers, W. L. (1974). Water conservation through proper timing of soybean irrigation. *Journal of Soil and Water Conservation*, *29*, 266–268.

Brevedan, R. E., & Egli, D. B. (2003). Short periods of water stress during seed fi lling, leaf senescence, and yield of soybean. *Crop Science*, *43*, 2083–2088. https://doi.org/10.2135/cropsci2003.2083

Brevedan, R. E., Egli, D. B., & Leggett, J. E. (1978). Influence of N nutrition on flower and pod abortion and yield of soybeans. *Agronomy Journal*, *70*, 81–84. https://doi.org/10.2134/agronj1978.00021962007000010019x

Browde, J. A., Pedigo, L. P., Owen, M. D. K., & Tylka, G. L. (1994). Soybean yield and pest management as influenced by nematodes, herbicides, and defoliating insects. *Agronomy Journal*, *86*, 601–608. https://doi.org/10.2134/agronj1994.00021962008600040005x

Brown, A. R., & Perkins, H. F. (1979). Single vs. double cropping under two levels of fertilization with and without irrigation. *Communications in Soil Science and Plant Analysis*, *10*, 1279–1289. https://doi.org/10.1080/00103627909366982

Browning, P. W. (2011). *Agronomic and economic comparison of full-season and double-cropped small grain and soybean systems in the mid-Atlantic USA* [Master's thesis, Virginia Polytechnic Institute and State University].

Bruns, H. A., & Young, L. D. (2012). Raised seedbeds for soybean in twin rows increase yields over flat seedbeds. *Crop Management*, *11*(1), 1–7. https://doi.org/10.1094/CM-2012-0712-01-RS

Brye, K. R., Longer, D. E., & Gbur, E. E. (2006). Impact of tillage and residue burning on carbon dioxide flux in a wheat–soybean production system. *Soil Science Society of America Journal*, *70*, 1145–1154. https://doi.org/10.2136/sssaj2005.0151

Buah, S. S. J., Polito, T. A., & Killorn, R. (2000). No-tillage soybean response to banded and broadcast and direct and residual fertilizer phosphorus and potassium applications. *Agronomy Journal*, *92*, 657–662. https://doi.org/10.2134/agronj2000.924657x

Bullock, D., Khan, S., & Rayburn, A. (1998). Soybean yield response to narrow rows is largely due to enhanced early growth. *Crop Science*, *38*, 1011–1016. https://doi.org/10.2135/cropsci1998.0011183X003800040021x

Burnside, O. C., & Colville, W. L. (1964). Soybean and weed yields as affected by irrigation, row spacing, tillage, and amiben. *Weeds*, *12*, 109–112. https://doi.org/10.2307/4040607

Caldwell, T. G., Johnson, D. W., Miller, W. W., & Qualls, R. G. (2002). Forest floor carbon and nitrogen losses due to prescription fire. *Soil Science Society of America Journal*, *66*, 262–267. https://doi.org/10.2136/sssaj2002.2620

Calviño, P. A., Sadras, V. O., & Andrade, F. H. (2003). Development, growth and yield of late-sown soybean in the southern Pampas. *European Journal of Agronomy*, *19*, 265–275. https://doi.org/10.1016/S1161-0301(02)00050-3

Campbell, R. B., Matheny, T. A., Hunt, P. G., & Gupta, S. C. (1979). Crop residue requirements for water erosion control in six southern states. *Journal of Soil and Water Conservation*, *34*, 83–85.

Camper, H. M., Jr., Genter, C. F., & Loope, K. E. (1972). Double cropping following winter barley harvest in eastern Virginia. *Agronomy Journal*, *64*, 1–3. https://doi.org/10.2134/agronj1972.00021962006400010001x

Carpenter, A. C., & Board, J. E. (1997). Branch yield components controlling soybean yield stability across plant populations. *Crop Science*, *37*, 885–891. https://doi.org/10.2135/cropsci1997.0011183X003700030031x

Carter, O. G. (1974). Detailed yield analysis of the effect of different planting dates on seven soybean varieties. *Iowa State Journal of Research*, *48*, 291–310.

Carter, T. E., & Boerma, H. R. (1979). Implications of genotype × planting date and row spacing interactions in double-cropped soybean cultivar development. *Crop Science*, *19*, 607–610. https://doi.org/10.2135/cropsci1979.0011183X001900050014x

Cartter, J. L., & Hartwig, E. E. (1963). Management of soybeans. In A. G. Norman (Ed.), *The soybean* (pp. 161–226). Academic Press.

Caviglia, O. P., & Andrade, F. H. (2010). Sustainable intensification of agriculture in the Argentinean pampas: Capture and use efficiency of environmental resources. *The American Journal of Plant Science and Biotechnology*, *3*, 1–8.

Caviglia, O. P., Sadras, V. O., & Andrade, F. H. (2004). Intensification of agriculture in the south-eastern Pampas. I. Capture and efficiency in the use of water and radiation in double-cropped wheat – soybean. *Field Crops Research*, *87*, 117–129. https://doi.org/10.1016/j.fcr.2003.10.002

Caviglia, O. P., Sadras, V. O., & Andrade, F. H. (2011). Yield and quality of wheat and soybean in sole- and double-cropping. *Agronomy Journal*, *103*, 1081–1089. https://doi.org/10.2134/agronj2011.0019

Caviness, C. E. (1966). *Spacing studies with Lee soybeans* (Bulletin 713). Arkansas Agricultural Experiment Station.

Caviness, C. E., & Collins, F. C. (1985). Double cropping. In R. M. Shibles (Ed.), *World soybean research conference III: Proceedings* (pp. 1032–1038). CRC Press.

Caviness, C. E., Collins, F. C., & Sullivan, M. (1986). Effect of wheat residue on early growth of soybean. *Arkansas Farm Research*, *35*, 8.

Caviness, C. E., & Smith, P. E. (1959). Effect of different dates and rates of planting soybeans. *Arkansas Agricultural Experiment Station Report Series*, *88*, 19.

Caviness, C. E., & Thomas, J. D. (1979). Influence of planting date on three soybean varieties. *Arkansas Farm Research*, *28*, 8.

Chan, K. Y., & Heenan, D. P. (2005). The effects of stubble burning and tillage on soil carbon sequestration and crop productivity in southeastern Australia. *Soil Use and Management*, *21*, 427–431. https://doi.org/10.1079/SUM2005357

Chen, G., & Wiatrak, P. (2010). Soybean development and yield are influenced by planting date and environmental conditions in the southeastern Coastal Plain, United States. *Agronomy Journal*, *102*, 1731–1737. https://doi.org/10.2134/agronj2010.0219

Chen, G., & Wiatrak, P. (2011). Seeding rate effects on soybean maturity group IV-VIII for the southeastern production system: I. Vegetation indices. *Agronomy Journal*, *103*, 32–37. https://doi.org/10.2134/agronj2010.0153

Chen, S. (2007). Suppression of *Heterodera glycines* in soils from fields with long-term soybean monoculture. *Biological Control*, *41*(3), 332–338. https://doi.org/10.1016/j.biocontrol.2007.02.009

Chowdhury, I. A., Yan, G., Halvorson, J., Thapa, A., Halvorson, M., & Markell, S. (2022). *Soybean cyst nematode (SCN)* (PP1732). North Dakota State University Extension.

Coale, F. J., & Grove, J. H. (1990). Root distribution and shoot development in no-till full-season and double-crop soybean. *Agronomy Journal*, *82*, 606–612. https://doi.org/10.2134/agronj1990.00021962008200030034x

Coale, F. J., & Grove, J. H. (1991). Potassium utilization by no-till full-season and double-crop soybean. *Agronomy Journal*, *83*, 190–194. https://doi.org/10.2134/agronj1991.00021962008300010045x

Coble, H. D., Williams, F. M., & Ritter, R. L. (1981). Common ragweed (*Ambrosia artemisiifolia*) interference in soybeans (*Glycine max*). *Weed Science*, *29*, 339–342. https://doi.org/10.1017/S0043174500062081

Collins, F. C., & Caviness, C. E. (1978). *Growth of soybeans on wheat straw residue* [*Abstract*] (pp. 92–93). American Society of Agronomy.

Collison, R. C. (1925). The presence of certain organic compounds in plants and their relation to the growth of other plants. *Agronomy Journal*, *17*, 58–68. https://doi.org/10.2134/agronj1925.00021962001700010006x

Collison, R. C., & Conn, H. J. (1925). *The effect of straw on plant growth* (Technical Bulletin No. 114). New York (Geneva) Agricultural Experiment Station.

Constable, G. A. (1977). Effect of planting date on soybeans in Naomi Valley, New South Wales. *Australian Journal of Experimental Agriculture and Animal Husbandry*, *17*, 148–155.

Constable, G. A., & Hearn, A. B. (1978). Agronomic and physiological responses of soybean and sorghum crops to water deficits I. Growth, development and yield. *Australian Journal of Plant Physiology*, *5*, 159–167.

Cooper, R. L. (1971). Influence of soybean production practices on lodging environments and seed yield in highly productive environments. *Agronomy Journal*, *63*, 490–493. https://doi.org/10.2134/agronj1971.00021962006300030043x

Cooper, R. L. (1977). Response of soybean cultivars to narrow rows and planting rates under weed-free conditions. *Agronomy Journal*, *69*, 89–92. https://doi.org/10.2134/agronj1977.00021962006900010023x

Cooper, R. L. (1981). Development of short-statured soybean cultivars. *Crop Science*, *21*, 127–131. https://doi.org/10.2135/cropsci1981.0011183X002100010034x

Cooper, R. L. (1985). Breeding semidwarf soybeans. In J. Janick (Ed.), *Plant breeding reviews* (Vol. 3, pp. 289–311). AVI.

Cooper, R. L., & Lambert, J. W. (1965). Narrow row: How do they increase soybean yields in Minnesota. *Minnesota Farm Home Science*, *22*, 5–7.

Cooper, R. L., & Lambert, J. W. (1971). Influence of soybean production practices on lodging and seed yield in a highly productive environment. *Agronomy Journal*, *63*, 490–493. https://doi.org/10.2134/agronj1971.00021962006300030043x

Cordell, M., Brye, K., Longer, D., & Gbur, E. (2007). Residue management practice effects on soybean establishment and growth in a young wheat – soybean double-cropping system. *Journal of Sustainable Agriculture*, *29*, 97–120. https://doi.org/10.1300/J064v29n02_08

Costa, J. A., Oplinger, E. S., & Pendleton, J. W. (1980). Response of soybean cultivars to planting patterns. *Agronomy Journal*, *72*, 153–156. https://doi.org/10.2134/agronj1980.00021962007200010029x

Cox, W. J., & Cherney, J. H. (2011). Growth and yield responses of soybean to row spacing and seeding rate. *Agronomy Journal*, *103*, 123–128. https://doi.org/10.2134/agronj2010.0316

Cox, W. J., Cherney, J. H., & Shields, E. (2010). Soybeans compensate at low seeding rates but not at high thinning rates. *Agronomy Journal*, *102*, 1238–1243. https://doi.org/10.2134/agronj2010.0047

Crabtree, R. J., Prater, J. D., & Mbolda, P. (1990). Long-term wheat, soybean, and grain sorghum double-cropping under rainfed conditions. *Agronomy Journal*, *82*, 683–686. https://doi.org/10.2134/agronj1990.00021962008200040007x

Crabtree, R. J., & Rupp, R. N. (1980). Double and monocropped wheat and soybeans under different tillage and row spacings. *Agronomy Journal*, *72*, 445–448. https://doi.org/10.2134/agronj1980.00021962007200030009x

Cruse, R. M., Yakle, G. A., Colvin, T. C., Timmons, D. R., & Mussleman, A. L. (1983). Tillage effects on corn and soybean production in farmer-managed, university-monitored field plots. *Journal of Soil and Water Conservation*, *38*, 512–514.

Cruz, C. D., Mills, D., Paul, P. A., & Dorrance, A. E. (2010). Impact of brown spot caused by Septoria glycines on soybean in Ohio. *Plant Disease*, *94*, 820–826. https://doi.org/10.1094/PDIS-94-7-0820

Culpepper, A. S., & York, A. C. (2000). Weed management in ultra narrow row cotton (*Gossypium hirsutum*). *Weed Technology*, *14*, 19–29. https://doi.org/10.1614/0890-037X(2000)014%5b0019:WMIUNR%5d2.0.CO;2

Dabney, S. M. (1998). Cover crop impacts on watershed hydrology. *Journal of Soil and Water Conservation*, *53*, 207–213.

Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using winter cover crops to improve soil and water quality. *Communications in Soil Science and Plant Analysis*, *32*, 1221–1250. https://doi.org/10.1081/CSS-100104110

Dabney, S. M., McGawley, E. C., Boethel, D. J., & Berger, D. A. (1988). Short-term crop rotation systems for soybean production. *Agronomy Journal*, *80*, 197–204. https://doi.org/10.2134/agronj1988.00021962008000020012x

Dalley, C. D., Kells, J. J., & Renner, K. A. (2004). Effect of glyphosate application timing and row spacing on corn (*Zea mays*) and soybean (*Glycine max*) yields. *Weed Technology*, *18*, 165–176. https://doi.org/10.1614/02-150A

Daniels, M., & Scott, H. (1991). Water use efficiency of double-cropped wheat and soybean. *Agronomy Journal*, *83*, 564–570. https://doi.org/10.2134/agronj1991.00021962008300030009x

Dao, T. H. (1993). Tillage and winter wheat residue management effects of water infiltration and storage. *Soil Science Society of America Journal*, *57*, 158–159. https://doi.org/10.2136/sssaj1993.03615995005700060032x

De Bruin, J. L., & Pedersen, P. (2008a). Effect of row spacing and seeding rate on soybean yield. *Agronomy Journal*, *100*, 704–710. https://doi.org/10.2134/agronj2007.0106

De Bruin, J. L., & Pedersen, P. (2008b). Soybean seed yield response to planting date and seeding rate in the upper Midwest. *Agronomy Journal*, *100*, 696–703. https://doi.org/10.2134/agronj2007.0115

De Bruin, J. L., Pedersen, P., Conley, S. P., Gaska, J. M., Naeve, S. L., Kurle, J. E., Elmore, R. W., Giesler, L. J., & Abendroth, L. J. (2010). Probability of yield response to inoculants in fields with a history of soybean. *Crop Science*, *50*, 265–272. https://doi.org/10.2135/cropsci2009.04.0185

DeFelice, M. S., Brown, W. B., Aldrich, R. J., Sims, B. D., Judy, D. T., & Guethle, D. R. (1989). Weed control in soybeans (*Glycine max*) with reduced rates of postemergence herbicides. *Weed Science*, *37*, 365–374. https://doi.org/10.1017/S0043174500072076

Deibert, E. J., Bijeriego, M., & Olson, R. A. (1979). Utilization of 15N fertilizer by nodulating and non-nodulating soybean isolines. *Agronomy Journal*, *71*, 717–723. https://doi.org/10.2134/agronj1979.00021962007100050006x

DeLaune, P. B. (2018). *Double-cropping and extended cover crops in Rolling Plains wheat systems*. Texas A&M AgriLife Research. https://agrilifetoday.tamu.edu/2018/09/13/double-cropping-longer-term-cover-crops-options-in-rolling-plains-wheat-systems/

de Mooy, C. J., Pesek, J., & Spaldon, E. (1973). Mineral nutrition. In B. E. Caldwell (Ed.), *Soybeans: Improvement, production, and uses* (pp. 267–352). Agronomy monographs 16. ASA.

Denison, R. F., & Sinclair, T. R. (1985). Diurnal and seasonal variation in dinitrogen fixation (acetylene reduction) rates by field-grown soybean. *Agronomy Journal*, *77*, 679–684. https://doi.org/10.2134/agronj1985.00021962007700050005x

Desclaux, D., & Roumet, P. (1996). Impact of drought stress on the phenology of two soybean (*Glycine max* L. Merr) cultivars. *Field Crops Research*, *46*, 61–70. https://doi.org/10.1016/0378-4290(95)00086-0

De Souza, P. I., Egli, D. B., & Bruening, W. P. (1997). Water stress during seed filling and leaf senescence in soybean. *Agron-*

omy Journal, *89*, 807–812. https://doi.org/10.2134/agronj1997.00021962008900050015x

Devlin, D. L., Fjell, D. L., Shroyer, J. P., Gordon, W. B., Marsh, B. H., Maddux, L. D., Martin, V. L., & Duncan, S. R. (1995). Row spacing and seeding rates for soybean in low and high yielding environments. *Journal of Production Agriculture*, *8*, 215–222. https://doi.org/10.2134/jpa1995.0215

Devlin, D. L., Long, J. H., & Maddux, L. D. (1991). Using reduced rates of postemergence herbicides in soybeans (*Glycine max*). *Weed Technology*, *5*, 834–840. https://doi.org/10.1017/S0890037X00033947

Dewell, R. A., Johnson, W. G., Nelson, K. A., Jianmei, L., & Wait, J. D. (2003). Weed removal timings in no-till, double-crop, glyphosate-resistant soybean grown on claypan soils. *Crop Management*, *2*(1), 1–6. https://doi.org/10:1094/CM-2003-1205-01-RS

Díaz-Zorita, M., Grove, J. H., Murdock, L., Herbeck, J., & Perfect, E. (2004). Soil structural disturbance effect on crop yields and soil properties in a no-till production system. *Agronomy Journal*, *96*, 1651–1659. https://doi.org/10.2134/agronj2004.1651

Dillon, J. E., & McKibben, G. E. (1972). Double-crop and play summer roulette. *Illinois Research*, *14*, 6–7.

Dillon, K. A. (2014). *Double-crop soybean vegetative growth, seed yield, and yield component response to agronomic inputs in the Mid-Atlantic, USA* [Doctoral dissertation, Virginia Polytechnic Institute and State University].

Dodd, J. R., & Mallarino, A. P. (2005). Soil-test phosphorus and crop grain yield responses to long-term phosphorus fertilization for corn-soybean rotations. *Soil Science Society of America Journal*, *69*, 1118–1128. https://doi.org/10.2136/sssaj2004.0279

Dorn, K. M., Tiedje, J. M., & Buckler, E. S. (2013). Soil microbial dynamics and nutrient cycling in double-crop soybean systems. *Soil Biology & Biochemistry*, *58*, 77–86. https://doi.org/10.1016/j.soilbio.2013.09.010

Dorrance, A. E., Cruz, C., Mills, D., Bender, R., Koenig, M., Labarge, G., Leeds, R., Mangione, D., Mccluer, G., Ruhl, S., Siegrist, H., Sundermeier, A., Sonnenberg, D., Yost, J., Watters, H., Wilson, G., & Hammond, R. B. (2010). Effect of foliar fungicide and insecticide applications on soybeans in Ohio. *Plant Health Progress*, *11*(1), 31. https://doi.org/10:1094/PHP-2010-0122-01-RS

Dorrance, A. E., Lipps, P. E., Mills, D., & Vega-Sanchez, M. (2004). *Soybean rust* (AC-0048-94). Ohio State University.

