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Residue management in double-crop systems: Impact on soybean growth and yield

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Abstract

Double-crop soybeans [*Glycine max* (L.) Merr.] have the potential to be a productive and profitable system. However, due to delayed planting, double-crop soybeans frequently experience lower yields and higher stress. Because planting is a major production constraint, a critical practice is the management of previous wheat residue. Trials were established in 2012, 2013, and 2014 in Saint Joseph, LA, and in 2013 and 2014 in Winnsboro, LA. The four residue management treatments investigated included conventionally tilled, planted into burned residue, planted into mowed residue, and planted into standing wheat residue. Vegetative and reproductive growth parameters, as well as yield, were used to evaluate the influence of residue management on productivity. Overall, residue management did not have a significant impact on early season growth parameters, except for plant height in 2012 at St. Joseph; however, it did significantly influence yield at both locations. In Saint Joseph in 2012, yields from planting into wheat residue were significantly lower than burned and mowed plots (1.2 compared with 2.8 and 2.7 Mg ha^{-1}, respectively), and tilled treatments yielded significantly less than all three nontilled treatments in 2013 and 2014. In Winnsboro, planting into residue left on the soil surface resulted in significantly higher yields than when residue was removed. Overall, leaving residue on the soil surface provided stable yields across years and locations; however, not managing the residue can result in diminished yields. Therefore, practices such as mowing of wheat residue prior to planting provide an alternative to traditional no-till planting.

1 | INTRODUCTION

Soybeans [*Glycine max* (L.) Merr.] are a critical field crop across the United States, only behind corn (*Zea mays* L.) in total planted hectares, total harvested hectares, and total production (USDA-NASS, 2015). A majority of soybean production in the United States occurs in the upper Midwest and in the northern Great Plains. However, soybeans are still planted at comparable levels in the lower Mississippi River valley of Arkansas, Mississippi, and Louisiana, ranking eleventh, thirteenth, and eighteenth, respectively, for total soybean hectares in the United States (USDA-NASS, 2015). Although soybean hectares for the state of Louisiana are lower compared with other regions, they are the most important row crop in Louisiana, with the highest planted hectares, harvested hectares, and farm production, with ~25% of the soybean hectares being produced as a wheat–soybean double-cropping system (USDA-NASS 2015).

Abbreviations: DAE, days after emergence; HFN, height to first harvestable node.

For much of this region, double-cropping consists of a winter wheat (*Triticum aestivum* L.) and soybean rotation, in which soybeans are planted immediately after wheat harvest. The major producer-driven benefits of this system in the Mid-South are (i) improved potential productivity and profitability due to increased production per hectare, (ii) better utilization of favorable sunlight, temperatures, and precipitation, and (iii) spreading the risk of crop failure or economic risk across crops. Despite these benefits, one major drawback of double-cropping systems is lower soybean yields (Sanford, 1982; Vyn, Opoku, & Swanton, 1998). Sanford (1982) reported the best managed double-cropped soybeans yielded 29% less than full-season soybeans. The main explanation for the decreased yields with the double-cropping system was the delayed planting. Although they did not use a double-crop system, Kane, Steele, and Grabau (1997) reported lower yields with later June planting compared with early June, May, or April, especially with maturity group IV soybean varieties that are common in systems in the Mid-South. Therefore, quickly transitioning from wheat harvest to soybean planting is vital for optimum growth in a double-crop system.

Wheat residue management greatly influences double-cropping systems and influences time between wheat harvest and soybean planting. To minimize time between harvest and planting, tillage practices are often eliminated, and no-tillage techniques are commonly used. Although most producers have adopted no-till, burning of the wheat residue prior to planting is a common practice in the Mid-South because planting into standing stubble can decrease early-season stands, delay early growth, and decrease soybean yields. However, studies evaluating the effects of residue management in double-crop soybeans have often found mixed results regarding early-season growth and yield (Beale & Langdale, 1967; Brye, Cordell, Longer, & Gbur, 2007b; Brye et al., 2007a;Chastain, Ward, & Wysocki, 1995; Cordell, Brye, Longer, & Gbur, 2007; Hairston, Stanford, Pope, & Horneck, 1987; NeSmith, Hargrove, Radcliffe, Tollner, & Arioglu, 1987; Sanford, 1982). Cordell et al. (2007) noted increased early-season plant population and high leaf area index in double-crop soybeans in a no-till system with standing residue; however, they found no differences in yields between tillage or residue-burning treatments. NeSmith et al. (1987) reported that tillage and residue burning had no significant influence on double-cropped soybean growth or yields. They theorized that burning of crop residue was more a matter of convenience rather than serving any agronomic benefit. However, Hairston et al. (1987) found that growth was suppressed when soybeans were planted where wheat straw was left on the soil surface. They noted that the highest yields and economic return for double-cropped soybeans were found when straw was removed from the soil surface.