Doss, B. D., Pearson, R. W., & Rogers, H. T. (1974). Effect of soil water stress at various growth stages on soybean yield. *Agronomy Journal*, *66*, 297–299. https://doi.org/10.2134/agronj1974.00021962006600020032x

Duiker, S. W., & Beegle, D. B. (2006). Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. *Soil and Tillage Research*, *88*(1-2), 30–41. https://doi.org/10.1016/j.still.2005.04.004

Duncan, W. G. (1986). Planting patterns and soybean yields. *Crop Science*, *26*, 584–588. https://doi.org/10.2135/cropsci1986.0011183X002600030033x

Dunphy, E. J., Hanway, J. J., & Green, D. E. (1979). Soybean yields in relation to days between specific developmental stages. *Agronomy Journal*, *71*, 917–920. https://doi.org/10.2134/agronj1979.00021962007100060005x

Dusek, D. A., Musick, J. T., & Porter, K. B. (1971). *Irrigation of soybeans in the Texas High Plains* (Misc. Publ. 973). Texas Agricultural Experiment Station.

Eaglesham, A. R. J., Hassouna, S., & Seegers, R. (1983). Fertilizer-N effects on N2 fixation by cowpea and soybean. *Agronomy Journal*, *75*, 61–66. https://doi.org/10.2134/agronj1983.00021962007500010016x

Edwards, J. H., Thurlow, D. L., & Eason, J. T. (1988). Influence of tillage and crop rotation on yields of corn, soybean, and wheat. *Agronomy Journal*, *80*, 76–80. https://doi.org/10.2134/agronj1988.00021962008000010018x

Edwards, J. T., Hunger, R. M., & Payton, M. E. (2012). Management of wheat harvest timing and its effect on yield and quality. *Agronomy Journal*, *104*(4), 918–925. https://doi.org/10.2134/agronj2011.0384

Edwards, J. T., & Purcell, L. C. (2005). Soybean yield and biomass response to increasing plant population among diverse maturity groups: I. Agronomic characteristics. *Crop Science*, *45*, 1770–1777. https://doi.org/10.2135/cropsci2004.0564

Edwards, J. T., Purcell, L. C., & Vories, E. D. (2005). Light interception and yield potential of short-season maize (*Zea mays* L.) hybrids in the Midsouth. *Agronomy Journal*, *97*, 225–234. https://doi.org/10.2134/agronj2005.0225a

Edwards, J. T., Purcell, L. C., Vories, E. D., Shannon, J. G., & Ashlock, L. O. (2003). Short-season soybean cultivars have similar yields with less irrigation than longer-season cultivars. *Crop Management*, *2*(1), 1–7. https://doi.org/10.1094/CM-2003-0922-01-RS

Egli, D. B. (1975). Rate of accumulation of dry weight in seed of soybeans and its relationship to yield. *Canadian Journal of Plant Science*, *55*, 215–219. https://doi.org/10.4141/cjps75-032

Egli, D. B. (1988). Plant density and soybean yield. *Crop Science*, *28*, 977–981. https://doi.org/10.2135/cropsci1988.0011183X002800060023x

Egli, D. B. (1994). Mechanisms responsible for soybean yield response to equidistant planting patterns. *Agronomy Journal*, *86*, 1046–1049. https://doi.org/10.2134/agronj1994.00021962008600060021x

Egli, D. B. (2008). Soybean yield trends from 1972 to 2003 in mid-western USA. *Field Crops Research*, *106*, 53–59. https://doi.org/10.1016/j.fcr.2007.10.014

Egli, D. B. (2011). Time and the productivity of agronomic crops and cropping systems. *Agronomy Journal*, *103*, 743–750. https://doi.org/10.2134/agronj2010.0508

Egli, D. B., & Bruening, W. P. (2000). Potential of early-maturing soybean cultivars in late plantings. *Agronomy Journal*, *92*, 532–537. https://doi.org/10.2134/agronj2000.923532x

Egli, D. B., & Bruening, W. P. (2004). Water stress, photosynthesis, seed sucrose levels and seed growth in soybean. *Journal of Agricultural Science*, *142*, 1–8. https://doi.org/10.1017/S0021859604004095

Egli, D. B., & Bruening, W. P. (2006). Temporal patterns of pod production and pod set in soybean. *European Journal of Agronomy*, *24*, 11–18. https://doi.org/10.1016/j.eja.2005.04.006

Egli, D. B., & Cornelius, P. L. (2009). A regional analysis of the response of soybean yield to planting date. *Agronomy Journal*, *101*, 330–335. https://doi.org/10.2134/agronj2008.0148

Egli, D. B., Guffy, R. D., & Heitholt, J. J. (1987). Factors associated with reduced yields of delayed planings of soybean. *Journal of Agronomy and Crop Science*, *159*, 176–185. https://doi.org/10.1111/j.1439-037X.1987.tb00083.x

Egli, D. B., & Leggett, J. E. (1973). Dry matter accumulation patterns in determinate and indeterminate soybeans. *Crop Science*, *13*, 220–222. https://doi.org/10.2135/cropsci1973.0011183X001300020021x

Egli, D. B., Meckel, L., Phillips, R. E., Radcliffe, D., & Leggett, J. E. (1983). Moisture stress and N redistribution in soybean. *Agron-*

omy Journal, *75*, 1027–1031. https://doi.org/10.2134/agronj1983.00021962007500060036x

Ellert, B., & Janzen, H. (1999). Short-term influence of tillage on CO2 fluxes from a semi-arid soil on the Canadian Prairies. *Soil and Tillage Research*, *50*, 21–32. https://doi.org/10.1016/S0167-1987(98)00188-3

Elmore, C. D., Heatherly, L. G., & Wesley, R. A. (1995). Weed control in no-till doublecrop soybean following winter wheat on a clay soil. *Weed Technology*, *9*, 306–315.

Elmore, R. W. (1990). Soybean cultivar response to tillage systems and planting date. *Agronomy Journal*, *82*, 69–73. https://doi.org/10.2134/agronj1990.00021962008200010015x

Elmore, R. W. (1991). Soybean cultivar response to planting rate and tillage. *Agronomy Journal*, *83*, 829–832. https://doi.org/10.2134/agronj1991.00021962008300050011x

Elmore, R. W. (1998). Soybean cultivar responses to row spacing and seeding rates in rainfed and irrigated environments. *Journal of Production Agriculture*, *11*, 326–331. https://doi.org/10.2134/jpa1998.0326

Elwali, A. M. O., & Gascho, G. J. (1985). Timing and rate of K application for wheat – soybean double cropping on a sandy soil. *Agronomy Journal*, *77*, 145–149. https://doi.org/10.2134/agronj1985.00021962007700010034x

Engel, R. E., Long, D. S., & Carlson, G. R. (2003). Predicting straw yield of hard red spring wheat. *Agronomy Journal*, *95*, 1454–1460. https://doi.org/10.2134/agronj2003.1454

Epler, M., & Staggenborg, S. (2008). Soybean yield and yield component responses to plant density in narrow row systems. *Crop Management*, *7*(1), 1–13. https://doi.org/10.1094/CM-2008-0925-01-RS

Esbenshade, W. R., Curran, W. S., Roth, G. W., Hartwig, N. L., & Orzolek, M. D. (2001a). Effect of tillage, row spacing, and herbicide on the emergence and control of burcucumber (*Sicyos angulatus*) in soybean (*Glycine max*). *Weed Technology*, *15*, 229–235. https://doi.org/10.1614/0890-037X(2001)015%5b0229:EOTRSA%5d2.0.CO;2

Esbenshade, W. R., Curran, W. S., Roth, G. W., Hartwig, N. L., & Orzolek, M. D. (2001b). Effect of row spacing and herbicides on burcucumber (*Sicyos angulatus*) control in herbicide-resistant corn (*Zea mays*). *Weed Technology*, *15*, 348–354. https://doi.org/10.1614/0890-037X(2001)015%5b0348:EORSAH%5d2.0.CO;2

Ethredge, W. J., Ashley, D. A., & Woodruff, J. M. (1989). Row spacing and plant population effects on yield components of soybean. *Agronomy Journal*, *81*, 947–951. https://doi.org/10.2134/agronj1989.00021962008100060020x

Evanylo, G. K. (1991). Potassium fertilization of doublecropped wheat and soybeans under two tillage systems. *Journal of Production Agriculture*, *4*, 555–560. https://doi.org/10.2134/jpa1991.0555

Farmaha, B. S., Sekaran, U., & Franzluebbers, A. J. (2021). Cover cropping and conservation tillage improve soil health in the southeastern United States. *Agronomy Journal*, *114*, 296–316. https://doi.org/10.1002/agj2.20865

Farno, L. A., Edwards, L. H., Keim, K., & Epplin, F. M. (2002). Economic analysis of soybean-wheat cropping systems. *Crop Management*, *1*(1), 1–6. https://doi.org/10.1094/CM-2002-0816-01-RS

Farrer, D., Weisz, R., Heiniger, R., Murphy, J. P., & Pate, M. H. (2006). Delayed harvest effect on soft red winter wheat in the southeastern USA. *Agronomy Journal*, *98*, 588–595. https://doi.org/10.2134/agronj2005.0211

Fehr, W. R., Caviness, C. E., Burmood, D. T., & Pennington, J. S. (1971). Stage of development descriptions for soybeans, *Glycine max* (L.) Merrill. *Crop Science*, *11*, 929–931. https://doi.org/10.2135/cropsci1971.0011183X001100060051x

Fehr, W. R., Caviness, C. E., & Vorst, J. J. (1977). Response of indeterminate and determinate soybean cultivars to defoliation and half-plant cut-off. *Crop Science*, *17*, 913–917. https://doi.org/10.2135/cropsci1977.0011183X001700060024x

Ferguson, R., Lanclos, D., Leonard, R., Boquet, D., Hollier, C., & Vidrine, R. (2008). *Suggestions for double-cropping soybeans and wheat in Louisiana during 2008* (Publication 3053). Louisiana Cooperative Extension Service.

Fernández, F. G., Brouder, S. M., Beyrouty, C. A., Volenec, J. J., & Hoyum, R. (2008). Assessment of plant-available potassium for no-till, rainfed soybean. *Soil Science Society of America Journal*, *72*, 1085–1095. https://doi.org/10.2136/sssaj2007.0345

Fischer, R. A., Santiveri, F., & Vidal, I. R. (2002). Crop rotation, tillage and crop residue management for wheat and maize in the sub-humid tropical highlands: I. Wheat and legume performance. *Field Crops Research*, *79*, 107–122. https://doi.org/10.1016/S0378-4290(02)00157-0

Foley, T. C., Orf, J. H., & Lambert, J. W. (1986). Performance of related determinate and indeterminate soybean lines. *Crop Science*, *26*, 5–8. https://doi.org/10.2135/cropsci1986.0011183X002600010002x

Francl, L. J., & Dropkin, V. H. (1986). *Heterodera glycines* population dynamics and relation of initial population to soybean yield. *Plant Disease*, *70*, 791–795.

Frans, R. E. (1959). Effect on soybean yields of herbicide and narrow row width combinations. *Arkansas Agricultural Experiment Station Report Series*, *84*, 19.

Franzluebbers, A. J. (2010). Achieving soil organic carbon sequestration with conservation agricultural systems in the southeastern United States. *Soil Science Society of America Journal*, *74*, 347–357. https://doi.org/10.2136/sssaj2009.0079

Frederick, J. R., Bauer, P. J., Busscher, W. J., & McCutcheon, G. S. (1998). Tillage management for doublecropped soybean grown in narrow and wide row width culture. *Crop Science*, *38*, 755–762. https://doi.org/10.2135/cropsci1998.0011183X003800030023x

Furseth, B. J., Conley, S. P., & Ané, J.-M. (2012). Soybean response to soil rhizobia and seed-applied rhizobia inoculants in Wisconsin. *Crop Science*, *52*, 339–344. https://doi.org/10.2135/cropsci2011.01.0041

Gai, J., Palmer, R. G., & Fehr, W. R. (1984). Bloom and pod set in determinate and indeterminate soybeans grown in China. *Agronomy Journal*, *76*, 979–984. https://doi.org/10.2134/agronj1984.00021962007600060026x

Gaillard, V., Chenu, C., & Recous, S. (2003). Carbon mineralization in soil adjacent to plant residues of contrasting biochemical quality. *Soil Biology & Biochemistry*, *35*, 93–99. https://doi.org/10.1016/S0038-0717(02)00241-9

Gammans, M., Mérel, P., & Ortiz-Bobea, A. (2025). Double cropping as an adaptation to climate change in the United States. *American Journal of Agricultural Economics*, *107*, 347–721. https://doi.org/10.1111/ajae.12491

Gerlow, A. R., & Mullins, T. (1960). *Economics of supplementary irrigation of soybeans* (Bulletin 634). Arkansas Agricultural Experiment Station.

Ghidey, F., & Alberts, E. E. (1998). Runoff and soil losses as affected by corn and soybean tillage systems. *Journal of Soil and Water Conservation*, *53*, 64–70.

Gill, M. (1997). Cropping management. In M. Anderson & R. Magleby (Eds.), *Agricultural resources and environmental indicators 1996-*

97 (AREI) (pp. 175–180). ERS-USDA. http://www.ers.usda.gov/publications/arei/ah712/AH7124-3.PDF

Gomes, M. A. F., & Sodek, L. (1987). Reproductive development and nitrogen fixation in soybean (*Glycine max* L. Merril). *Journal of Experimental Botany*, *38*, 1982–1987. https://doi.org/10.1093/jxb/38.12.1982

Grabau, L. J., & Pfeiffer, T. W. (1990). Management effects on harvest losses and yield of double-crop soybean. *Agronomy Journal*, *82*, 715–718. https://doi.org/10.2134/agronj1990.00021962008200040014x

Grabau, Z. J., & Chen, S. (2016). Influence of tillage and crop rotation on suppression of soybean cyst nematode and soybean yield. *Journal of Nematology*, *48*(2), 78–85. https://doi.org/10.21307/jofnem-2017-063

Graham, P. H. (1992). Stress tolerance in Rhizobium and Bradyrhizobium, and nodulation under adverse soil conditions. *Canadian Journal of Microbiology*, *38*, 475–484. https://doi.org/10.1139/m92-079

Graterol, Y. E., Elmore, R. W., & Eisenhauer, D. E. (1996). Narrow-row planting systems for furrow-irrigated soybean. *Journal of Production Agriculture*, *9*, 546–553. https://doi.org/10.2134/jpa1996.0546

Grau, C. R., & Radke, V. L. (1984). Effects of cultivars and cultural practices on *Sclerotinia* stem rot of soybean. *Plant Disease*, *68*(1), 56–58. https://doi.org/10.1094/PD-68-56

Grey, T. L. (2007). Utility of residual herbicides in no-till double crop glyphosate-resistant soybean production. *Crop Management*, *6*(1), 1–6. https://doi.org/10.1094/CM-2007-0122-01-RS

Grichar, W. J. (2007). Row spacing, plant populations, and cultivar effects on soybean production along the Texas Gulf Coast. *Crop Management*, *6*(1), 1–6. https://doi.org/10.1094/CM-2007-0615-01-RS

Griffith, D. R., Mannering, J. V., & Moldenhauer, W. C. (1977). Conservation tillage in eastern Corn Belt. *Journal of Soil and Water Conservation*, *32*, 22–28.

Groover, G. E., Kenyon, D. E., & Kramer, R. A. (1989). *An evaluation of production and marketing strategies for eastern Virginia cash grain producers* (Publication 89-1). Virginia Cooperative Extension, Virginia Polytechnic Institute and State University.

Grove, J. H., Thom, W. O., Murdock, L. W., & Herbek, J. H. (1987). Soybean response to available potassium in three silt loam soils. *Soil Science Society of America Journal*, *51*, 1231–1238. https://doi.org/10.2136/sssaj1987.03615995005100050026x

Grymes, C. F., Griffin, J. L., Boethel, D. J., Leonard, B. R., Jordan, D. L., & Russin, J. S. (1999). Soybean response to weed interference and defoliation. *Weed Science*, *47*, 90–94. https://doi.org/10.1017/S0043174500090706

Guenzi, W. D., & McCalla, T. M. (1962). Inhibition of germination and seedling development by crop residues. *Soil Science Society of America, Proceedings*, *26*, 456–458. https://doi.org/10.2136/sssaj1962.03615995002600050015x

Guenzi, W. D., & McCalla, T. M. (1966a). Phytotoxic substances extracted from soil. *Soil Science Society of America, Proceedings*, *30*, 214–216. https://doi.org/10.2136/sssaj1966.03615995003000020021x

Guenzi, W. D., & McCalla, T. M. (1966b). Phenolic acids in oats, wheat, sorghum, and corn residues and their phytotoxicity. *Agronomy Journal*, *58*, 303–304. https://doi.org/10.2134/agronj1966.00021962005800030017x

Guffy, R. D., Egli, D. B., & Leggett, J. E. (1983). Effect of cultivar and planting date on vegetative growth and yield of soybeans [Abstract]. *Agronomy Abstracts*, 14–19.