Although the impact residue management can have on double-crop soybean production is evident, there are still major gaps in the current literature, such as the integration of differing residue management techniques into the double-cropping system. Most of the literature has focused on maintaining or removing the wheat residue and comparing conventional and no-till planting techniques. Little information is available on practices that maintain residue but attempt to manage the residue for planting of double-crop soybean. Additionally, the majority of the current knowledge base is >10 yr old. During this time, integration of more advanced varieties and equipment has the potential to drastically change the response of the system to residue management, especially for soybean production. These facts emphasize the need to continue to evaluate the impact of residue management on this critical production system. Therefore, the objective of this study was to determine the impact of wheat residue management on soybean growth and productivity in a wheat–soybean double-crop system. It is hypothesized that residue management will influence soybean stand densities and plant growth characteristics, thereby influencing final grain yield.

Core Ideas

- Double-crop soybean systems were significantly affected by residue management prior to planting.
- Planting double-crop soybeans into managed, non-tilled residue resulted in higher yields, better in-season growth, and higher placement of first harvestable node.
- Residue management did not consistently influence early-season stands.

2 | MATERIALS AND METHODS

2.1 | Site location

Trials were established in two distinct growing systems in northeastern Louisiana. In the fall of 2011, plots were established at the Northeast Research Station in Saint Joseph, LA (31.9186°N, 91.2383°W), on a Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquert). The following fall, plots were established at the Macon Ridge Research Station in Winnsboro, LA (32.1633°N, 91.7233°W), on a Gigger silt loam (fine-silty, mixed, active, thermic Typic Fragiudalf). Prior to establishment of plots, the land at St. Joseph was dedicated to wheat followed by rice production, whereas land at Winnsboro was fallow followed by cotton. Both trials were conducted through the 2014 growing season, and treatments were maintained in the same plots throughout the experiment. Annual precipitation and temperature for both locations