Gutiérrez-Boem, F. H., Scheiner, J. D., Rimski-Korsakov, H., & Lavado, R. S. (2004). Late season nitrogen fertilization of soybeans: Effects on leaf senescence, yield, and environment. *Nutrient Cycling in Agroecosystems*, *68*, 109–115. https://doi.org/10.1023/B:FRES.0000019040.02605.ee

Hairston, J. E., Sanford, J. O., Pope, D. F., & Horneck, D. A. (1987). Soybean-wheat doublecropping: Implications from straw management and supplemental nitrogen. *Agronomy Journal*, *79*, 281–286. https://doi.org/10.2134/agronj1987.00021962007900020021x

Ham, G. E., Liener, I. E., Evans, S. D., Frazier, R. D., & Nelson, W. W. (1975). Yield and composition of soybean seed as affected by N and S fertilization. *Agronomy Journal*, *67*, 293–297. https://doi.org/10.2134/agronj1975.00021962006700030004x

Hamid, M. I., Hussain, M., Wu, Y., Zhang, X., Xiang, M., & Liu, X. (2017). Biological control of plant diseases using Pochonia chlamydosporia. *Biological Control*, *109*, 44–56. https://doi.org/10.1016/j.biocontrol.2017.03.006

Hanna, S., Conley, S. P., Shaner, G., & Santini, J. (2006). *Impact of application timing and crop row spacing on fungicide penetration into a soybean canopy and grain yield* [Conference presentation]. Proceedings of the 2006 National Soybean Rust Symposium, St. Louis, MO, United States. http://www.plantmanagementnetwork.org/infocenter/topic/soybeanrust/2006

Hanna, S. O., Conley, S. P., Shaner, G. E., & Santini, J. B. (2008). Fungicide application timing and row spacing effect on soybean canopy penetration and grain yield. *Agronomy Journal*, *100*, 1488–1492. https://doi.org/10.2134/agronj2007.0135

Hansel, D. S. S., Schwalbert, R. A., Shoup, D. E., Holshouser, D. L., Parvej, R., Vara Prasad, P. V., & Ciampitti, I. A. (2019). A review of soybean yield when double-cropped after wheat. *Agronomy Journal*, *111*, 677–685. https://doi.org/10.2134/agronj2018.06.0371

Hanway, J. J., & Johnson, J. W. (1985). Potassium nutrition of soybean. In R. D. Munson (Ed.), *Potassium in agriculture* (pp. 753–764). ASA, CSSA, and SSSA. https://doi.org/10.2134/1985.potassium.c32

Hanway, J. J., & Weber, C. R. (1971). Accumulation of N, P, and K by soybean (*Glycine max* (L.) Merrill) plants. *Agronomy Journal*, *63*, 406–408. https://doi.org/10.2134/agronj1971.00021962006300030017x

Haq, M. U., & Mallarino, A. P. (2005). Response of soybean grain oil and protein concentrations to foliar and soil fertilization. *Agronomy Journal*, *97*, 910–918. https://doi.org/10.2134/agronj2004.0215

Haque, E., Epplin, F. M., & Horn, G. W. (2014). Optimal wheat harvest timing to balance grain yield, quality, and drying costs. *Journal of Agricultural and Applied Economics*, *46*(3), 345–361. https://doi.org/10.1017/S107407080002783X

Hardman, L. L., & Brun, W. A. (1971). Effect of atmospheric carbon dioxide enrichment at different developmental stages on growth and yield components of soybeans. *Crop Science*, *11*, 886–888. https://doi.org/10.2135/cropsci1971.0011183X001100060037x

Hardy, R. W. F., Burns, R. C., Hebert, R. R., Holsten, R. D., & Jackson, E. K. (1971). Biological nitrogen fixation: A key to world protein. *Plant and Soil*, *35*, 561–590.

Harper, J. E. (1987). Nitrogen metabolism. In J. R. Wilcox (Ed.), *Soybeans: Improvements, production, and uses* (2nd ed., pp. 497–533). ASA, CSSA, and SSSA.

Harper, T. W., Brye, K. R., Daniel, T. C., Slaton, N. A., & Haggard, B. E. (2008). Land use effects on runoff and water quality on an eastern Arkansas soil under simulated rainfall. *Journal of Sustainable Agriculture*, *32*, 231–253. https://doi.org/10.1080/10440040802170806

Harrison, S. K., Williams, C. S., & Wax, L. M. (1985). Interference and control of giant foxtail (*Setaria faberi*) in soybeans (*Glycine max*). *Weed Science*, *33*, 203–208. https://doi.org/10.1017/S0043174500082102

Hartman, G. L., Sinclair, J. B., & Rupe, J. C. (Eds.). (1999). *Compendium of soybean diseases* (4th ed.). American Phytopathological Society.

Hartschuh, J., & Lindsey, L. (2025). *Relay intercropping soybean into winter wheat* (AGF-0504). Ohio State University Extension.

Hartwig, E. E. (1954). *Factors affecting time of planting soybeans in the southern states* (USDA Circular No. 943). U.S. Government Printing Office.

Hartwig, E. E. (1957). Row width and rates of planting in the southern states. *Soybean Digest*, *17*, 13–16.

Hartwig, E. E. (1970). Growth and reproductive characteristics of soybeans [*Glycine max* (L) Merr.] grown under short-day conditions. *Tropical Science*, *12*, 47–53.

Hartwig, E. E., Young, L. D., & Buehring, N. (1987). Effects of monocropping resistant and susceptible soybean cultivars on cyst nematode infested soil. *Crop Science*, *27*, 576–579. https://doi.org/10.2135/cropsci1987.0011183X002700030032x

Harwood, R. R., & Bantilan, R. T. (1974). Integrated weed management: 2. Shifts in composition of the weed community in intensive cropping systems. *Philippine Weed Science Bulletin*, *1*, 37–59.

Heatherly, L. G. (1985). Irrigation management for soybean yield enhancement. In *Proceedings of the 3rd world soybean research conference* (pp. 980–988). Westview Press.

Heatherly, L. G. (1988). Planting date, row spacing, and irrigation effects on soybean grown on clay soil. *Agronomy Journal*, *80*, 227–231. https://doi.org/10.2134/agronj1988.00021962008000020017x

Heatherly, L. G. (1993). Drought stress and irrigation effects on germination of harvested soybean seed. *Crop Science*, *33*, 777–781. https://doi.org/10.2135/cropsci1993.0011183X003300040029x

Heatherly, L. G. (1996). Yield and germinability of seed from irrigated and nonirrigated early- and late-planted MG IV and V soybean. *Crop Science*, *36*, 1000–1006. https://doi.org/10.2135/cropsci1996.0011183X003600040031x

Heatherly, L. G. (1999a). Early soybean production system (ESPS). In L. G. Heatherly & H. F. Hodges (Eds.), *Soybean production in the Mid-South* (pp. 103–118). CRC Press.

Heatherly, L. G. (1999b). Soybean irrigation. In L. G. Heatherly & H. F. Hodges (Eds.), *Soybean production in the Mid-South* (pp. 119–142). CRC Press.

Heatherly, L. G., & Elmore, C. D. (1986). Irrigation and planting date effects on soybean grown on clay soil. *Agronomy Journal*, *78*, 576–580. https://doi.org/10.2134/agronj1986.00021962007800040004x

Heatherly, L. G., Elmore, C. D., Wesley, R. A., & Spurlock, S. R. (1996). Net returns from no-till doublecrop winter wheat and irrigated soybean on a clay soil. *Journal of Production Agriculture*, *9*, 554–558. https://doi.org/10.2134/jpa1996.0554

Heatherly, L. G., & Elmore, R. W. (2004). Managing inputs for peak production. In H. R. Boerma & J. E. Specht (Eds.), *Soybeans: Improvement, production, and uses* (pp. 451–536). ASA, CSSA, and SSSA.

Heatherly, L. G., & Spurlock, S. R. (1999). Yield and economics of traditional and early soybean production system (ESPS) seedings in the midsouthern United States. *Field Crops Research*, *63*, 35–45. https://doi.org/10.1016/S0378-4290(99)00025-8

Heatherly, L. G., Spurlock, S. R., & Elmore, C. D. (2002). Row width and weed management systems for early soybean production system plantings in the midsouthern USA. *Agronomy Journal*, *94*, 1172–1180. https://doi.org/10.2134/agronj2002.1172

Heckman, J. R., & Kamprath, E. J. (1995). Potassium accumulation and soybean yield related to potassium fertilizer rate and placement. *Communications in Soil Science and Plant Analysis*, *26*, 123–143. https://doi.org/10.1080/00103629509369285

Heitholt, J. J., Farr, J. B., & Eason, R. (2005). Planting configuration × cultivar effects on soybean production in low-yield environments. *Crop Science*, *45*, 1800–1808. https://doi.org/10.2135/cropsci2004.0603

Heitholt, J. J., Pettigrew, W. T., & Meredith, W. R. (1992). Light interception and lint yield of narrow-row cotton. *Crop Science*, *32*, 728–733. https://doi.org/10.2135/cropsci1992.0011183X003200030030x

Helgason, B. L., Walley, F. L., & Germida, J. J. (2014). No-till promotes microbial nitrogen cycling in Canadian prairie soils. *Soil Biology and Biochemistry*, *78*, 170–178. https://doi.org/10.1016/j.soilbio.2014.07.017

Hellevang, K. J. (2013). *Grain drying and storage: Managing high-moisture wheat*. North Dakota State University Extension Service.

Herbert, J. J., & Toews, M. D. (2011). Seasonal abundance and population structure of brown stink bug (Hemiptera: Pentatomidae) in farmscapes containing corn, cotton, peanut, and soybean. *Annals of the Entomological Society of America*, *104*, 909–918. https://doi.org/10.1603/AN11060

Herbert, S. J., & Litchfield, G. V. (1984). Growth response of short-season soybean to variations in row spacing and density. *Field Crops Research*, *9*, 163–171. https://doi.org/10.1016/0378-4290(84)90022-4

Herrin, L. L. (1984). *Screening of soybean germplasm for tolerance to phytotoxic substances in wheat straw* [Master's thesis, University of Arkansas].

Hershman, D. E. (2009). *The value of wheat residue in soybean cyst nematode management programs* (PPFS-AG-S-08) [Fact sheet]. University of Kentucky Cooperative Extension Service, University of Kentucky. http://www2.ca.uky.edu/agcollege/plantpathology/ext_files/PPFShtml/PPFS-AG-S-8.pdf

Hershman, D. E. (2011). *2012 soybean cyst nematode (SCN) management recommendations for Kentucky* (PPFS-AG-S-24) [Fact sheet]. University of Kentucky Cooperative Extension Service, University of Kentucky. http://www.ca.uky.edu/agcollege/plantpathology/ext_files/PPFShtml/ppfsags24.pdf

Hershman, D. E., & Bachi, P. R. (1995). Effect of wheat residue and tillage on *Heterodera glycines* and yield of doublecrop soybean in Kentucky. *Plant Disease*, *79*, 631–633.

Hesterman, O. B., & Isleib, T. G. (1991). Response of first-year soybeans to row spacing, inoculation treatments, and nitrogen fertilization. *Journal of Production Agriculture*, *4*, 589–593. https://doi.org/10.2134/jpa1991.0589

Hicks, D. R., Pendleton, J. W., Bernard, R. L., & Johnston, T. J. (1969). Response of soybean plant types to planting patterns. *Agronomy Journal*, *61*, 290–293. https://doi.org/10.2134/agronj1969.00021962006100020034x

Higgins, J. M., Whitwell, T., & Toler, J. E. (1988). Herbicide efficacy for various application times in doublecrop wheat and soybean.

Agronomy Journal, 80, 475–478. https://doi.org/10.2134/agronj1988.00021962008000030017x

Higley, L. G. (1992). New understandings of soybean defoliation and their implication for pest management. In L. G. Copping, M. B. Green, & R. T. Rees (Eds.), *Pest management in soybean* (pp. 56–65). Elsevier Science Publishers.

Hiltbold, A. E., Thurlow, D. L., & Skipper, H. D. (1980). Evaluation of commercial soybean inoculants by various techniques. *Agronomy Journal*, *72*, 675–682. https://doi.org/10.2134/agronj1980.00021962007200040026x

Hodges, H. F., Whisler, F. D., Buckring, N. W., Coats, R. E., McMillan, J., Edwards, N. C., & Hovermade, C. (1983). *The effects of planting date, row spacing and variety on soybean yield in Mississippi* (MAFES Research Bulletins 817). Mississippi Agricultural and Forestry Experiment Station. https://scholarsjunction.msstate.edu/mafes-bulletins/817

Hoeft, R. G., Nafziger, E. D., Johnson, R. R., & Aldrich, S. R. (2000). *Modern corn and soybean production*. R.R. Donnelley and Sons.

Holshouser, D., Eisenback, J., Phipps, P., & Moore, D. (2011). *Soybean nematose management guide*. Virginia Cooperative Extension, Virginia Polytechnic Institute and State University.

Holshouser, D. L. (2014). *Double cropping soybeans in Virginia*. Virginia Cooperative Extension, Virginia Polytechnic Institute and State University.

Holshouser, D. L., Grisso, R. D., & Pitman, R. M. (2006). Uniform stand and narrow rows are needed for higher double-crop soybean yield. *Crop Management*, *5*(1), 1–7. https://doi.org/10.1094/CM-2006-0417-01-RS

Holshouser, D. L., & Jones, B. P. (2003). Early-maturing double-crop soybean requires higher plant populations to meet leaf area requirements. *Crop Management*, *2*(1), 1–5. https://doi.org/10.1094/CM-2003-0408-01-RS

Holshouser, D. L., & Taylor, R. D. (2008). Wheel traffic to narrow-row reproductive-stage soybean lowers yield. *Crop Management*, *7*(1), 1–7. https://doi.org/10.1094/CM-2008-0317-02-RS

Holshouser, D. L., & Whittaker, J. P. (2002). Plant population and row spacing effects on early soybean production systems in the mid-Atlantic USA. *Agronomy Journal*, *94*, 603–611.

Houx, J. H., III, Wiebold, W. J., & Fritschi, F. B. (2011). Long-term tillage and crop rotation determines the mineral nutrient distributions of some elements in a Vertic Epiaqualf. *Soil and Tillage Research*, *112*, 27–35.

Hovermale, C. H., Camper, H. M., & Alexander, M. W. (1979). Effects of small grain stubble height and mulch on no-tillage soybean production. *Agronomy Journal*, *71*, 644–647. https://doi.org/10.2134/agronj1979.00021962007100040030x

Howard, D. D., Chambers, A. Y., & Lessman, G. M. (1998). Rotation and fertilization effects on corn and soybean yields and soybean cyst nematode populations in a no-tillage system. *Agronomy Journal*, *90*, 518–522. https://doi.org/10.2134/agronj1998.00021962009000040013x

Hu, M., & Wiatrak, P. J. (2012). Planting date effects on soybean yield in double-cropping systems. *Agronomy Journal*, *104*(3), 719–726. https://doi.org/10.2134/agronj2011.0405

Hunt, P. G., Wollum, A. G., & Matheny, T. A. (1981). Effects of soil water on Rhizobium japonicum infection, nitrogen accumulation, and yield in Bragg soybeans. *Agronomy Journal*, *73*, 501–505. https://doi.org/10.2134/agronj1981.00021962007300030024x

Hunt, T. E., Higley, L. G., & Witkowski, J. F. (1994). Soybean growth and yield after simulated bean leaf beetle injury to seedlings. *Agronomy Journal*, *86*, 140–146. https://doi.org/10.2134/agronj1994.00021962008600010026x

Huxley, P. A., & Summerfield, R. J. (1974). Effects of night temperature and photoperiod on the reproductive ontogeny of cultivars of cowpea and of soybean selected for the wet tropics. *Plant Science Letters*, *3*, 11–17.

Huxley, P. A., Summerfield, R. J., & Hughes, A. P. (1976). Growth and development of soybean cv. TK5 as affected by tropical daylengths, day/night temperatures and nitrogen nutrition. *Annals of Applied Biology*, *82*, 117–133.

IPNI. (2011). *Nutrient uptake and harvest removal for southern crops*. http://nase.ipni.net/articles/NASE0044-EN

Janovicek, K. J., Deen, W., & Vyn, T. J. (2006). Soybean response to zone tillage, twin-row planting, and row spacing. *Agronomy Journal*, *98*, 800–807. https://doi.org/10.2134/agronj2005.0231

Jeffers, D. L., Schmitthenner, A. F., & Kroetz, M. E. (1982). Potassium fertilization effects on phomopsis seed infection, seed quality, and yield of soybeans. *Agronomy Journal*, *74*, 886–890. https://doi.org/10.2134/agronj1982.00021962007400050028x

Jeffers, D. L., Triplett, G. B., & Beyerlein, J. E. (1973). Management is the key to success double-cropped soybeans. *Ohio Report on Research and Development*, *58*, 67–69.

Johnson, D. R., & Major, D. J. (1979). Harvest index of soybeans as affected by planting date and maturity rating. *Agronomy Journal*, *71*, 538–541. https://doi.org/10.2134/agronj1979.00021962007100040004x

Johnson, H. W., Borthwick, H. A., & Leffel, R. C. (1960). Effects of photoperiod and time of planting on rates of development of the soybean in various stages of the life cycle. *Botanical Gazette*, *122*, 77–95. https://doi.org/10.1086/336090

Johnson, R. R. (1987). Crop Management. In J. R. Wilcox (Ed.), *Soybeans: Improvement, production, and uses* (2nd ed., pp. 355–390). Agronomy monographs 16. ASA, CSSA, and SSSA.

Johnson, W. G., Earl Creech, J., & Mock, V. A. (2008). Role of winter annual weeds as alternative hosts for soybean cyst nematode. *Crop Management*, *7*(1), 1–9. https://doi.org/10.1094/CM-2008-0701-01-RV

Jones, B. P. (2002). *Determination and manipulation of leaf area index to facilitate site-specific management of double-crop soybean in the Mid-Atlantic, USA* [Docoral dissertation, Virginia Tech]. https://doi.org/10.1094/CM-2003-1112-01-RS

Jones, B. P., Holshouser, D. L., Alley, M. M., Roygard, J. K. F., & Anderson-Cook, C. M. (2003). Double-crop soybean leaf area and yield responses to mid-Atlantic soils and cropping systems. *Agronomy Journal*, *95*, 436–445. https://doi.org/10.2134/agronj2003.4360

Jones, G. D., Lutz, J. A., & Smith, T. J. (1977). Effects of phosphorus and potassium on soybean nodules and seed yield. *Agronomy Journal*, *69*, 1003–1006. https://doi.org/10.2134/agronj1977.00021962006900060024x

Jones, P. G., & Laing, D. R. (1978). The effects of phenological and meteorological factors on soybean yield. *Agricultural Meteorology*, *19*, 485–495. https://doi.org/10.1016/0002-1571(78)90045-6

Jordan, D. L., York, A. C., Griffin, J. L., Clay, P. A., Vidrine, P. R., & Reynolds, D. B. (1997). Influence of application variables on efficacy of glyphosate. *Weed Technology*, *11*, 354–362. https://doi.org/10.1017/S0890037X00043062

Joshi, J. M. (1980). Effect of planting dates and soybean cultivars on pod damage by corn earworm. *Crop Science*, *20*, 59–63. https://doi.org/10.2135/cropsci1980.0011183X002000010014x

Kadhem, F. A., Specht, J. E., & Williams, J. H. (1985a). Soybean irrigation serially timed during stages Rl to R6. I. Agronomic responses. *Agronomy Journal*, *77*, 291–298. https://doi.org/10.2134/agronj1985.00021962007700020026x

Kadhem, F. A., Specht, J. E., & Williams, J. H. (1985b). Soybean irrigation serially timed during stages R1 to R6. II. Yield component responses. *Agronomy Journal*, *77*, 299–304. https://doi.org/10.2134/agronj1985.00021962007700020027x

Kahlon, C. S., Board, J. E., & Kang, M. S. (2011). An analysis of yield component changes for new vs. old soybean cultivars. *Agronomy Journal*, *103*, 13–22. https://doi.org/10.2134/agronj2010.0300

Kane, M. V., Steele, C. C., & Grabau, L. J. (1997). Early-maturing soybean cropping system.I. Yield responses to planting date. *Agronomy Journal*, *89*, 454–458. https://doi.org/10.2134/agronj1997.00021962008900030014x

Kantolic, A. G., Peralta, G. E., & Slafer, G. A. (2013). Seed number responses to extended photoperiod and shading during reproductive stages in indeterminate soybean. *European Journal of Agronomy*, *51*, 91–100. https://doi.org/10.1016/j.eja.2013.07.006

Kapusta, G. (1979). Seedbed tillage and herbicide influence on soybean (*Glycine max*) weed control and yield. *Weed Science*, *27*, 520–526. https://doi.org/10.1017/S0043174500044520

Karathanasis, A. D., & Wells, K. L. (1990). Conservation tillage effects on the potassium status of some Kentucky soils. *Soil Science Society of America Journal*, *54*, 800–806. https://doi.org/10.2136/sssaj1990.03615995005400030030x

Karlen, D. L., Berry, E. C., Colvin, T. S., & Kanwar, R. S. (1991). Twelve-year tillage and crop rotation effects on yield and soil chemical properties in northeast Iowa. *Communications in Soil Science and Plant Analysis*, *22*, 1985–2003. https://doi.org/10.1080/00103629109368552

Kelley, K. W. (2003). Double-cropping winter wheat and soybean improves net returns in the eastern Great Plains. *Crop Management*, *2*, 1094–1112.

Kelley, K. W., & Sweeney, D. W. (1998). Effects of wheat-residue management on double-cropped soybean and subsequent crops. *Journal of Production Agriculture*, *11*, 452–456. https://doi.org/10.2134/jpa1998.0452

Kering, M. K., Fultz, S. W., & Hancock, D. W. (2017). Maximizing soybean yield and soil benefits in a wheat-soybean double-crop system. *Field Crops Research*, *204*, 153–161. https://doi.org/10.1016/j.fcr.2016.11.007

Ketcheson, J. W. (1980). Effect of tillage on fertilizer requirements for corn on a silt loam soil. *Agronomy Journal*, *72*, 540–542. https://doi.org/10.2134/agronj1980.00021962007200030031x

Kimber, R. W. L. (1973). Phytotoxicity from plant residues II. The effect of time on rotting of straw from some grasses and legumes on the growth of wheat seedlings. *Plant and Soil*, *38*, 347–361. https://doi.org/10.1007/BF00779018

Kirlies, A. W., Housley, T. L., Emam, A. M., Patterson, F. L., & Okos, M. R. (1982). Effect of preripe harvest and artificial drying on the milling and baking quality of soft red winter wheat. *Crop Science*, *22*, 871–876. https://doi.org/10.2135/cropsci1982.0011183X002200040041x

Knake, E. L., & Slife, F. W. (1962). Competition of *Setaria faberii* with corn and soybeans. *Weeds*, *10*, 26–29. https://doi.org/10.2307/4040555

Koenning, S. R., & Anand, S. C. (1991). Effects of wheat and soybean planting date on *Heterodera glycines* population dynamics and soybean yield with conventional tillage. *Plant Disease*, *75*, 301–303.

Koenning, S. R., Schmitt, D. P., & Barker, K. R. (1993). Effects of cropping systems on population density of *Heterodera glycines* and soybean yield. *Plant Disease*, *77*, 780–787.

Koenning, S. R., Schmitt, D. P., Barker, K. R., & Gumpertz, M. L. (1995). Impact of crop rotation and tillage system on *Heterodera glycines* population density and soybean yield. *Plant Disease*, *79*, 282–286.

Koger, C. H. (2009). *Optimal plant populations/seeding rates for soybean*. Mississippi State University Extension. http://msucares.com/crops/soybeans/seeding09.pdf

Kolar, J. S., & Grewal, H. S. (1994). Effect of split application of potassium on growth, yield and potassium accumulation by soybean. *Fertilizer Research*, *39*, 217–222. https://doi.org/10.1007/BF00750249

Korte, L. L., Specht, J. E., Williams, J. H., & Sorensen, R. C. (1983). Irrigation of soybean genotypes during reproductive ontogeny II. Yield component responses. *Crop Science*, *23*, 528–533. https://doi.org/10.2135/cropsci1983.0011183X002300030020x

Korte, L. L., Williams, J. H., Specht, J. E., & Sorensen, R. C. (1983). Irrigation of soybean genotypes during reproductive ontogeny. I. Agronomic responses. *Crop Science*, *23*, 521–527. https://doi.org/10.2135/cropsci1983.0011183X002300030019x

Kratochvil, R. J., Pearce, J. T., & Harrison, M. R., Jr. (2004). Row-spacing and seeding rate effects on glyphosate-resistant soybean for Mid-Atlantic production systems. *Agronomy Journal*, *96*, 1029–1038. https://doi.org/10.2134/agronj2004.1029

Krausz, R. F., & Young, B. G. (2001). Response of double-crop glyphosate-resistant soybean (*Glycine max*) to broadleaf herbicides. *Weed Technology*, *15*, 300–305. https://doi.org/10.1614/0890-037X(2001)015%5b0300:RODCGR%5d2.0.CO;2

Kumar, S., Yadav, R., Singh, A., Sharma, P., & Verma, R. (2021). The adoption impact of wheat-chickpea double cropping on yield, income, and soil health. *Scientific Reports*, *11*, 12345. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8213906/

Kyei-Boahen, S., & Zhang, L. (2006). Early-maturing soybean in a wheat-soybean double-crop system: Yield and net returns. *Agronomy Journal*, *98*, 295–301. https://doi.org/10.2134/agronj2005.0198

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, *123*(1–2), 1–22. https://doi.org/10.1016/j.geoderma.2004.01.032

Lal, R., & Kimble, J. (1997). Conservation tillage for carbon sequestration. *Nutrient Cycling in Agroecosystems*, *49*, 243–253. https://doi.org/10.1023/A:1009794514742

Lamb, J. A., Rehm, G. W., Severson, R. K., & Cymbaluk, T. E. (1990). Impact of inoculation and use of fertilizer nitrogen on soybean production where growing seasons are short. *Journal of Production Agriculture*, *3*, 241–245. https://doi.org/10.2134/jpa1990.0241

Lambert, D. M., & Lowenberg-Deboer, J. (2003). Economic analysis of row spacing for corn and soybean. *Agronomy Journal*, *95*, 564–573. https://doi.org/10.2134/agronj2003.5640

Langdale, G. W., Barnett, A. P., Leonard, R. A., & Fleming, W. G. (1979). Reduction of soil erosion by the no-till system in the Southern Piedmont. *Transactions of the ASAE*, *22*, 82–92.

Larson, W. E., & Beale, O. W. (1961). *Using crop residues on soils of the humid area* (Farmers Bulletin No. 2155). USDA.

Lawn, R. J., & Brun, W. A. (1974). Symbiotic nitrogen fixation in soybeans. I. Effect of photosynthetic source-sink manipulations. *Crop Science*, *14*, 11–16. https://doi.org/10.2135/cropsci1974.0011183X001400010004x

Lee, C. D. (2006). Reducing row widths to increase yield: Why it does not always work. *Crop Management*, *5*, 1–7. https://doi.org/10.1094/CM-2006-0227-04-RV

Lee, C. D., Egli, D. B., & TeKrony, D. M. (2008). Soybean response to plant population at early and late planting dates in the Mid-South. *Agronomy Journal*, *100*, 971–976. https://doi.org/10.2134/agronj2007.0210

Lee, J., Smith, D. L., & Burras, C. L. (2019). The impact of residue management on soil organic matter in double-crop soybean systems. *Soil & Tillage Research*, *194*, 104322. https://doi.org/10.1016/j.still.2019.104322

Leffel, R. C. (1961). *Planting date and varietal effects on agronomic and seed compositional characters of soybeans* (Bulletin A-117). Maryland Agricultural Experiment Station.

Leffel, R. C., & Barber, G. W. (1961). *Row widths and seeding rates in soybeans* (Bulletin 470). University of Maryland Agricultural Experiment Station.

Leffel, R. C., Cregan, P. B., Bolgiano, A. P., & Thibeau, D. J. (1992). Nitrogen metabolism of normal and high-seed-protein soybean. *Crop Science*, *32*, 747–750. https://doi.org/10.2135/cropsci1992.0011183X003200030034x

Légère, A., & Schreiber, M. M. (1989). Competition and canopy architecture as affected by soybean (*Glycine max*) row width and density of redroot pigweed (*Amaranthus retroflexus*). *Weed Science*, *37*, 84–92. https://doi.org/10.1017/S0043174500055909

Lehman, W. F., & Lambert, J. W. (1960). Effects of spacing on soybean plants between and within rows on yield and its components. *Agronomy Journal*, *52*, 84–86. https://doi.org/10.2134/agronj1960.00021962005200020008x

LeMahieu, P. J., & Brinkman, M. A. (1990). Double-cropping soybean after harvesting small grains as forage in the north central USA. *Journal of Production Agriculture*, *3*, 385–389. https://doi.org/10.2134/jpa1990.0385

Levy, C. (2005). Epidemiology and chemical control of soybean rust in southern Africa. *Plant Disease*, *89*, 669–674. https://doi.org/10.1094/PD-89-0669

Lewis, W. M. (1972). No tillage production systems for double-cropping, and for cotton and other crops. In *Proceedings, no-tillage systems symposium* (pp. 146–152). The Ohio State University.

Lewis, W. M. (1985). Weed control in reduced-tillage soybean production. In A. F. Wiese (Ed.), *Weed control in limited-tillage systems* (pp. 41–50). Weed Science Society of America.

Li, X., & Yang, X. B. (2009). Similarity, pattern, and grouping of soybean fungal diseases in the United States: Implications for the risk of soybean rust. *Plant Disease*, *93*, 162–169. https://doi.org/10.1094/PDIS-93-2-0162

Liebl, R. A., & Worsham, A. D. (1983). Tillage and mulch effects on morningglory (*Ipomoea* spp.) and certain other weed species. In *Proceedings, southern weed science society, 36th annual meeting* (pp. 405–414). Southern Weed Society.

Liebman, M., & Davis, A. S. (2000). Integration of soil, crop and weed management in low-external-input farming systems. *Weed Res*, *40*, 27–48. https://doi.org/10.1046/j.1365-3180.2000.00164.x

Lindsey, L., & Richer, E. (2021). Double-crop soybean recommendations. *Ohio's Country Journal*. https://ocj.com/2021/06/double-crop-soybean-recommendations/

Lindsey, L. E., Sherwin, J., & Brown, C. (2023). Economic and agronomic evaluation of soybean double-cropping systems in the United States. *Crop, Forage & Turfgrass Management*, *9*(1), e20208. https://doi.org/10.1002/cft2.20208

Liu, B., Liu, X., Wang, C., Jin, J., Herbert, S. J., & Hashemi, M. (2010). Responses of soybean yield and yield components to light enrichment and planting density. *International Journal of Plant Production*, *4*, 1–10.

Locke, M. A., Zablotowicz, R. M., Steinriede, R. W., & Dabney, S. M. (2002). Conservation management practices in Mississippi delta agriculture: Implications for crop production and environmental quality. In E. van Santen (Ed.), *Making conservation tillage conventional: Building a future on 25 years of research. Proceedings of 25 annual southern conservation tillage conference for sustainable agriculture* (pp. 320–326). Alabama Agricultural Experiment Station and Auburn University.

Lofton, J., Harris, C., Zander, A., & Leonard, K. (2020). *Management strategies for double-crop soybean* (PSS-2197). Oklahoma Cooperative Extension Service.

Long, J. H., Jr., & Todd, T. C. (2001). Effect of crop rotation and cultivar resistance on seed yield and the soybean cyst nematode in full-season and double-cropped soybean. *Crop Science*, *41*, 1137–1143. https://doi.org/10.2135/cropsci2001.4141137x

Lueschen, W. E., Ford, J. H., Evans, S. D., Kanne, B. K., Hoverstad, T. R., Randall, G. W., Orf, J. H., & Hicks, D. R. (1992). Tillage, row spacing, and planting date effects on soybean following corn or wheat. *Journal of Production Agriculture*, *5*, 254–260. https://doi.org/10.2134/jpa1992.0254

Lueschen, W. E., & Hicks, D. R. (1977). Influence of plant population on field performance of three soybean cultivars. *Agronomy Journal*, *69*, 390–393. https://doi.org/10.2134/agronj1977.00021962006900030015x

Lutz, J. A., Jr., & Jones, G. D. (1975). Effect of irrigation, lime, and fertility treatments on the yield and chemical composition of soybeans. *Agronomy Journal*, *67*, 523–526. https://doi.org/10.2134/agronj1975.00021962006700040017x

Ma, B. L., Dwyer, L. M., Costa, C., Cober, E. R., & Morrison, M. J. (2001). Early prediction of soybean yield from canopy reflectance measurements. *Agronomy Journal*, *93*, 1227–1234. https://doi.org/10.2134/agronj2001.1227

Mackay, A. D., Kladivko, E. J., Barber, S. A., & Griffith, D. R. (1987). Phosphorus and potassium uptake by corn in conservation tillage systems. *Soil Science Society of America Journal*, *51*, 970–974. https://doi.org/10.2136/sssaj1987.03615995005100040027x

Magdoff, F., & van Es, H. (2000). *Building soil for better crops* (2nd ed.). Sustainable Agriculture Network.

Magdoff, F., & Weil, R. R. (2004a). Soil organic matter management strategies. In F. Magdoff & R. R. Weil (Eds.), *Soil organic matter in sustainable agriculture* (pp. 45–66). CRC Press.

Magdoff, F., & Weil, R. R. (2004b). Significance of soil organic matter to soil quality and health. In F. Magdoff & R. R. Weil (Eds.), *Soil organic matter in sustainable agriculture* (pp. 1–59). CRC press.

Mahler, R. L., & Wollum, A. G. (1981). The influence of irrigation and *Rhizobium japonicum* strains on yields of soybeans grown in a Lakeland sand. *Agronomy Journal*, *73*, 647–651. https://doi.org/10.2134/agronj1981.00021962007300040019x

Malcom, K. W. (1980). *Tillage, planting equipment, row spacing and plant population effects on yields in a wheat – soybean double cropping system* [Master's thesis, Oklahoma State University].

Mallarino, A. P., Barcos, S. R., Prater, J. R., & Wittry, D. J. (2009). Timing of broadcast phosphorus fertilization for no-till corn and soybean. *Soil Science Society of America Journal*, *73*, 2143–2150. https://doi.org/10.2136/sssaj2008.0383

Mallarino, A. P., & Borges, R. (2006). Phosphorus and potassium distribution in soil following long-term deep band fertilization in different tillage systems. *Soil Science Society of America Journal*, *70*, 702–707. https://doi.org/10.2136/sssaj2005.0129

Mallarino, A. P., Webb, J. R., & Blackmer, A. M. (1991). Soil test values and grain yields during 14 years of potassium fertilization of corn and soybean. *Journal of Production Agriculture*, *4*, 560–567. https://doi.org/10.2134/jpa1991.0560

Malone, S., Ames Herbert, D., & Holshouser, D. L. (2002). Relationship between leaf area index and yield in double-crop and full-season soybean systems. *Journal of Economic Entomology*, *95*, 945–951. https://doi.org/10.1093/jee/95.5.945

Mancuso, N., & Caviness, C. E. (1991). Association of selected plant traits with lodging of four determinate soybean cultivars. *Crop Science*, *31*, 911–914. https://doi.org/10.2135/cropsci1991.0011183X003100040014x

Mannering, J. V., & Meyer, L. D. (1963). The effects of various rates of surface mulch on infiltration and erosion. *Soil Science Society of America Journal*, *27*, 84–86. https://doi.org/10.2136/sssaj1963.03615995002700010029x

Martin, M. A. (1985). *Inheritance of tolerance in soybean to phytotoxic residues of wheat* [Master's thesis, University of Arkansas].

MASS. (2004). *Maryland grain & livestock report*. Maryland Agricultural Statistics Service. http://www.nass.usda.gov/md/xf&g2926.pdf

Mastrodomenico, A. T., & Purcell, L. C. (2012). Soybean nitrogen fixation and nitrogen remobilization during reproductive development. *Crop Science*, *52*, 1281–1289. https://doi.org/10.2135/cropsci2011.08.0414

Matson, A. L. (1964). Some factors affecting the yield response of soybeans to irrigation. *Agronomy Journal*, *56*, 552–555. https://doi.org/10.2134/agronj1964.00021962005600060009x

Mauchline, T. H., Kerry, B. R., & Hirsch, P. R. (2013). Distribution and diversity of Pochonia chlamydosporia associated with plant-parasitic nematodes. *Journal of Nematology*, *45*(2), 86–93. https://doi.org/10.21307/jofnem-2017-040

Mbuthia, L. W., Acosta-Martínez, V., DeBruyn, J., Schaeffer, S., Tyler, D., & Odoi, E. (2015). Long-term tillage, cover crop, and fertilization effects on microbial community structure, activity, and abundance in sandy loam soils. *Soil and Tillage Research*, *149*, 79–89. https://doi.org/10.1016/j.still.2014.12.003

McAvoy, T. J. (1977). *The effect of hand defoliation on several agronomic characteristics of soybean,* Glycine max *(L.) Merrill, and the development of an economic injury level for the Mexican bean beetle,* Epilachna varivestis *Mulsant, on soybean* [Master's thesis, Virginia Polytechnic Institute and State University].

McCauley, G. N. (1981). Water management for soybeans in the Texas Coastal Prairie. In *Soybeans on the Texas Coastal Prairie* (Vol. RM-11, pp. 31–36). Texas Agricultural Experiment Station.

McGee, D. C. (1992). *Soybean diseases: A reference source for seed technologists*. American Phytopathological Society.

McGregor, K. C., Cullum, R. F., Mutchler, C. K., & Johnson, J. R. (2006). *Long-term no-till and conventional-till soybean yields (1983-1999)* (Bulletin 1146). Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

McGregor, K. C., Greer, J. D., & Gurley, G. E. (1975). Erosion control with no-till cropping practices. *Transactions of the ASAE*, *18*, 918–920.