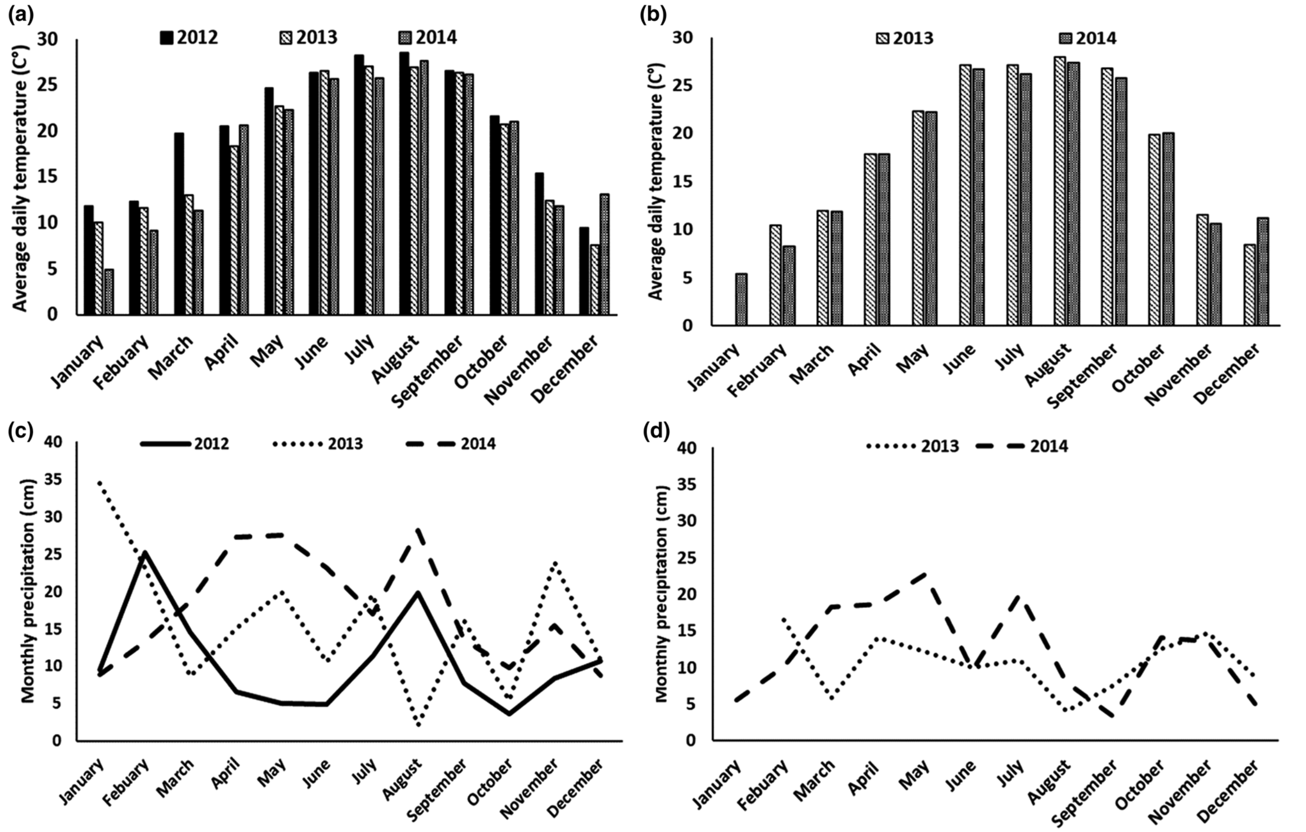

FIGURE 1 Average monthly temperatures and monthly precipitation distribution for Saint Joseph, LA, from 2012 through 2014 (a and c) and for Winnsboro, LA, from 2013 through 2014 (b and d).

throughout the trial are shown in Figure 1. Both locations were under furrow irrigation.

2.2 | Treatments and experimental design

A detailed description of all agronomic practices conducted at both locations is provided in Table 1. Four wheat residue management treatments were evaluated at both locations, including (i) tilled, (ii) planting into burned residue (burned), (iii) planting into mowed residue (mowed), and (iv) planting into standing residue (no-till). The same methods and equipment were used between locations to reduce potential differences due to planting or treatment implementation. The no-till treatments consisted of soybean planted into standing wheat residue, with heights ranging from 20 to 30 cm. In the burned treatments, winter wheat residue was burned immediately after harvest. For the mowed treatments, a 1.5-m-wide Brush Hog was used to shred the standing wheat stubble to between <1 and 3 cm high or approximately ground level and to distribute the shredded material throughout the plot. This variability was due to the contour of the bed, resulting in decreased height at the top of the bed and taller residue in the furrows. For the tilled treatments, plots were disked immediately after harvest. Follow-up tillage was conducted within 24 h of initial tillage using a field cultivator, and beds were remade using a custom bedding hipper (AMCO Manufacturing, Inc.) implement. Treatments were arranged in a randomized complete block design with four replications.

2.3 | Trial management

A composite soil sample was collected prior to each site establishment in October 2011 for Saint Joseph and in October 2012 for Winnsboro. The soil samples were analyzed at A&L Analytical Laboratories (Memphis, TN), and LSU AgCenter recommendations were used to guide nutrient analysis for the remainder of the experiment. For each season, P, K, and micronutrient fertilizer were applied based on soil sampling prior to planting of the winter wheat crop. Phosphorus applications were made using triple superphosphate (0-45-0), whereas all K application was applied using potassium chloride (0-0-60). All N for the winter wheat was applied in-season after jointing but before heading. Nitrogen was applied as a mix between urea (46-0-0) and ammonium sulfate (21-0-0-24) (Table 1). No further fertilizer was applied for either the winter wheat or soybean crop.