McHarry, M. J., & Kapuśta, G. (1979). Herbicide applications in tillered winter wheat for doublecrop soybean weed control. *Agronomy Journal*, *71*, 1051–1055. https://doi.org/10.2134/agronj1979.00021962007100060037x

McKibben, G. E., & Oldham, M. G. (1973). Double cropping soybeans in small grain stubble. *Illinois Research*, *15*, 10–11.

Meckel, L., Egli, D. B., Phillips, R. E., Radcliffe, D., & Leggett, J. E. (1984). Effect of moisture stress on seed growth in soybeans. *Agronomy Journal*, *76*, 647–650. https://doi.org/10.2134/agronj1984.00021962007600040033x

Mederski, H. J., & Jeffers, D. L. (1973). Yield response of soybean varieties grown at two soil moisture stress levels. *Agronomy Journal*, *65*, 410–412. https://doi.org/10.2134/agronj1973.00021962006500030017x

Mederski, H. J., Jeffers, D. L., & Peters, D. B. (1973). Water and water relations. In B. E. Caldwell (Ed.), *Soybeans: Improvement, production, and uses* (pp. 239–266). Agronomy monographs 16. ASA.

Mehl, H. L., & Phipps, P. M. (2013). *Applied research on field crop disease control* (Ext. Pub. AREC-76). Virginia Cooperative Extension. http://pubs.ext.vt.edu/AREC/AREC-76/AREC-76.html

Mickelson, J. A., & Renner, K. A. (1997). Weed control using reduced rates of postemergence herbicides in narrow and wide row soybean. *Journal of Production Agriculture*, *10*, 431–437. https://doi.org/10.2134/jpa1997.0431

Miles, M. R., Levy, C., Morel, W., Mueller, T., Steinlage, T., van Rij, N., Frederick, R. D., & Hartman, G. L. (2007). International fungicide efficacy trials for the management of soybean rust. *Plant Disease*, *91*, 1450–1458. https://doi.org/10.1094/PDIS-91-11-1450

Miller, R. J., & Beard, B. H. (1967). Effects of irrigation management on chemical composition of soybeans in the San Joaquin Valley. *California Agriculture*, *21*, 8–10.

Mills, H. A., & Jones, J. B., Jr. (1996). *Plant analysis handbook II*. MicroMacro Publishing.

Minor, H. C., & Wiebold, W. J. (1998). *Wheat – soybean double-crop management in Missouri* (G 4953). University of Missouri Extension Publication.

Momen, N. N., Carlson, R. E., Shaw, R. H., & Arjmand, O. (1979). Moisture-stress effects on the yield components of two soybean cultivars. *Agronomy Journal*, *71*, 86–90. https://doi.org/10.2134/agronj1979.00021962007100010022x

Moncrief, J. F., & Schulte, E. E. (1982). *Fertilizer placement in tillage systems-Wisconsin* [Conference presentation]. Proceedings of the 34th Annual Fertilizer and Agricultural Chemical Dealers Conference, Des Moines, IA, United States.

Monks, C. D., Wilcut, J. W., & Richburg, J. S. (1993). Broadleaf weed control in soybean (*Glycine max*) with chlorimuron plus acifluorfen or thifensulfuron mixtures. *Weed Technology*, *7*, 317–321. https://doi.org/10.1017/S0890037X00027652

Moomaw, R. S., & Powell, T. A. (1990). Multiple cropping systems in small grains in northeast Nebraska. *Journal of Production Agriculture*, *3*, 569–576. https://doi.org/10.2134/jpa1990.0569

Moraghan, B. J. (1970). *Plant characters related to yield responses of unselected lines in various row widths and plant populations* [Doctoral dissertation, Iowa State University].

Morandi, E. N., Casano, L. M., & Reggiardo, L. M. (1988). Post-flowering photoperiodic effect on reproductive efficiency and seed growth in soybean. *Field Crops Research*, *18*, 227–241. https://doi.org/10.1016/0378-4290(88)90017-2

Morell, F. J., Cantero-Martínez, C., Lampurlanés, J., Plaza-Bonilla, D., & Álvaro-Fuentes, J. (2011). Soil carbon dioxide flux and organic carbon content: Effects of tillage and nitrogen fertilization. *Soil Science Society of America Journal*, *75*, 1874–1884. https://doi.org/10.2136/sssaj2011.0030

Morris, T. C., Vann, R. A., Heitman, J., Collins, G. D., & Heiniger, R. W. (2021). Maximizing soybean yield by understanding planting date, maturity group, and seeding rate interactions in North Carolina. *Crop Science*, *61*(1), 152–166. https://doi.org/10.1002/csc2.20603

Morrison, W. C., & Rabb, J. L. (1996). Doublecropping with soybean. In W. C. Morrison (Ed.), *Louisiana soybean handbook* (pp. 100–103). Louisiana Cooperative Extension Service.

Mourtzinis, S., & Conley, S. P. (2017). Delayed planting and soybean yield: A meta-analysis of historical U.S. data. *Agronomy Journal*, *109*(2), 455–463. https://doi.org/10.2134/agronj2016.09.0532

Mourtzinis, S., & Conley, S. P. (2023). Corn and soybean planting order decisions impact farm gross revenue. *Crop, Forage & Turfgrass Management*, *9*(1), e20242. https://doi.org/10.1002/cft2.20242

Mourtzinis, S., Gaspar, A. P., Naeve, S. L., & Conley, S. P. (2017). Planting date, maturity, and temperature effects on soybean seed yield and composition. *Agronomy Journal*, *109*(5), 2040–2049. https://doi.org/10.2134/agronj2017.03.0142<./bib>

Mourtzinis, S., Gaspar, A. P., Naeve, S. L., & Conley, S. P. (2019). Soybean planting date: A U.S. perspective. *Frontiers in Plant Science*, *10*, Article 1642. https://doi.org/10.3389/fpls.2019.01642

MTD. (2010). *Biology and management of soybean cyst nematode*. Monsanto. http://www.merschmanseeds.com/pdfs/resources/agronomy/agronomic-spotlight-biology-and-management-of-soybean-cyst-nematode.pdf

Mueller, D. S., Dorrance, A. E., Derksen, R. C., Ozkan, H. E., Kurle, J. E., Grau, C. R., Gaska, J. M., Hartman, G. L., Bradley, C. A., & Bradley, C. A. (2004). Efficacy of fungicide applications during flowering to reduce Sclerotinia stem rot of soybean. *Plant Disease*, *88*(6), 675–682. https://doi.org/10.1094/PDIS.2004.88.6.675

Mueller, T. A., Bradley, C. A., Chesrown, C. D., Kemerait, R. C., Wright, D. L., Marois, J. J., Miles, M. R., & Hartman, G. L. (2006). *Evaluation of fungicides and fungicide timing for the management of Phakospora pachyrhizi in the United States* [Conference presentation]. Proceedings of the 2006 National Soybean Rust Symposium, St. Louis, MO, United States. http://www.plantmanagementnetwork.org/infocenter/topic/soybeanrust/2006

Mueller, T. A., Miles, M. R., Morel, W., Marois, J. J., Wright, D. L., Kemerait, R. C., Levy, C., & Hartman, G. L. (2009). Effect of fungicide and timing of application on soybean rust severity and yield. *Plant Disease*, *93*, 243–248.

Murphy, J. D., Johnson, D. W., Miller, W. W., Walker, R. F., Carroll, E. F., & Blank, R. R. (2006). Wildfire effect on soil nutrients and leaching in Tahore basin watershed. *Journal of Environmental Quality*, *35*, 479–489. https://doi.org/10.2134/jeq2005.0144

Nagata, T. (1960). Morphological, physiological, and genetic aspects of the summer versus autumn soybean habit, the plant habit, and the interrelation between them in soybeans. *Science Reports of the Hyogo University of Agriculture*, *4*, 71–95.

Neeser, C., Aguero, R., & Swanton, C. J. (1997). Incident photosynthetically active radiation as a basis for integrated management of purple nutsedge (*Cyperus rotundus*). *Weed Science*, *45*, 777–783. https://doi.org/10.1017/S0043174500088962

Nelson, A. N., & Weaver, R. W. (1980). Seasonal nitrogen accumulation and fixation by soybeans grown at different densities. *Agronomy Journal*, *72*, 613–616. https://doi.org/10.2134/agronj1980.00021962007200040010x

Nelson, D. R., Bellville, R. J., & Porter, C. A. (1983). Role of nitrogen assimilation in seed development of soybean. *Plant Physiology*, *74*, 128–133. https://doi.org/10.1104/pp.74.1.128

Nelson, K. A., Massey, R. E., & Burdick, B. A. (2011). Harvest aid application timing affects wheat and relay intercropped soybean yield. *Agronomy Journal*, *103*, 851–855. https://doi.org/10.2134/agronj2010.0384

Nelson, K. A., Motavalli, P. P., & Nathan, M. (2005). Response of no-till soybean [*Glycine max* (L.) Merr.] to timing of preplant and foliar potassium applications in a claypan soil. *Agronomy Journal*, *97*, 832–838. https://doi.org/10.2134/agronj2004.0241

Nelson, K. A., Motavalli, P. P., Stevens, W. E., Dunn, D., & Meinhardt, C. G. (2010). Soybean response to preplant and foliar-applied potassium chloride with strobilurin fungicides. *Agronomy Journal*, *102*, 1657–1663. https://doi.org/10.2134/agronj2010.0065

Nelson, K. A., & Renner, K. A. (1998). Weed control in wide-and narrow-row soybean (*Glycine max*) with imazamox, imazethapyr, and CGA-277476 plus quizalofop. *Weed Technology*, *12*, 137–144. https://doi.org/10.1017/S0890037X00042706

Nelson, K. A., & Renner, K. A. (1999). Weed management in wide- and narrow-row glyphosate resistant soybean. *Journal of Production Agriculture*, *12*, 460–465. https://doi.org/10.2134/jpa1999.0460

Nelson, L. R., Gallaher, R. N., Holmes, M. R., & Bruce, R. R. (1977). Corn forage production in no-till and conventional tillage double-cropping systems. *Agronomy Journal*, *69*, 635–638. https://doi.org/10.2134/agronj1977.00021962006900040029x

NeSmith, D. S., Hargrove, W. L., Radcliffe, D. E., Tollner, E. W., & Arioglu, H. H. (1987). Tillage and residue management effects on properties of an Ultisol and double-cropped soybean production. *Agronomy Journal*, *79*, 570–576. https://doi.org/10.2134/agronj1987.00021962007900030034x

Nielson, D. C., Aiken, R. M., & MsMaster, G. S. (2003). *Optimum wheat stubble height to reduce erosion and evaporation* [Conservation tillage fact sheet 4-97]. USDA ARS, NRCS and Colorado Conservation Tillage Association.

Nolting, S. P., & Richard Edwards, C. (1989). Yield response of soybean to defoliation by the Mexican bean beetle (Coleoptera: Coccinellidae). *Journal of Economic Entomology*, *82*, 1212–1218. https://doi.org/10.1093/jee/82.4.1212

Noor, R. B. M. (1973). *Effect of date of planting and row spacing on yield and other agronomic characteristics of three varieties of soybeans* [Doctoral dissertation, Louisiana State University].

Noor, R. B. M., & Caviness, C. E. (1980). Influence of induced lodging on pod distribution and seed yield in soybeans. *Agronomy Journal*, *72*, 904–906. https://doi.org/10.2134/agronj1980.00021962007200060010x

Norstadt, F. A., & McCalla, T. M. (1968). Microbially induced phytotoxicity in stubble-mulched soil. *Soil Science Society of America, Proceedings*, *32*, 241–245. https://doi.org/10.2136/sssaj1968.03615995003200020024x

Norsworthy, J. K., & Frederick, J. R. (2002). Reduced seeding rate for glyphosate-resistant, drilled soybean on the southeastern coastal plain. *Agronomy Journal*, *94*, 1282–1288. https://doi.org/10.2134/agronj2002.1282

Okoli, P. S. O., Drolsom, P. N., & Scholl, J. M. (1984). Forage production and weed control in a double-cropping program. *Agronomy Journal*, *76*, 363–366. https://doi.org/10.2134/agronj1984.00021962007600030003x

Onstad, C. A., & Otterby, M. A. (1979). Crop residue effects on runoff. *Journal of Soil and Water Conservation*, *34*, 94–96.

Oplinger, E. S., & Philbrook, B. D. (1992). Soybean planting date, row width, and seeding rate response in three tillage systems. *Journal of Production Agriculture*, *5*, 94–99. https://doi.org/10.2134/jpa1992.0094

Oriade, C. A., Dillon, C. R., Vories, E. D., & Bohanan, M. E. (1997). An economic analysis of alternative cropping and row spacing systems for soybean production. *Journal of Production Agriculture*, *10*, 619–624. https://doi.org/10.2134/jpa1997.0619

Osler, R. D., & Cartter, J. L. (1954). Effect of planting date on chemical composition and growth characteristics of soybeans. *Agronomy Journal*, *46*, 267–270. https://doi.org/10.2134/agronj1954.00021962004600060007x

Ostlie, K. R. (1984). *Soybean transpiration, vegetative morphology, and yield components following simulated and actual insect defoliation* [Doctoral dissertation, Iowa State University].

Ouattara, S., & Weaver, D. B. (1994). Effect of growth habit on yield and agronomic characteristics of late-planted soybean. *Crop Science*, *34*, 870–873. https://doi.org/10.2135/cropsci1994.0011183X003400040008x

Ouattara, S., & Weaver, D. B. (1995). Effect of growth habit on yield components of late-planted soybean. *Crop Science*, *35*, 411–415. https://doi.org/10.2135/cropsci1995.0011183X003500020022x

Padgett, G. B., Purvis, M. A., Hogan, A., Martin, S., & Hollier, C. A. (2006). *Fungicide evaluations for managing Asian soybean rust and other diseases affecting Louisiana soybean* [Conference presentation]. Proceedings of the 2006 National Soybean Rust Symposium, St. Louis, MO, United States. http://www.plantmanagementnetwork.org/infocenter/topic/soybeanrust/2006

Padgitt, M., Newton, D., Penn, R., & Sadretto, C. (2000). *Production practices for major crops in U. S. Agriculture, 1990-1997* (Statistical Bulletin No. SB969). Economic Research Service (ERS)/United States Department of Agriculture (USDA). http://www.esr.usda.gov/publications/sb969/sb969f.pdf

Parker, M. B., & Boswell, F. C. (1980). Foliage injury, nutrient intake, and yield of soybeans as influenced by foliar fertilization. *Agronomy Journal*, *72*, 110–113. https://doi.org/10.2134/agronj1980.00021962007200010022x

Parker, M. B., Marchant, W. H., & Mullinix, B. J. (1981). Date of planting and row spacing effects on four soybean cultivars. *Agronomy Journal*, *73*, 759–762. https://doi.org/10.2134/agronj1981.00021962007300050003x

Parks, W. L., Davis, J., Evans, R., Smith, M., McCutchen, T., Sofley, L., & Sanders, W. (1982). *Soybean yields as affected by row spacing and within row plant density* (Bull. Vol. 615). University of Tennessee Agricultural Experiment Station.

Parsch, L. D., Keisling, T. C., Sauer, P. A., Oliver, L. R., & Crabtree, N. S. (2001). Economic analysis of conservation and conventional tillage cropping systems on clayey soil in eastern Arkansas. *Agronomy Journal*, *93*, 1296–1304. https://doi.org/10.2134/agronj2001.1296

Parvej, M. R., Holshouser, D. L., Kratochvil, R. J., Whaley, C., Dunphy, J., Roth, G. W., & Faé, G. S. (2020a). Early high-moisture wheat harvest improves double-cropping system: I. Wheat yield and quality. *Crop Science*, *2020*, 2633–2649. https://doi.org/10.1002/csc2.20172

Parvej, M. R., Holshouser, D. L., Kratochvil, R. J., Whaley, C., Dunphy, J., Roth, G. W., & Faé, G. S. (2020b). Early high-moisture wheat harvest improves double-cropping system: II. Soybean growth and yield. *Crop Science*, *2020*, 2650–2666. https://doi.org/10.1002/csc2.20174

Parvej, M. R., Slaton, N. A., Purcell, L. C., & Roberts, T. L. (2015). Potassium fertility effects yield components and seed potassium concentration of determinate and indeterminate soybean. *Agronomy Journal*, *107*, 943–950. https://doi.org/10.2134/agronj14.0464

Parvej, M. R., Slaton, N. A., Purcell, L. C., & Roberts, T. L. (2016). Critical trifoliolate leaf and petiole potassium concentrations during the reproductive stages of soybean. *Agronomy Journal*, *108*, 2502–2518. https://doi.org/10.2134/agronj2016.04.0234

Parvej, M. R., Williams, A. S., Holshouser, D. L., Frame, W. H., & Reiter, M. S. (2018). Double-crop soybean response to potassium on Mid-Atlantic coastal plain and piedmont soils. *Agronomy Journal*, *110*, 399–410. https://doi.org/10.2134/agronj2017.07.0397

Parvez, A. Q., Gardner, F. P., & Boote, K. J. (1989). Determinate-and indeterminate-type soybean cultivar responses to pattern, density, and planting date. *Crop Science*, *29*, 150–157. https://doi.org/10.2135/cropsci1989.0011183X002900010034x

Pataky, J. K. (1981). Efficacy of benomyl for controlling Septoria brown spot of soybeans. *Phytopathology*, *71*, 438–442. https://doi.org/10.1094/Phyto-71-438

Patrick, Z. A., Toussoun, T. A., & Koch, L. W. (1964). Effect of crop-residue decomposition products on plant roots. *Annual Review of Phytopathology*, *2*, 267–292. https://doi.org/10.1146/annurev.py.02.090164.001411

Patterson, M. G., Walker, R. H., Colvin, D. L., Wehtje, G., & McGuire, J. A. (1988). Comparison of soybean (*Glycine max*)-weed interference from large and small plots. *Weed Science*, *36*, 836–839. https://doi.org/10.1017/S0043174500075925

Patterson, T. G., & LaRue, T. A. (1983). Nitrogen fixation by soybean: Seasonal and cultivar effects and comparisons of estimates. *Crop Science*, *23*, 488–492. https://doi.org/10.2135/cropsci1983.0011183X002300030012x

Paulsen, M. R., & Hill, L. D. (2005). Corn quality factors affecting dry milling performance. *Cereal Foods World*, *50*(1), 23–29.

Payne, S. A., & Oliver, L. R. (2000). Weed control programs in drilled glyphosate-resistant soybean. *Weed Technology*, *14*, 413–422. https://doi.org/10.1614/0890-037X(2000)014%5b0413:WCPIDG%5d2.0.CO;2

Pearce, J. T. (2005). *Double-cropped soybean response to various wheat stubble managements* [Master's thesis, University of Maryland].

Pearce, R. C., Grabau, L. J., Grove, J. H., & Lin, H. (1993). Development of double-crop soybean under different soil water regimes. *Agronomy Journal*, *85*, 576–583. https://doi.org/10.2134/agronj1993.00021962008500030011x

Pedersen, P. (2004). Do we really need to inoculate our fields? In *Proceedings of the 2004 integrated crop management conference* (pp. 23–25). Iowa State University.

Pedersen, P., & Lauer, J. G. (2004). Response of soybean yield components to management system and planting date. *Agronomy Journal*, *96*, 1372–1381. https://doi.org/10.2134/agronj2004.1372

Pedersen, P., Tylka, G. L., & Mallarino, A. P. (2010). Crop rotation effect on soybean cyst nematode population densities and soybean yield. *Agronomy Journal*, *102*(5), 1488–1496. https://doi.org/10.2134/agronj2010.0125

Pendleton, J. W., Bernard, R. L., & Hadley, H. (1960). Grow soybeans in narrow rows. *Illinois Research*, *2*, 3–4.

Pendleton, J. W., & Hartwig, E. E. (1973). Management. In B. E. Caldwell (Ed.), *Soybeans: Improvement, production, and uses* (pp. 211–237). ASA.

Peters, E. J., Gebhardt, M. R., & Stritzke, J. F. (1965). Interrelations of row spacings, cultivations and herbicides for weed control in soybeans. *Weeds*, *13*, 285–289. https://doi.org/10.2307/4040876

Peterson, T. A., & Varvel, G. E. (1989). Crop yield as affected by rotation and nitrogen rate in soybean. *Agronomy Journal*, *81*, 727–731. https://doi.org/10.2134/agronj1989.00021962008100050005x

Phipps, P. M., Stromberg, E. L., Rideout, S., Holshouser, D., Pitman, R., Clarke, T., Lawrence, W., Moore, D., & Balderson, K. (2010). *Soybean rust incidence and the response of soybeans to fungicides in 2009* (Publ. 3012-1520). Virginia Polytechnic Institute and State University, Virginia Cooperative Extension.

Phipps, P. M., & Telenko, D. E. P. (2011). *Applied research on field crop disease control* (Publ. AREC-12). Virginia Polytechnic Institute and State University, Virginia Cooperative Extension.

Pikul, J., & Zuzel, J. (1994). Soil crusting and water infiltration affected by long-term tillage and residue management. *Soil Science Society of America Journal*, *58*, 1524–1530. https://doi.org/10.2136/sssaj1994.03615995005800050036x

Pikul, J. L., Schumacher, T. E., & Vigil, M. (2001). Nitrogen use and carbon sequestered by corn rotations in the northern corn belt, US. *The Scientific World Journal*, *1*, 707–713. https://doi.org/10.1100/tsw.2001.90

Pires, J. L. F., Costa, J. A., Thomas, A. L., & Maehler, A. R. (2000). Effect of population and spacing on soybean potential yield during ontogeny. *Pesquisa Agropecuaria Brasileira*, *35*, 1541–1547. https://doi.org/10.1590/S0100-204X2000000800006

Pittelkow, C. M., Linquist, B. A., Lundy, M. E., Liang, X., van Groenigen, K. J., Lee, J., van Gestel, N., Six, J., Venterea, R. T., & van Kessel, C. (2015). When does no-till yield more? A global meta-analysis. *Field Crops Research*, *183*, 156–168. https://doi.org/10.1016/j.fcr.2015.07.020

Popp, M. P., Edwards, J. T., Purcell, L. C., & Manning, P. M. (2006). Profit-maximizing seeding rates and replanting thresholds for soybean: Maturity group interactions in the Mid-South. *Agricultural Systems*, *91*, 211–228. https://doi.org/10.1016/j.agsy.2006.02.011

Popp, M. P., Keisling, T. C., McNew, R. W., Oliver, L. R., Dillon, C. R., & Wallace, D. M. (2002). Planting date, cultivar, and tillage system effects on dryland soybean production. *Agronomy Journal*, *94*, 81–88. https://doi.org/10.2134/agronj2002.8100

Popp, M. P., Oliver, L. R., Dillon, C. R., Keisling, T. C., & Manning, P. M. (2000). Evaluation of seedbed preparation, planting method, and herbicide alternatives for dryland soybean production. *Agronomy Journal*, *92*, 1149–1155. https://doi.org/10.2134/agronj2000.9261149x

Porter, P. M. (1993). Canola response to boron and nitrogen grown on the southeastern Coastal Plain. *Journal of Plant Nutrition*, *16*, 2371–2381. https://doi.org/10.1080/01904169309364694

Porter, P. M. (1995). Doublecropping soybean after canola and wheat. *Journal of Production Agriculture*, *8*, 222–226. https://doi.org/10.2134/jpa1995.0222

Poston, F. L., & Pedigo, L. P. (1976). Simulation of painted lady and green cloverworm damage to soybean. *Journal of Economic Entomology*, *69*, 423–426. https://doi.org/10.1093/jee/69.4.423

Prasad, R., Gangaiah, B., & Aipe, K. C. (1999). Effect of crop residue management in a rice–wheat cropping system on growth and yield of crops and on soil fertility. *Experimental Agriculture*, *35*, 427–435. https://doi.org/10.1017/S001447979935403X

Proulx, R. A., & Naeve, S. L. (2009). Pod removal, shade, and defoliation effects on soybean yield, protein, and oil. *Agronomy Journal*, *101*, 971–978. https://doi.org/10.2134/agronj2008.0222x

Purcell, L. C. (2014). *Nitrogen nutrition in soybean – fertilization, fixation, and a paradox* [Conference presentation]. Symposium—Does soybean require additional nitrogen to maximize yield. ASA/CSSA/SSSA Annual Meeting, Long Beach, CA, United States.

Purcell, L. C., Ball, R. A., Reaper, J. D., & Vories, E. D. (2002). Radiation use efficiency and biomass production in soybean at different plant population densities. *Crop Science*, *42*, 172–177. https://doi.org/10.2135/cropsci2002.1720

Purcell, L. C., & King, A. C. (1996). Drought and nitrogen source effects on nitrogen nutrition, seed growth, and yield in soybean. *Journal of Plant Nutrition*, *19*, 969–993. https://doi.org/10.1080/01904169609365173

Purcell, L. C., Sinclair, T. R., & McNew, R. W. (2003). Drought avoidance assessment for summer annual crops using long-term weather data. *Agronomy Journal*, *95*, 1566–1576. https://doi.org/10.2134/agronj2003.1566

Rahman, M. M., Hampton, J. G., & Hill, M. J. (2005). The effect of time of sowing on soybean seed quality. *Seed Science and Technology*, *33*, 687–697. https://doi.org/10.15258/sst.2005.33.3.16

Ramseur, E. L., Quisenberry, V. L., Wallace, S. U., & Palmer, J. H. (1984). Yield and yield components of 'Braxton'soybeans as influenced by irrigation and intrarow spacing. *Agronomy Journal*, *76*, 442–446. https://doi.org/10.2134/agronj1984.00021962007600030017x

Randall, G. W., Evans, S. D., & Iragavarapu, T. K. (1997). Long-term P and K applications: II. Effect on corn and soybean yields and plant P and K concentrations. *Journal of Production Agriculture*, *10*, 572–580. https://doi.org/10.2134/jpa1997.0572

Rasmussen, P. E., Allmaras, R. R., Rohde, C. R., & Roager, N. C. (1980). Crop residue influences on soil carbon and nitrogen in a wheat-fallow system. *Soil Science Society of America Journal*, *44*, 596–600. https://doi.org/10.2136/sssaj1980.03615995004400030033x

Rasmussen, P. E., & Rohde, C. R. (1988). Stubble burning effects on winter wheat yield and nitrogen utilization under semiarid conditions. *Agronomy Journal*, *80*, 940–942. https://doi.org/10.2134/agronj1988.00021962008000060020x

Rathore, T. R., Chhonkar, P. K., Sachan, R. S., & Ghildyal, B. P. (1981). Effect of soil moisture stress on legume-rhizobium symbiosis in soybeans. *Plant and Soil*, *60*, 445–450. https://doi.org/10.1007/BF02149640

Reddy, K. N. (2001a). Effects of cereal and legume cover crop residues on weeds, yield, and net return in soybean *(Glycine max)*. *Weed Technology*, *15*, 660–668. https://doi.org/10.1614/0890-037X(2001)015%5b0660:EOCALC%5d2.0.CO;2

Reddy, K. N. (2001b). Broadleaf weed control in ultra narrow row bromoxynil-resistant cotton (*Gossypium hirsutum*). *Weed Technology*, *15*, 497–504.

Reddy, K. N. (2002). Weed control and economic comparisons in soybean planting systems. *Journal of Sustainable Agriculture*, *21*, 21–35. https://doi.org/10.1300/J064v21n02_04

Reddy, K. N., Locke, M. A., Wagner, S. C., Zablotowicz, R. M., Gaston, L. A., & Smeda, R. J. (1995). Chlorimuron ethyl sorption and desorption kinetics in soils and herbicide-desiccated cover crop residues. *Journal of Agricultural and Food Chemistry*, *33*, 2752–2757.

Reddy, K. N., Locke, M. A., & Zablotowicz, R. M. (2014). Impacts of cropping systems on soil quality indicators in soybean production. *Soil Science Society of America Journal*, *78*(3), 922–931. https://doi.org/10.2136/sssaj2013.10.0435

Reese, P. F., Jr., & Buss, G. R. (1992). Response of dryland soybeans to nitrogen in full-season and doublecrop systems. *Journal of Production Agriculture*, *5*, 528–531.

Reeves, D. (1997). The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil and Tillage Research*, *43*, 131–167.

Rehm, G. W. (1986). Response of irrigated soybeans to rate and placement of fertilizer phosphorus. *Soil Science Society of America Journal*, *50*, 1227–1230. https://doi.org/10.2136/sssaj1986.03615995005000050028x

Rehm, G. W., Randall, G. W., Scobbie, A. J., & Vetsch, J. A. (1995). Impact of fertilizer placement and tillage system on phosphorus distribution in soil. *Soil Science Society of America Journal*, *59*, 1661–1665. https://doi.org/10.2136/sssaj1995.03615995005900060022x

Reicosky, D. C., & Deaton, D. E. (1979). Soybean water extraction, leaf water potential, and evapotranspiration during drought. *Agronomy Journal*, *71*, 45–50. https://doi.org/10.2134/agronj1979.00021962007100010011x

Reiter, M. S., Frame, W. H., & Holshouser, D. L. (2018). Economic analysis of soybean cropping systems: Comparing double-crop and full-season approaches. *Journal of Agricultural and Applied Economics*, *50*(4), 567–584. https://doi.org/10.1017/aae.2018.28

Rhoton, F. E. (2000). Influence of time on soil response to no till practices. *Soil Science Society of America Journal*, *64*, 700–709. https://doi.org/10.2136/sssaj2000.642700x

Rice, E. L. (1983). *Pest control with nature's chemicals*. University of Oklahoma Press.

Rice, E. L. (1984). *Allelopathy* (2nd ed.). Academic Press.

Riedell, W. E., Schumacher, T. E., & Pikul, J. L., Jr. (1998). *Soybean row spacing and nitrogen fertilizer effects on yield and potential nitrate leaching* (Soil/Water Research, 1997 Progress Report SOIL PR 97-38). Plant Science Department, Agricultural Experiment Station, South Dakota State University.

Robinson, A. P., Conley, S. P., Volenec, J. J., & Santini, J. B. (2009). Analysis of high yielding, early-planted soybean in Indiana. *Agronomy Journal*, *101*, 131–139. https://doi.org/10.2134/agronj2008.0014x

Rogers, H. T., & Thurlow, D. L. (1970). Water—key to high soybean yields. *Highlights of Agricultural Research*, *17*, 9.

Ross, J. P. (1962). Crop rotation effects on the soybean cyst nematode population and soybean yields. *Phytopathology*, *52*, 815–818.

Rucker, K. S., Roth, C. I., Ciampitti, I. A., & Lollato, R. P. (2022). Early wheat harvest: Effects on grain yield, protein, and economic returns in the US Central Plains. *Crop Science*, *62*(1), 58–72. https://doi.org/10.1002/csc2.20630

Runge, E. C. A., & Odell, R. T. (1960). The relation between precipitation, temperature, and the yield of soybeans on the Agronomy South Farm, Urbana, Illinois. *Agronomy Journal*, *52*, 245–247. https://doi.org/10.2134/agronj1960.00021962005200050001x

Sabbe, W. E., Lessman, G. M., & Bell, P. F. (2000). Soybean. In C. R. Campbell (Ed.), *Reference sufficiency ranges for plant analysis in the southern region of the United States* (Southern Cooperative Series Bulletin 394, pp. 33–34). North Carolina Department of Agriculture and Consumer Services Agronomic Division. http://www.ncagr.gov/agronomi/saaesd/scsb394.pdf

Sainju, U. M., Jabro, J. D., & Stevens, W. B. (2008). Soil carbon dioxide emission and carbon content as affected by irrigation, tillage, cropping system, and nitrogen fertilization. *Soil and Tillage Research*, *37*, 98–106.

Salmerón, M., Gbur, E. E., Bourland, F. M., Buehring, N. W., Earnest, L., Fritschi, F. B., Golden, B. R., Hathcoat, D., Lofton, J., McClure, A. T., Miller, T. D., Neely, C., Shannon, G., Udeigwe, T. K., Verbree, D. A., Vories, E. D., Wiebold, W. J., & Purcell, L. C. (2016). Yield response to planting date among soybean maturity groups for irrigated production in the US Midsouth. *Crop Science*, *56*, 747–759. https://doi.org/10.2135/cropsci2015.07.0466

Salmerón, M., Gbur, E. E., Bourland, F. M., Earnest, L., Golden, B. R., & Purcell, L. C. (2015). Soybean maturity group choices for maximizing radiation interception across planting dates in the Midsouth United States. *Agronomy Journal*, *107*, 2132–2142. https://doi.org/10.2134/agronj15.0091

Salmeron, M., Gbur, E. E., Bourland, F. M., Buehring, N. W., Earnest, L., Fritschi, F. B., Golden, B. R., Hathcoat, D., Lofton, J., Miller, T. D., Neely, C., Shannon, G., Udeigwe, T. K., Verbree, D. A., Vories, E. D., Wiebold, W. J., & Purcell, L. C. (2014). Soybean maturity group choices for early and late planting in the Midsouth. *Agronomy Journal*, *106*, 1893–1901. https://doi.org/10.2134/agronj14.0222

Salter, P. J., & Goode, J. E. (1967). *Crop responses to water at different stages of growth*. Commonwealth Agricultural Bureax.

Salvagiotti, F., Cassman, K. G., Specht, J. E., Walters, D. T., Weiss, A., & Dobermann, A. (2008). Nitrogen uptake, fixation and response to fertilizer N in soybeans. A review. *Field Crops Research*, *108*, 1–13. https://doi.org/10.1016/j.fcr.2008.03.001

Sanford, J. O. (1982). Straw and tillage management practices in soybean-wheat double-cropping. *Agronomy Journal*, *74*, 1032–1035. https://doi.org/10.2134/agronj1982.00021962007400060023x

Sanford, J. O., Eddleman, B. R., Spurlock, S. R., & Hairston, J. E. (1986). Evaluating ten cropping alternatives for the midsouth. *Agronomy Journal*, *78*, 875–880. https://doi.org/10.2134/agronj1986.00021962007800050026x

Sanford, J. O., & Hairston, J. E. (1984). Effects of N fertilization on yield, growth, and extraction of water by wheat following soybeans and grain sorghum. *Agronomy Journal*, *76*, 623–627. https://doi.org/10.2134/agronj1984.00021962007600040028x

Sanford, J. O., Myhre, D. L., & Merwine, N. C. (1973). Double cropping systems involving no-tillage and conventional tillage. *Agronomy Journal*, *65*, 978–982. https://doi.org/10.2134/agronj1973.00021962006500060040x

Sasser, J. N., & Zzell, G., Jr. (1991). Control of the soybean cyst nematode by crop rotation in combination with a nematicide. *Journal of Nematology*, *23*, 333–337.

Scharf, P. C., & Wiebold, W. J. (2003). Soybean yield responds minimally to nitrogen applications in Missouri. *Crop Management*, *2*(1), 1–6. https://doi.org/10.1094/CM-2003-1117-01-RS

Schlesinger, W. H., & Andrews, J. A. (2000). Soil respiration and the global carbon cycle. *Biogeochemistry*, *48*, 7–20. https://doi.org/10.1023/A:1006247623877

Schmitt, D. P. (1991). Management of *Heterodera glycines* by cropping and cultural practices. *Journal of Nematology*, *23*, 338–352.

Schmitz, P. K., & Kandel, H. J. (2021). Individual and combined effects of planting date, seeding rate, relative maturity, and row spacing on soybean yield. *Agronomy*, *11*(3), 605. https://doi.org/10.3390/agronomy11030605

Schneider, R., Sikora, E., Padgett, B., & Sciumbato, G. (2007). Managing late-season soybean diseases and soybean rust: A southern perspective. In A. E. Dorrance, M. A. Draper, & D. E. Hershman (Eds.) *Using foliar fungicides to manage soybean rust* (pp. 72–77). The Ohio State University.

Schnitkey, G., Swanson, K., Zulauf, C., Coppess, J., Paulson, N., & Baltz, J. (2022). Production from double-crop soybean rotations. *farmdoc daily*, *12*, 71.

Schou, J. B., Jeffers, D. L., & Streeter, J. G. (1978). Effects of reflectors, black boards, or shades applied at different stages of plant development on yield of soybeans. *Crop Science*, *18*, 29–34. https://doi.org/10.2135/cropsci1978.0011183X001800010009x

Schulz, T. J., & Thelen, K. D. (2008). Soybean seed inoculants and fungicidal seed treatment effects on soybean. *Crop Science*, *48*, 1975–1983. https://doi.org/10.2135/cropsci2008.02.0108

Scott, D. H., Ferguson, J. A., Hanson, L., Fugitt, T., & Smith, E. (1998). *Agricultural water management in the Mississippi Delta region of Arkansas*. Arkansas Agricultural Experiment Station, Division of Agriculture, University of Arkansas.