TABLE 1 Agronomic management practices conducted throughout the trial at Saint Joseph and Winnsboro locations from 2012 through 2014

Site	Year	Wheat harvest and residue treatment	Soybean planting	Soybean variety	Soil organic matter	Wheat fertilizer application[a]			Wheat grain yield
						N	P	K	
					g kg^{-1}	kg ha^{-1}			Mg ha^{-1}
Saint Joseph	2012	4 June 2012	4 June 2012	P95Y01	2210	134.4	67.0	44.8	6.3
	2013	12 June 2013	12 June 2013	P95Y01	–[b]	112.0	67.0	44.8	5.1
	2014	10 June 2014	11 June 2014	51-R50	–	112.0	67.0	44.8	4.5
Winnsboro	2013	8 June 2013	9 June 2013	P95Y01	1580	134.4	89.6	89.6	5.5
	2014	10 June 2013	11 June 2014	51-R50	–	112.0	89.6	89.6	5.7

[a]Fertilizer application made prior to 31 on the Zadoks wheat scale (jointing).
[b]Baseline soil organic matter contents collected prior to trial establishment at both locations.

The winter wheat crop was grown on beds similar to the successive soybean crop. The wheat crop was then broadcast planted using a 1.5-m linear applicator (Gandy Company) and incorporated by reforming the beds using a custom-built bedding hipper. The wheat cultivar planted was SY Harrison (AgriPro). Beds were established on 102-cm-wide row spacing. Although the drill seeded wheat would potentially provide a better stand in flat planted wheat, not only does broadcast provide adequate, if not better, stands in bedded systems, but this is also the most common wheat planting technique for growers intending to proceed with double-crop soybean production in the lower Mid-South. All winter wheat management was carried out based on current LSU AgCenter recommendations across the entire trial. At maturity, winter wheat was harvested using a John Deere 9610 combine. Wheat grain yield was collected and is reported in Table 1. Wheat stubble was cut at ∼20–30 cm to allow for adequate residue remaining for the no-till and mowed treatments. Immediately after harvest, residue management treatments were applied.

Planting of all soybean plots was conducted at the same time. This resulted in other treatments planting being delayed to match tilled treatments; however, this delay in planting was never >24 h. The soybean variety used was REV 49R94 (Terral Seed, Inc.). After soybean planting, four-row plots were established measuring 3.05 m in width and 6.70 m in length with 1.52 m alleys in between replications. After the initial establishment of plots, permanent markers were put in place so plots could be maintained throughout the experiment. Management of fertility, insect, weed, disease, and irrigation was based on current LSU AgCenter recommendations for wheat and soybean production. Irrigation was applied to ensure adequate plant-available water across all treatments. Emergence date was determined on the trial as a whole when >75% soybeans planted had emerged, based on comparing stands with the seeding rate. At 7 d after emergence (DAE), stand density and plant height were determined. Stand density was determined by counting the number of emerged soybean plants from randomly selected 1-m row lengths for all four rows for every plot (i.e., stand density was determined for every row of the trial and averaged to determine by plot values). Plant height was determined for 10 randomly selected plants in each plot by measuring the distance from the soil surface to the highest fully unfurled trifoliate or cotyledon. Additionally, plant height was determined 20 DAE in the same manner as described above.

When soybeans reached the R7 growth stage (i.e., physiological maturity), 175 g a.i. ha^{-1} of paraquat (N,N′-dimethyl-4,4′-bipyridinium dichloride) was used to desiccate the soybean crop. Once the soybeans reached the R8 growth stage (i.e., harvest maturity), 10 plants were randomly selected from each plot to determine final agronomic growth parameters. Plant height was determined by measuring from the soil surface to the highest point on the plant. In a similar procedure, height to first harvestable node (HFN) was measured from the soil surface to the lowest seeded pod. This was often the lowest pod; however, on the occasion where a nonseeded pod was the first pod encountered, it was omitted. Total node number was determined from the same plants selected. Node number was determined by counting actual nodes from the soil surface to the final terminal node. Nodes were counted for total node number whether pods were present or not.

2.4 | Statistical analysis

Statistical analysis software (SAS, 1994) was used for all statistical analysis. Normality analysis, using Procedure Univariate, was used to ensure the normality of in-season growth, yield, and growth at maturity data. Analysis of variance was used to determine the significant differences between residue management treatments and in-season plant growth, yield, and growth at maturity analysis using Procedure Mixed. Within these models, the variable of residue management was used as a fixed variable, and year, location, and replication were considered random variables. Post hoc analysis was done using Tukey's adjustment of least square means, with an $\alpha = .05$.

TABLE 2 *P*-values for main and interactive effects on soybean yield, stand density, plant height, height to first harvestable node (HFN), and total node count (TNC) for trials at Saint Joseph and Winnsboro, LA

Variable		Soybean yield	Stand density	Plant height 10 DAE[a]	Plant height 20 DAE	Plant height End of season	HFN	TNC
Saint Joseph								
Fixed effect	Residue management	**<.001**[b]	.312	**.0419**	**.02**	.221	**.036**	**.044**
Random effect	Year	**<.001**	.124	.085	.273	.187	.260	.629
	Year × residue management	**.017**	.657	**.039**	**.008**	.581	.185	.548
Winnsboro								
Fixed effect	Residue management	**<.001**	.485	.412	.185	**.042**	**.018**	.171
Random effect	Year	.919	.396	.839	.104	.185	.049	.089
	Year × residue management	.632	.569	.791	.397	.639	.116	.201

[a]Days after emergence.
[b]Bold values indicate significant interactive effects ($p < .05$).

TABLE 3 Early-season growth parameters for Saint Joseph location from 2012 through 2014

Year	Residue management	Stand density no. plants m^{-2}	Plant height 10 DAE[a] cm	Plant height 20 DAE
2012	No-till	10.4a[b]	2.8b	4.3b
	Mowed	11.5a	4.3a	7.9a
	Burned	12.1a	4.5a	7.4a
	Tilled	11.7a	3.8a	6.1a
2013	No-till	11.8a	3.3a	7.6a
	Mowed	12.4a	3.9a	8.1a
	Burned	12.6a	3.8a	8.1a
	Tilled	11.9a	3.3a	7.8a
2014	No-till	12.0a	2.6a	6.1a
	Mowed	12.2a	3.1a	6.6a
	Burned	12.4a	3.1a	6.9a
	Tilled	12.1a	2.5a	6.1a

[a]Days after emergence.
[b]Different letters within the same column within a single year indicate significant differences ($p < .05$).

3 | RESULTS AND DISCUSSION

3.1 | In-season growth parameters

A significant interaction between residue management treatments and year was found for plant height at both 10 and 20 DAE at the Saint Joseph location (Table 2). Therefore, stand density and plant height measurements will be discussed independently by year.

The only significant influence of residue management on early-season growth was found with plant height during the 2012 season at Saint Joseph (Table 3). During the 2012 season, a significant decrease in plant height at 10 and 20 DAE was found for no-till treatments compared with other residue management treatments. High residue levels, especially the initial year after converting between conventional and no-till production, can result in decreased growth (Hairston et al., 1987). Wheat grain yield at Saint Joseph was 6.3 Mg ha^{-1} in 2012, and grain yields in 2013 and 2014 were 5.1 and 4.5 Mg ha^{-1}, respectively. The high grain yield in 2012 indicates that there was likely a greater amount of residue during the 2012 season. This is a probable cause for the decrease in plant height that was found at Saint Joseph in 2012. In 2013 and 2014 for both Saint Joseph and Winnsboro (data not shown), there was no significant difference between residue management systems and early-season soybean growth.

Yields from double-crop systems are traditionally reduced compared with their full-season counterparts (Kane et al., 1997). This is often due to the shortened growing season resulting in decreased vegetative growth periods and lower leaf area accumulation of these systems. Although yields cannot typically reach those of full-season soybeans, early emergence and early-season growth are critical to optimize productivity. The lack of response of soybean plant height early in the season to residue management has been more predominantly seen in the literature (Brye et al., 2007a, 2007b; Chastain et al., 1995). Although Cordell et al. (2007) found an influence of residue on soybean populations 8 d after planting, these differences were not present at 10 and 30 d. Additionally, they noted that leaf area index values were not influenced by residue burning or wheat residue level at 90 d after planting. Brye et al. (2007) and Chastain et al. (1995) also found no negative effect of residue level on soybean emergence or height; in fact, increasing residue levels typically increased early-season plant growth.