Seneviratne, G., Van Holm, L. H. J., & Ekanayake, E. M. H. G. S. (2000). Agronomic benefits of rhizobial inoculants use over nitrogen fertilizer application in tropical soybean. *Field Crops Research*, *68*, 199–203. https://doi.org/10.1016/S0378-4290(00)00123-4

Settimi, J. R., & Board, J. E. (1988). Photoperiod and planting date effects on the spatial distribution of branch development in soybean. *Crop Science*, *28*, 259–263. https://doi.org/10.2135/cropsci1988.0011183X002800020016x

Shaw, D. R., & Rainere, H. P. (1990). Weed control in soybean under different cropping and tillage systems. *Journal of Production Agriculture*, *3*, 453–460. https://doi.org/10.2134/jpa1990.0453

Shaw, R. H., & Laing, D. R. (1966). Moisture stress and plant response. In W. H. Pierre, D. Kirkham, J. Pesek, & R. Shaw (Eds.), *Plant environment and efficient water use* (pp. 73–94). ASA and SSSA.

Shaw, R. H., & Weber, C. R. (1967). Effects of canopy arrangements on light interception and yield of soybeans. *Agronomy Journal*, *59*, 155–159. https://doi.org/10.2134/agronj1967.00021962005900020009x

Shear, G. M., & Moschler, W. W. (1969). Continuous corn by the no-tillage and conventional tillage method: A six-year comparison. *Agronomy Journal*, *61*, 524–526. https://doi.org/10.2134/agronj1969.00021962006100040012x

Sherman, L. A., Brye, K. R., Gill, D. E., & Koenig, K. A. (2005). Soil chemistry as affected by first-time prescribed burning of a grassland restoration on a coastal plain Ultisol. *Soil Science*, *170*, 913–927. https://doi.org/10.1097/01.ss.0000196772.53574.a2

Shetty, S. V. R., Sivakumar, M. V. K., & Ram, S. A. (1982). Effect of shading on the growth of some common weeds of the semi-arid tropics. *Agronomy Journal*, *74*, 1023–1029. https://doi.org/10.2134/agronj1982.00021962007400060021x

Shibles, R. M. (1998). *Soybean nitrogen acquisition and utilization* [Conference presentation]. North Central Extension-Industry Soil Fertility Conference, St. Louis, MO, United States.

Shibles, R. M., & Weber, C. R. (1965). Leaf area, solar radiation interception and dry matter production by soybeans. *Crop Science*, *5*, 575–577. https://doi.org/10.2135/cropsci1965.0011183X000500060027x

Shibles, R. M., & Weber, C. R. (1966). Interception of solar radiation and dry matter production by various soybean planting patterns. *Crop Science*, *6*, 55–59. https://doi.org/10.2135/cropsci1966.0011183X000600010017x

Shipitalo, M., & Owens, L. (2006). Tillage system, application rate, and extreme event effects on herbicide losses in surface runoff. *Journal of Environmental Quality*, *35*, 2186–2194. https://doi.org/10.2134/jeq2005.0476

Shipitalo, M. J., Edwards, W. M., & Owens, L. B. (1997). Herbicide losses in runoff from conservation-tilled watersheds in a corn-soybean rotation. *Soil Science Society of America Journal*, *61*, 267–272. https://doi.org/10.2136/sssaj1997.03615995006100010038x

Shipley, J. L., & Regier, C. (1968). *Water response on irrigated soybeans, Northern High Plains of Texas* (PR–2546). Texas Agricultural Experiment Station.

Shrestha, A., Knezevic, S. Z., Roy, R. C., Ball-Coelho, B. R., & Swanton, C. J. (2002). Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. *Weed research*, *42*, 76–87. https://doi.org/10.1046/j.1365-3180.2002.00264.x

Shrestha, R., Lee, C., & McClure, M. (2021). Economic feasibility of double-cropping wheat and soybean in the Midwestern United States. *Agronomy Journal*, *113*(6), 5253–5265. https://doi.org/10.1002/agj2.20598

Sij, J. W., Turner, F. T., & Craigmiles, J. P. (1979). "Starter nitrogen" fertilization in soybean culture. *Communications in Soil Science and Plant Analysis*, *10*, 1451–1457. https://doi.org/10.1080/00103627909366999

Sims, B. D., & Guethle, D. R. (1992). Herbicide programs in no-tillage and conventional-tillage soybeans (*Glycine max*) double cropped after wheat (*Triticum aestivum*). *Weed Science*, *40*, 255–263. https://doi.org/10.1017/S0043174500057313

Sinclair, J. B., & Hartman, G. L. (Eds.). (1995). Management of soybean rust. In *Proceedings of the soybean rust workshop* (pp. 6–11). College of Agriculture, Consumer, and Environmental Sciences, National Soybean Research Laboratory.

Singer, J. W., Malone, R. W., Meek, D. W., & Drake, D. (2004). Predicting yield loss in indeterminate soybean from pod density using simulated damage studies. *Agronomy Journal*, *96*, 584–589. https://doi.org/10.2134/agronj2004.5840

Sionit, N., & Kramer, P. J. (1977). Effect of water stress during different stages of growth of soybean. *Agronomy Journal*, *69*, 274–278. https://doi.org/10.2134/agronj1977.00021962006900020018x

Six, J., Elliott, E., & Paustian, K. (2000). Soil macroaggregate turnover and microaggregate formation: A mechanism for C sequestration under no-tillage agriculture. *Soil Biology & Biochemistry*, *32*, 2099–2103. https://doi.org/10.1016/S0038-0717(00)00179-6

Slater, G. P., Elmore, R. W., Doupnik, B. L., Jr., & Ferguson, R. B. (1991). Soybean cultivar response to benomyl, nitrogen, phosphorus, and irrigation levels. *Agronomy Journal*, *83*, 804–809. https://doi.org/10.2134/agronj1991.00021962008300050006x

Slaton, N. A., Delong, R. E., Massey, C. G., Clark, S., Shafer, J., & Branson, J. (2012). Wheat and double-crop soybean yield response to phosphorus and potassium fertilization. In N. A. Slaton (Ed.), *Wayne E. Sabbe Arkansas soil fertility studies 2011* (pp. 37–41). Research series 599. University of Arkansas.

Slaton, N. A., Delong, R. E., Massey, C. G., Clark, S., Shafer, J., & Branson, J. (2013). Wheat and double-crop soybean yield response to phosphorus and potassium fertilization. In N. A. Slaton (Ed.), *Wayne E. Sabbe Arkansas soil fertility studies 2012* (pp. 46–50). Research series 608. University of Arkansas.

Slaton, N. A., Golden, B. R., Delong, R. E., & Mozaffari, M. (2010). Correlation and calibration of soil potassium availability with soybean yield and trifoliolate potassium. *Soil Science Society of America Journal*, *74*, 1642–1651. https://doi.org/10.2136/sssaj2009.0197

Smiciklas, K. D., Mullen, R. E., Carlson, R. E., & Knapp, A. D. (1989). Drought-induced stress effect on soybean seed calcium and quality. *Crop Science*, *29*, 1519–1523. https://doi.org/10.2135/cropsci1989.0011183X002900060041x

Smith, P. E. (1952). Soybean yields as affected by row width. *Arkansas Farm Research*, *1*, 3.

Smith, R. L. (1968). Effect of planting date and row width on yield of soybeans. *Proceedings of the Soil and Crop Science Society of Florida*, *28*, 130–133.

Smith, R. L., & Hinson, K. (1969). *Soybeans in Florida* (Bulletin 716). Florida Agricultural Experiment Station.

Snyder, R. L., Carlson, R. E., & Shaw, R. H. (1982). Yield of indeterminate soybeans in response to multiple periods of soilwater stress during reproduction. *Agronomy Journal*, *74*, 855–859. https://doi.org/10.2134/agronj1982.00021962007400050020x

Somerhalder, B. P., & Schleusener, P. E. (1960). In West Central Nebraska, proper timing of irrigation can increase soybean production. *Nebraska Agricultural Experiment Station Quarterly*, *QR-5*, 16–17.

Sorensen, R. C., & Penas, E. J. (1978). Nitrogen fertilization of soybeans. *Agronomy Journal*, *70*, 213–216. https://doi.org/10.2134/agronj1978.00021962007000020001x

Spaeth, S. C., & Sinclair, T. R. (1983). Variation in nitrogen accumulation and distribution among soybean cultivars. *Field Crops Research*, *7*, 1–12. https://doi.org/10.1016/0378-4290(83)90002-3

Specht, J., Rees, J., Glewen, K., & Grassini, P. (2014). *Soybean planting depth: Consider planting deeper*. University of Nebraska-Lincoln Crop Watch. http://cropwatch.unl.edu

Starling, M. E., Wood, C. W., & Weaver, D. B. (1998). Starter nitrogen and growth habit effects on late-planted soybean. *Agronomy Journal*, *90*, 658–662. https://doi.org/10.2134/agronj1998.00021962009000050015x

Starling, M. E., Wood, C. W., & Weaver, D. B. (2000). Late-planted soybeans respond to nitrogen starter. *Fluid Journal*, *28*, 26–30.

Steinsiek, J. W., III (1981). *Influence of wheat straw residue on weed control in no-till double cropped soybeans* [Master's thesis, University of Arkansas].

Stoller, E. W., Wax, L. M., & Alm, D. M. (1993). Survey results on environmental issues and weed science research priorities within the corn belt. *Weed Technology*, *7*, 763–770. https://doi.org/10.1017/S0890037X00037684

Stutte, C. A., & Weiland, R. T. (1980). Irrigation and temperature influences on soybean yields. *Arkansas Farm Research*, *29*, 8.

Swanton, C. J., Vyn, T. J., Chandler, K., & Shrestha, A. (1998). Weed management strategies for no-till soybean (*Glycine max*) grown on clay soils. *Weed Technology*, *12*, 660–669. https://doi.org/10.1017/S0890037X00044523

Swearingin, M. L. (1973). Double cropping in the Corn Belt. *Better Crops Plant Food*, *57*, 20–24.

Swoboda, D., & Pedersen, P. (2009). Effect of fungicide on soybean growth and yield. *Agronomy Journal*, *101*, 352–356. https://doi.org/10.2134/agronj2008.0150

Talekar, N. S., & Lee, H. R. (1988). Response of soybean to foliage loss in Taiwan. *Journal of Economic Entomology*, *81*, 1363–1368. https://doi.org/10.1093/jee/81.5.1363

Taylor, H. M. (1980). Soybean growth and yield as affected by row spacing and by seasonal water supply. *Agronomy Journal*, *72*, 543–547. https://doi.org/10.2134/agronj1980.00021962007200030032x

Taylor, H. M., Mason, W. K., Bennie, A. T. P., & Rowse, H. R. (1982). Responses of soybeans to 2 row spacings and 2 soil-water levels.1. An analysis of biomass accumulation, canopy development, solarradiation interception and components of seed yield. *Field Crops Research*, *5*, 1–14. https://doi.org/10.1016/0378-4290(82)90002-8

Taylor, R. S., Weaver, D. B., Wood, C. W., & van Santen, E. (2005). Nitrogen application increases yield and early dry matter accumulation in late-planted soybean. *Crop Science*, *45*, 854–858. https://doi.org/10.2135/cropsci2003.0344

Teasdale, J. R. (1995). Influence of narrow row/high population corn (*Zea mays*) on weed control and light transmittance. *Weed Technology*, *9*, 113–118. https://doi.org/10.1017/S0890037X00023046

Tenuta, A., Hershman, D., Draper, M., & Dorrance, A. (2007). Fungicide basics. In A. E. Dorrance, M. A. Draper, & D. E. Hershman (Eds.), *Using foliar fungicides to manage soybean rust* (pp. 48–56). The Ohio State University.

Tenuta, M., & Tenuta, A. (2015). Slowing the spread of soybean cyst nematode. *Crops & Soils*, *48*(5), 28–30. https://doi.org/10.2134/cs2015-48-5-7

Tharp, B. E., & Kells, J. J. (2001). Effect of glufosinate-resistant corn (*Zea mays*) population and row spacing on light interception, corn yield, and common lambsquarters (*Chenopodium album*) growth. *Weed Technology*, *15*, 413–418. https://doi.org/10.1614/0890-037X(2001)015%5b0413:EOGRCZ%5d2.0.CO;2

Thelen, K., & Schulz, T. (2009). *Soybean facts: Soybean seed applied inoculation*. Michigan State University Extension. http://web1.msue.msu.edu/soybean2010/Soybean%20Seed%20Applied%20Innoculation.pdf

Thelen, K. D., & Leep, R. H. (2002). Integrating a double-cropped winter annual forage into a corn-soybean rotation. *Crop Management*, *1*(1), 1–5. https://doi.org/10.1094/CM-2002-1218-01-RS

Thibodeau, P. S., & Jaworski, E. G. (1975). Patterns of nitrogen utilization in the soybean. *Planta*, *127*, 133–147. https://doi.org/10.1007/BF00388374

Thomas, A. L., Costa, J. A., & Pires, J. L. (1998). Soybean grain yield affected by row spacing and soil fertility. *Ciência Rural*, *28*, 543–546. https://doi.org/10.1590/S0103-84781998000400002

Thomas, D. L., Breve, M. A., Raymer, P. L., & Dasilva, J. F. K. (1990). Planting date effect and double-cropping potential of rape in the southeastern United States. *Applied Agricultural Research*, *5*, 205–211.

Thomas, G. D., Ignoffo, C. M., Biever, K. D., & Smith, D. B. (1974). Influence of defoliation and depodding on yield of soybean. *Journal of Economic Entomology*, *67*, 683–685. https://doi.org/10.1093/jee/67.5.683

Thomas, G. W. (1989). Risks and benefits from second-crop soybeans in Kentucky. In A. J. Pascale (Ed.), *Proceedings of the world soybean research conference IV* (pp. 591–595). Buenos Aires Asociacion Agrentina de la Soja Argentina.

Thomas, J. F., & Raper, C. D. (1977). Morphological response of soybeans as governed by photoperiod, temperature, and age at treatment. *Botanical Gazette*, *138*, 321–328. https://doi.org/10.1086/336931

Thompson, J. A. (1977). Effect of irrigation termination on yield of soybeans in southern New South Wales. *Australian Journal of Experimental Agriculture and Animal Husbandry*, *17*, 156–160.

Thompson, L. M. (1970). Weather and technology in the production of soybeans in the central United States. *Agronomy Journal*, *62*, 232–236. https://doi.org/10.2134/agronj1970.00021962006200020016x

Thompson, N. M., Larson, J. A., Lambert, D. M., Roberts, R. K., Mengistu, A., Bellaloui, N., & Walker, E. R. (2015). Mid-South soybean yield and net return as affected by plant population and row spacing. *Agronomy Journal*, *107*, 979–989. https://doi.org/10.2134/agronj14.0453

Timmons, D. R. (1982). *Fertilizer placements in tillage systems-Iowa* [Conference presentation]. Proceedings of the 34th Annual Fertilizer and Agricultural Chemical Dealers Conference, Des Moines, IA, United States.

Timmons, D. R., Holt, R. F., & Thompson, R. L. (1967). Effect of plant population and row spacing on evapotranspiration and water use efficiency by soybeans. *Agronomy Journal*, *59*, 262–265. https://doi.org/10.2134/agronj1967.00021962005900030018x

Touchton, J. T., Hargrove, W. L., Sharpe, R. R., & Boswell, F. C. (1982). Time, rate, and method of phosphorus application for continuously double-cropped wheat and soybeans. *Soil Science Society of America Journal*, *46*, 861–864. https://doi.org/10.2136/sssaj1982.03615995004600040038x

Touchton, J. T., & Rickerl, D. H. (1986). Soybean growth and yield response to starter fertilizers. *Soil Science Society of America Journal*, *50*, 234–237. https://doi.org/10.2136/sssaj1986.03615995005000010045x

Triplett, G. B., Jr. (1978). Weed control for doublecrop soybeans planted with the no-tillage method following small grain harvest. *Agronomy Journal*, *70*, 577–581. https://doi.org/10.2134/agronj1978.00021962007000040015x

Tyler, D. D., Chambers, A. Y., & Young, L. D. (1987). No-tillage effects on population dynamics of soybean cyst nematode. *Agronomy Journal*, *79*, 799–802. https://doi.org/10.2134/agronj1987.00021962007900050008x

Tyler, D. D., & Overton, J. R. (1982). No-tillage advantages for soybean seed quality during drought stress. *Agronomy Journal*, *74*, 344–347. https://doi.org/10.2134/agronj1982.00021962007400020020x

Tylka, G. L., & Marett, C. C. (2014). Known distribution of soybean cyst nematode, Heterodera glycines, in the United States and Canada, 1954 to 2014. *Plant Health Progress*, *15*(2), 85–87. https://doi.org/10.1094/PHP-BR-14-0011

Undersander, D. J., & Reiger, C. (1985). Effect of wheat residue management on continuous production of irrigated winter wheat. *Agronomy Journal*, *77*, 508–511.

USDA-ERS. (2016). *Table 18—Wheat: Average price received by farmers, United States*. USDA-ERS. http://www.ers.usda.gov/datafiles/Wheat_Wheat_Data/Yearbook_Tables/Domestic_and_International_Prices/WheatYearbookTable18.xls

USDA-ERS. (2022). *Soybean production costs and returns per planted acre*. https://www.ers.usda.gov/data-products/commodity-costs-and-returns/

USDA-NASS. (1990). *Acreage*. USDA-NASS. http://usda.mannlib.cornell.edu/usda/nass/Acre/1990s/1990/Acre-06-28-1990.pdf

USDA-NASS. (1995). *Acreage*. USDA-NASS. http://usda.mannlib.cornell.edu/usda/nass/Acre/1990s/1995/Acre-06-30-1995.pdf

USDA-NASS. (2000). *Acreage*. USDA-NASS. http://usda.mannlib.cornell.edu/usda/nass/Acre/2000s/2000/Acre-06-30-2000.pdf

USDA-NASS. (2005). *Acreage*. USDA-NASS. http://usda.mannlib.cornell.edu/usda/nass/Acre/2000s/2005/Acre-06-30-2005.pdf

USDA-NASS. (2007). *Agricultural statistics database: State and county data—crops*. http://www.nass.usda.gov/QuickStats/

USDA-NASS. (2010). *Acreage*. USDA-NASS. http://usda.mannlib.cornell.edu/usda/nass/Acre/2010s/2010/Acre-06-30-2010.pdf

USDA-NASS. (2015). *Acreage*. USDA-NASS. http://usda.mannlib.cornell.edu/usda/nass/Acre/2010s/2015/Acre-06-30-2015.pdf

USDA-NASS. (2016). *Soybeans: 2014-15*. USDA-NASS. http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm

USDA-RMA. (2023). *Double-cropping initiative*. United States Department of Agriculture Risk Management Agency. https://www.rma.usda.gov/en/Topics/Double-Cropping-Initiative

Vail, G. D., & Oliver, L. R. (1993). Barnyardgrass (*Echinochloa crus-galli*) interference in soybeans (*Glycine max*). *Weed Technology*, *7*, 220–225. https://doi.org/10.1017/S0890037X00037167

Van Doren, D. M., Jr., & Reicosky, D. C. (1987). Tillage and irrigation. In J. R. Wilcox (Ed.), *Soybeans: Improvement, production, and uses* (2nd ed., pp. 391–428). Agronomy monographs 16. ASA, CSSA, and SSSA.