3.2 | Soybean grain yields

Soybean grain yields varied considerably across treatments at both locations (Figures 2 and 3). A significant residue

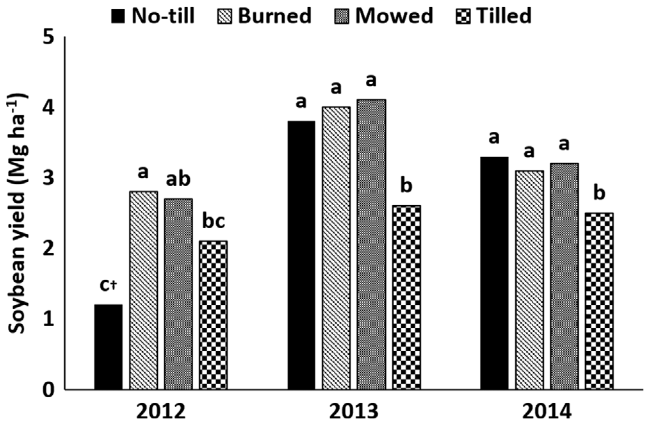

FIGURE 2 Influence of wheat residue management on double-crop soybean yields in Saint Joseph, LA, from 2012 through 2014. Different letters within the same year indicate significant differences in yields ($p \leq .05$).

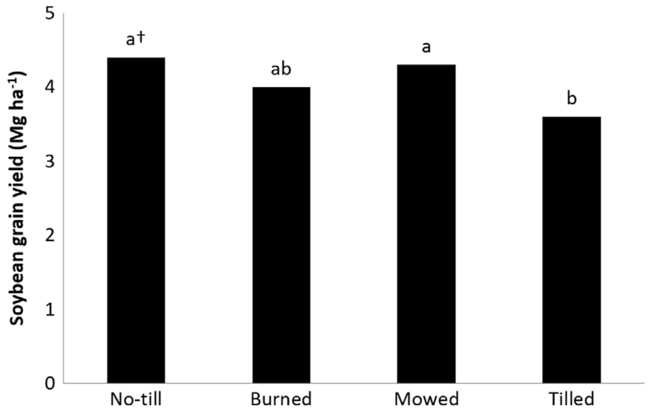

FIGURE 3 Influence of wheat residue management on double-crop soybean yields in Winnsboro, LA, pooled across 2013 and 2014 seasons. Different letters indicate significant differences in yields ($p \leq .05$).

management × location interactive effect was noted; therefore, yields were analyzed separately for the Winnsboro and Saint Joseph locations. For Saint Joseph, a significant treatment × year interaction was present; therefore, results were analyzed and will be discussed separately between years. A significant treatment effect was noted for all years of the study (Figure 2). With the exception of 2012, no-till planting of soybean following wheat harvest yielded significantly higher than soybean planted following tillage. However, during 2012, no-till plots yielded significantly lower than all other treatments. Similar results were found from the early-season plant populations. Cordell et al. (2007) theorized that shifts in soybean establishment and early-season growth would influence yields at the end of the season. Hairston et al. (1987) found a significant decrease in plant height both 21 and 55 DAE for plots where residue remained standing compared with burned stubble, which translated into a significant decline in yield. However, in both 2013 and 2014, no significant differences were noted between no-till, mowed, and burned treatments; however, all of these residue management practices yielded higher than when the residue was tilled prior to planting.

The discrepancy in soybean yield between years at the Saint Joseph location can most likely be attributed to the warmer and drier conditions experienced at time of planting in 2012 (Figure 1). These warm and dry conditions resulted in unsuitable seedbed conditions and limited early-season growth, which is critical for double-crop soybean production. In addition, increased rainfall in August 2012 season stemmed from a precipitation event over a 48-h period associated with hurricane Isaac causing saturated to near-saturated soil conditions for a prolonged period during critical reproductive stages.

At the Winnsboro location, no significant year × treatment effect was present. This allowed for yields to be pooled across the 2013 and 2014 seasons (Figure 3). Similar to the results found at Saint Joseph, yields from the tilled plots were significantly lower than those in no-till or mowed conditions. The benefits of residue and lack of tillage on soils were highlighted by Boquet et al. (1997). They indicated that using practices that maintained residue on the soil surface was critical to optimize production because of how easily eroded, drought prone, and low in organic material these soils were. Additionally, burned treatments did not significantly differ from any other treatments. The lack of agronomic benefits of residue burning has also been noted in the literature (Cordell et al., 2007; NeSmith et al., 1987). NeSmith et al. (1987) indicated that the lack of agronomic benefit from residue burning was associated with adverse soil effects, specifically lower soil moisture.

3.3 | End-of-season growth parameters

The response of the end-of-season growth parameters to residue management practices varied across site but not years (Table 4). Total nodes were found to be significantly different only at the Saint Joseph location, with no-till treatments having significantly fewer total nodes than other residue treatments. At the Winnsboro location, plant height did vary with residue management treatment, with increased height in no-till plots compared with the burned wheat residue. The influence of crop residue on crop height has been mixed; however, most literature suggests that leaving crop residue will either have no impact on crop height or result in an increase (Warren, 2014). Hovermale, Camper, and Alexander (1979) theorized that taller plants could result in increased growth rate response from altered red/far-red ratios, similar to that found with high soybean planting populations. Nelson, Smoot, Bliefert, and Kittle (2001) further emphasized this concept demonstrating that soybeans were ~25% taller when planted into 25-cm stubble as opposed to similar residue loads that had been mowed.

TABLE 4 End-of-season growth parameters for Saint Joseph and Winnsboro locations from 2012 through 2014, pooled across years

Location	Residue management	Plant height	HFN[a]	Total node count
		cm		no. plant^{-1}
Saint Joseph	No-till	29.6a[b]	7.5a	13.4b
	Mowed	30.5a	5.7b	17.3a
	Burned	31.4a	4.1c	16.7a
	Tilled	30.9a	3.9c	16.6a
Winnsboro	No-till	36.5a	7.7a	12.4a
	Mowed	36.1ab	7.5ab	11.9a
	Burned	33.5b	6.5c	12.7a
	Tilled	34.2ab	6.8bc	12.2a

[a]Height to first harvestable node.
[b]Different letters within the same column within a single year indicate significant differences ($p < .05$).

Although plant height can demonstrate fluctuations in soybean growth associated with residue management treatments, the influences of these imposed treatments on HFN can have a major impact on soybean yields. Grabau and Pfeiffer (1990) noted that soybean pods are typically harvested at 7.5 cm above the soil surface. If a substantial number of pods occurs below this point, significant yield losses can occur (Edwards & Purcell, 2005). The HFN showed a similar trend to residue management for both Winnsboro and Saint Joseph (Table 4). For the Saint Joseph location, no-till treatments had significantly higher HFN values compared with all other treatments. Although mowed residue treatments were lower than no-till, they were significantly higher than both burned and tilled treatments, which were not different from one another. At Winnsboro, no-till and mowed treatments were not significantly different, but both were significantly higher than the burned treatments. No significant difference was measured between tilled and burned treatments. Per the results of this study, several residue management options (mowed, burned, and tilled in Saint Joseph as well as burned and tilled in Winnsboro) had the potential for loss of soybean yield due to harvestable nodes being below the critical 7.5-cm harvest height (Grabau & Pfeiffer, 1990). However, differences in harvest height did not have similar trends to that found on crop yield throughout the trial, especially at the Saint Joseph location. This would indicate that yield loss associated with the burned treatments, especially at the Winnsboro location, were due to factors other than shortened HFN.

4 | CONCLUSIONS

The results of this study indicate that residue management has a significant impact on double-crop soybean systems. At both the Winnsboro and St. Joseph locations, tilling residue prior to planting, rather than leaving standing residue, resulted in lower soybean grain yields, with the exception of 2012 at the St. Joseph location. Planting the crop without tillage but while managing the wheat residue (e.g., by mowing) produced consistent and favorable yields across production systems and years. Burning of crop residue prior to planting did not provide consistent agronomic benefit compared with mowed or no-till plots. With modern equipment and varieties, the study demonstrated that similar stands could be achieved when residue was maintained on the soil surface. In adverse conditions, such as those at the Saint Joseph location in 2012, not managing the previous crop residue can result in significant declines in double-crop yield. However, practices that minimize the negative impacts of the residue but that maintain residue on the soil surface, such as the mowed treatment, may result in favorable yields, good in-season growth, and first node height that would allow for minimal yield losses across a wide range of environmental conditions and production systems.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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