Vangessel, M. J., Ayeni, A. O., & Majek, B. A. (2001). Glyphosate in double-crop no-till glyphosate-resistant soybean: Role of preplant applications and residual herbicides. *Weed Technology*, *15*, 703–713. https://doi.org/10.1614/0890-037X(2001)015%5b0703:GIDCNT%5d2.0.CO;2

Van Roekel, R. J. (2015). *Physiological and nutritional characterization of high yield soybean* [Doctoral dissertation, University of Arkansas].

Van Schaik, P. H., & Probst, A. H. (1958). Effects of some environmental factors on flower production and reproductive efficiency in soybeans. *Agronomy Journal*, *50*, 192–197. https://doi.org/10.2134/agronj1958.00021962005000040007x

Verhulst, N., Nelissen, V., Jespers, N., Haven, H., Sayre, K. D., Raes, D., Deckers, J., & Govaerts, B. (2011). Soil water content, maize yield and its stability as affected by tillage and crop residue management in rainfed semi-arid highlands. *Plant and Soil*, *344*, 73–85. https://doi.org/10.1007/s11104-011-0728-8

Verkler, T. L., Brye, K. R., Popp, J. H., Gbur, E. E., Chen, P., & Amuri, N. (2009). Soil properties, soybean response, and economic return as affected by residue and water management practices. *Journal of Sustainable Agriculture*, *33*, 716–744. https://doi.org/10.1080/10440040903220724

Vidrine, P. R., Reynolds, D. B., & Griffin, J. L. (1993). Weed control in soybean (*Glycine max*) with lactofen plus chlorimuron. *Weed Technology*, *7*, 311–316. https://doi.org/10.1017/S0890037X00027640

Vieira, R. D., Tekrony, D. M., & Egli, D. B. (1992). Effect of drought and defoliation stress in the field on soybean seed germination and vigor. *Crop Science*, *32*, 471–475. https://doi.org/10.2135/cropsci1992.0011183X003200020037x

Vyn, T. J., & Janovicek, K. J. (2001). Potassium placement and tillage system effects on corn response following long-term no till. *Agronomy Journal*, *93*, 487–495. https://doi.org/10.2134/agronj2001.933487x

Vyn, T. J., Opoku, G. S., & Clarence, J. (1998). Residue management and minimum tillage systems for soybean following wheat. *Agronomy Journal*, *90*, 131–138. https://doi.org/10.2134/agronj1998.00021962009000020002x

Walker, A. K., & Fioritto, R. J. (1984). Effect of cultivar and planting pattern on yield and apparent harvest index in soybean. *Crop Science*, *24*, 154–155. https://doi.org/10.2135/cropsci1984.0011183X002400010036x

Walker, E. R., Mengistu, A., Bellaloui, N., Koger, C. H., Roberts, R. K., & Larson, J. A. (2010). Plant population and row-spacing effects on maturity group III soybean. *Agronomy Journal*, *102*, 821–826. https://doi.org/10.2134/agronj2009.0219

Wallace, M. K., Orf, J. H., & Stienstra, W. C. (1995). Field population dynamics of soybean cyst nematode on resistant and susceptible soybeans and their blends. *Crop Science*, *35*, 703–707. https://doi.org/10.2135/cropsci1995.0011183X003500030009x

Walsh, M., & Newman, P. (2007). Burning narrow windrows for weed seed destruction. *Field Crops Research*, *104*, 24–30. https://doi.org/10.1016/j.fcr.2007.05.012

Wani, S. P., Rupela, O. P., & Lee, K. K. (1995). Sustainable agriculture in the semi-arid tropics through biological nitrogen-fixation in grain legumes. *Plant and Soil*, *174*, 29–49. https://doi.org/10.1007/BF00032240

Wax, L. M., & Pendleton, J. W. (1968). Effect of row spacing on weed control in soybeans. *Weed Science*, *1968*, 462–465. https://doi.org/10.1017/S0043174500047743

Webb, J. R., Mallarino, A. P., & Blackmer, A. M. (1992). Effects of residual and annually applied phosphorus on soil test values and yields of corn and soybean. *Journal of Production Agriculture*, *5*, 148–152. https://doi.org/10.2134/jpa1992.0148

Weber, C. R. (1966). Nodulating and nonnodulating soybean isolines. II. Response to applied nitrogen and modified soil conditions. *Agronomy Journal*, *58*, 46–49. https://doi.org/10.2134/agronj1966.00021962005800010015x

Weber, C. R., & Fehr, W. R. (1966). Seed losses from lodging and combine harvesting in soybeans. *Agronomy Journal*, *58*, 287–289. https://doi.org/10.2134/agronj1966.00021962005800030012x

Weber, C. R., Shibles, R. M., & Byth, D. E. (1966). Effect of plant population and row spacing on soybean development and production. *Agronomy Journal*, *58*, 99–102. https://doi.org/10.2134/agronj1966.00021962005800010034x

Weil, R. R., & Magdoff, F. (2004). Signifance of soil organic matter to soil quality and health. In F. Magdoff & R. R. Weil (Eds.), *Soil organic matter in sustainable agriculture* (pp. 1–44). CRC Press.

Weiss, M. G. (1950). *Variability of agronomic and seed compositional characters in soybeans, as influenced by variety and time of planting* (USDA Technical Bulletin No. 1017). U.S. Government Printing Office.

Welch, L. F., Boone, L. V., Chambliss, C. G., Christiansen, A. T., Mulvaney, D. L., Oldham, M. G., & Pendleton, J. W. (1973). Soybean yields with direct and residual nitrogen fertilization. *Agronomy Journal*, *65*, 547–550. https://doi.org/10.2134/agronj1973.00021962006500040007x

Wells, R. (1991). Soybean growth response to plant density: Relationships among canopy photosynthesis, leaf area, and light interception. *Crop Science*, *31*, 755–761. https://doi.org/10.2135/cropsci1991.0011183X003100030044x

Wells, R. (1993). Dynamics of soybean growth in variable planting patterns. *Agronomy Journal*, *85*, 44–48. https://doi.org/10.2134/agronj1993.00021962008500010009x

Wells, R., Burton, J. W., & Kilen, T. C. (1993). Soybean growth and light interception: Response to differing leaf and stem morphology. *Crop Science*, *33*, 520–524. https://doi.org/10.2135/cropsci1993.0011183X003300030020x

Wesley, R. A. (1999). Doublecropping wheat and soybeans. In L. G. Heatherly & H. F. Hodges (Eds.), *Soybean production in the midsouth* (pp. 143–170). CRC Press LLC.

Wesley, R. A., & Cooke, F. T. (1988). Wheat – soybean double-crop systems on clay soil in the Mississippi Valley area. *Journal of Production Agriculture*, *1*, 166–171. https://doi.org/10.2134/jpa1988.0166

Wesley, R. A., Elmore, C. D., Heatherly, L. G., & Spurlock, S. R. (1995). Net returns from eight nonirrigated cropping systems on clay soil. *Journal of Production Agriculture*, *8*, 514–520. https://doi.org/10.2134/jpa1995.0514

Wesley, R. A., Heatherly, L. G., & Elmore, C. D. (1991). Cropping systems for clay soil: Crop rotation and irrigation effects on soybean and wheat doublecropping. *Journal of Production Agriculture*, *4*, 345–352. https://doi.org/10.2134/jpa1991.0345

Wesley, R. A., Heatherly, L. G., Elmore, C. D., & Spurlock, S. R. (1994). Net returns from eight irrigated cropping systems on clay soil. *Journal of Production Agriculture*, *7*, 109–115. https://doi.org/10.2134/jpa1994.0109

Wesley, R. A., Heatherly, L. G., Pringle, H. C., & Tupper, G. R. (1988). Seedbed tillage and irrigation effects on yield of mono- and double-crop soybean and wheat on a silt loam. *Agronomy Journal*, *80*, 139–143. https://doi.org/10.2134/agronj1988.00021962008000010030x

Wesley, T. L., Lamond, R. E., Martin, V. L., & Duncan, S. R. (1998). Effects of late-season nitrogen fertilizer on irrigated soybean yield and composition. *Journal of Production Agriculture*, *11*, 331–336. https://doi.org/10.2134/jpa1998.0331

Westgate, M. E. (1999). Managing soybean for photosynthetic efficiency. In H. E. Kauffman (Ed.), *Proceedings of the world soybean research conference VI* (pp. 223–228).

Westgate, M. E., Schussler, J. R., Reicosky, D. C., & Brenner, M. L. (1989). Effect of water deficits on seed development in soybean: II. Conservation of seed growth rate. *Plant Physiology*, *91*, 980–985. https://doi.org/10.1104/pp.91.3.980

Whaley, C., Sylvester, P., Adkins, J., & Miller, J. (2018). *2017-2018 irrigated soybean seeding rates*. Delaware Agronomy Blog, University of Delaware Cooperative Extension. https://sites.udel.edu/agronomy/2018/12/20/2017-2018-soybean-seeding-rate-study/

Whigham, K., Farnham, D., Lundvall, J., & Tranel, D. (2000). *Soybean replant decisions* (Ext. Bulletin PM 1851). Iowa State University.

Wicks, G. A., & Somerhalder, B. R. (1971). Effect of seedbed preparation for corn on distribution of weed seed. *Weed Science*, *19*, 666–668. https://doi.org/10.1017/S0043174500051006

Wiggans, R. G. (1939). The influence of space and arrangement on the production of soybean plants. *Agronomy Journal*, *31*, 314–321. https://doi.org/10.2134/agronj1939.00021962003100040005x

Wilcox, J. R., & Frankenberger, E. M. (1987). Indeterminate and determinate soybean responses to planting date. *Agronomy Journal*, *79*, 1074–1078. https://doi.org/10.2134/agronj1987.00021962007900060025x

Willbur, J. F., Swaminathan, A., Catala-Luque, R., Kabbage, M., & Smith, D. L. (2019). Sclerotinia sclerotiorum (white mold): An evaluation of pathogen virulence, host susceptibility, and disease management. *Phytopathology*, *109*(9), 1712–1725. https://doi.org/10.1094/PHYTO-04-19-0121-R

Williams, A. S., Parvej, M. R., Holshouser, D. L., Frame, W. H., & Reiter, M. S. (2018). Correlation and calibration of soil-test potassium from different soil depths for full-season soybean on coarse-textured soils. *Agronomy Journal*, *110*, 369–379. https://doi.org/10.2134/agronj2017.06.0344

Williams, C., Mason, L., & Newman, B. E. (1970). Response of four soybean varieties to varying plant-population: Density and row spacing. *Louisiana Agricultural Experiment Station, Department of Agronomy Report Progress*, 135–143.

Williams, J. L., Jr., & Wicks, G. A. (1978). Weed control problems associated with crop residue systems. In W. R. Oschwald (Ed.), *Crop* *residue management systems* (Spec. Pub. 31, pp. 165–172). American Society of Agronomy. https://doi.org/10.2134/asaspecpub31.c9

Williamson, A. J. P. (1974). Effects of various plant populations on agronomic characters of several varieties of soybean under rain-grown conditions in southern Queensland. *Queensland Journal of Agricultural and Animal Sciences*, *31*, 285–299.

Wischmeier, W. H. (1973). Conservation tillage to control water erosion. In *Conservation tillage* (pp. 133–141). Soil Conservation Society of America.

Witt, W. W. (1980). Weed control in no-tillage. In R. E. Philliips, G. W. Thomas, & R. L. Blevins (Eds.), *No-tillage research: Research reports and reviews* (pp. 96–102). University of Kentucky College of Agriculture and the Agricultural Experiment Station.

Wittry, D. J., & Mallarino, A. P. (2004). Comparison of uniform- and variable-rate phosphorus fertilization for corn-soybean rotations. *Agronomy Journal*, *96*, 26–33. https://doi.org/10.2134/agronj2004.2600

Wood, C. W., Torbert, H. A., & Weaver, D. B. (1993). Nitrogen fertilizer effects on soybean growth, yield, and seed composition. *Journal of Production Agriculture*, *6*, 354–360. https://doi.org/10.2134/jpa1993.0354

Woodard, H. J., Bly, A., & Winther, D. (1998). *The effect of N applications on agronomic parameters and soybean nodulation* (Soil/Water Research, 1997 Progress Report SOIL PR 97-14). Plant Science Department, Agricultural Experiment Station, South Dakota State University.

Woodruff, J. R., & Parks, C. L. (1980). Topsoil and subsoil potassium calibration with leaf potassium for fertility ratin1. *Agronomy Journal*, *72*, 392–396. https://doi.org/10.2134/agronj1980.00021962007200020032x

Workneh, F., Yang, X. B., & Tylka, G. L. (1999). Effects of tillage practices on survival of Heterodera glycines eggs in soybean fields. *Plant Disease*, *83*(6), 573–579. https://doi.org/10.1094/PDIS.1999.83.6.573

Worsham, A. D. (1974). Influence of no-tillage planters on tolerance of soybeans to linuron. *Weed Science*, *22*, 340–344. https://doi.org/10.1017/S0043174500037401

Wright, A. L., & Hons, F. M. (2004). Soil aggregation and carbon and nitrogen storage under soybean cropping sequences. *Soil Science Society of America Journal*, *68*, 507–513. https://doi.org/10.2136/sssaj2004.5070

Wuest, S. B., Caesar-TonThat, T., Wright, S. F., & Williams, J. D. (2005). Organic matter addition, N, and residue burning effects on infiltration, biological, and physical properties of an intensively tilled silt-loam soil. *Soil and Tillage Research*, *84*, 154–167. https://doi.org/10.1016/j.still.2004.11.008

Yang, F., Liu, Q., Cheng, Y., Feng, L., Wu, X., Fan, Y., Raza, M. A., Wang, X., Yong, T., Liu, W., Liu, J., Du, J., Shu, K., & Yang, W. (2020). Low red/far-red ratio as a signal promotes carbon assimilation of soybean seedlings by increasing the photosynthetic capacity. *BMC Plant Biology*, *20*, Article 148. https://doi.org/10.1186/s12870-020-02352-0

Yang, X. B., & Robertson, A. (2007). The importance of risk assessment. In A. E. Dorrance, M. A. Draper, & D. E. Hershman (Ed.), *Using foliar fungicides to manage soybean rust* (pp. 29–34). The Ohio State University.

Yelverton, F. H., & Coble, H. D. (1991). Narrow row spacing and canopy formation reduces weed resurgence in soybeans (*Glycine max*). *Weed Technology*, *5*, 169–174. https://doi.org/10.1017/S0890037X00033467

Yin, X., & Vyn, T. J. (2002a). Soybean responses to potassium placement and tillage alternatives following no-till. *Agronomy Journal*, *94*, 1367–1374. https://doi.org/10.2134/agronj2002.1367

Yin, X., & Vyn, T. J. (2002b). Residual effects of potassium placement and tillage systems for corn on subsequent no-till soybean. *Agronomy Journal*, *94*, 1112–1119. https://doi.org/10.2134/agronj2002.1112

Yin, X., & Vyn, T. J. (2003). Potassium placement effects on yield and seed composition of no-till soybean seeded in alternate row widths. *Agronomy Journal*, *95*, 126–132. https://doi.org/10.2134/agronj2003.1260

Yoneyama, T., Karasuyama, M., Kouchi, H., & Ishizuka, J. (1985). Occurrence of uride accumulation in soybean plants, effects of nitrogen fertilization and N2 fixation. *Soil Science and Plant Nutrition*, *31*, 133–140. https://doi.org/10.1080/17470765.1985.10555224

Yorinori, J. T., Paiva, W. M., Frederick, R. D., Costamilan, L. M., Bertagnolli, P. F., Hartman, G. E., Godoy, C. V., & Nunes, J., Jr. (2005). Epidemics of soybean rust (*Phakopsora pachyrhizi*) in Brazil and Paraguay from 2001 to 2003. *Plant Disease*, *89*, 675–677. https://doi.org/10.1094/PD-89-0675

Yoshida, T. (1979). Soil management and nitrogen fertilization for increasing soybean yield. *Japan Agricultural Research Quarterly*, *13*, 163–168.

Young, L. D., Hartwig, E. E., Anand, S. C., & Widick, D. (1986). Responses of soybeans and soybeans cyst nematodes to cropping sequences. *Plant Disease*, *70*, 787–791.

Zapata, F., Danso, S. K. A., Hardarson, G., & Fried, M. (1987). Time course of nitrogen fixation in field-grown soybean using nitrogen-15 methodology. *Agronomy Journal*, *79*, 172–176. https://doi.org/10.2134/agronj1987.00021962007900010035x

Zhang, J., Sun, L., & Yu, Q. (2016). Climate variability and soybean yield stability in double-crop and full-season systems. *Theoretical and Applied Climatology*, *124*(1–2), 255–267. https://doi.org/10.1007/s00704-015-1424-1

Zhang, L., Zhang, J., Watson, C. E., & Kyei-Boahen, S. (2004). Developing phenological prediction tables for soybean. *Crop Management*, *3*(1), 1–10. https://doi.org/10.1094/CM-2004-1025-01-RS

Zhang, L. X. (2004). *Exploring the feasibility of growing maturity group III soybeans in the MidSouth* (Research Sheet 1343). Mississippi Agricultural and Forestry Experiment Station.

Zhang, L. X., Kyei-Boahen, S., Zhang, J., Zhang, M. H., Freeland, T. B., Watson, C. E., Jr., & Liu, X. (2007). Modifications of optimum adaptation zones for soybean maturity groups in the USA. *Crop Management*, *6*(1), 1–11. https://doi.org/10.1094/CM-2007-0927-01-RS

Zhang, Q. Y., Gao, Q. L., Herbert, S. J., Li, Y. S., & Hashemi, A. M. (2010). Influence of sowing date on phenological stages, seed growth and marketable yield of four vegetable soybean cultivars in North-eastern USA. *African Journal of Agricultural Research*, *5*, 2556–2562.

How to cite this article: Parvej, M. R., & Holshouser, D. L. (2025). A review of double-crop soybean production in comparison to full-season system in the United States. *Agronomy Journal*, *117*, e70057. https://doi.org/10.1002/agj2.70057