Claypan soils in the Midwest cover approximately 9.6 million acres. These soils drain poorly, partly because of an argillic claypan layer 3.8–7.0 inches below the soil surface, and are commonly classified as highly erodible. Conservation tillage is recommended on claypan soils to reduce soil loss. Cropping systems have shifted from a corn–soybean–wheat rotation to a corn–soybean rotation due to economic considerations and relatively strong corn and soybean prices. Crop rotations using small grains such as wheat can increase water infiltration, organic matter, and soil structure and can reduce soil erosion from surface water runoff.

Farmers in the Midwest have used double-crop soybean production to increase profitability of wheat. Relay intercrop production has been proposed in this region because double-cropping soybean after wheat is risky due to low rainfall and dry soils at planting and a relatively short growing season that is limited by an early fall frost that can reduce grain yield. Relay intercrop soybean production has been challenging in upstate Missouri due to dry weather in mid- to late June, especially on claypan soils that are prone to drought. Dry conditions during this period caused stress to soybean plants, reduced harvested stand, and reduced yield of relay-intercropped soybean.

Relay intercrop production involves overlapping growth cycles of two or more crops. Intercropping is common with legumes seeded into small grains. Relay intercropping soybean into wheat before wheat harvest has been proposed as a method to reduce risk associated with double-crop soybean production and to increase farm profitability. This cropping system may also allow farmers to more easily qualify for low-risk Federal Crop Insurance because soybean is seeded before the double-crop soybean cutoff date. Specifically, soybean relay intercropped into wheat involves seeding wheat in the fall and intercrop seeding soybean into standing wheat in the spring.

Previous research has evaluated relay-intercropped soybean planted in the southern United States, Missouri, Kansas, and Nebraska using solid-seeded wheat or skip-row wheat planting patterns. Late-planted soybean resulted in mechanical planter injury to the wheat that reduced wheat grain yields from 0 to 34%. Other research evaluated the effects of travel lanes and skip rows in wheat to help solve these problems, but widespread adoption has been limited because specialized field equipment and field layout was required. Soybean grain yield in a relay intercrop system has ranged from 27 to 72% of full-season soybean while grain yields were 0 to 35% greater than double-crop soybean. Solid-seeded (7.5-inch-wide rows) and skip rows (30-inch-wide rows) planted at heading were the most successful when wheat injury was minimized. However, earlier soybean planting dates lowered wheat grain yields due to soybean interference while harvest damage to soybean resulted in some instances. In Kansas, relay intercrop soybean increased gross returns over double-crop wheat–soybean or wheat, but gross returns were equal to monocrop soybean.
Since this previous research was conducted, the industry has seen the introduction of glyphosate-resistant and polymer-coated soybean technology, widespread use of planters on 15-inch-wide row spacings, and tractor guidance systems for specialized no-till soybean production. Polymer-coated seed technology regulates germination based on soil temperature and moisture levels. This may allow earlier relay intercrop soybean planting dates and reduce mechanical damage to wheat. Delayed soybean germination may also reduce interference between wheat and soybean. However, additional cost of the polymer coating may affect farmers’ decisions to use this technology in a relay intercrop production system. It appears that using glyphosate as a wheat harvest aid would reduce the impact of wheat on relay-intercropped soybean grain yield.

In a recent *Agronomy Journal* article, researchers report on a study in which they evaluated (i) the impact of glyphosate harvest aid application timings on wheat and relay-intercropped soybean grain yields compared with full-season soybean, double-crop wheat–soybean, and wheat only production systems as well as (ii) the cost effectiveness of these production systems.

### Materials and methods

Field experiments were conducted in 2003, 2004, and 2005 at the University of Missouri Greenley Research Center near Novelty and the Hundle–Whaley Center near Albany in 2004. The experiment was arranged as a randomized complete block design with four replicates each year. The soil was a Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs) at Novelty and a Grundy silt loam (fine, smectitic, mesic Aquic Argiudolls) at Albany. Soil properties, cultural practices, and planting dates are available in the *Agronomy Journal* article (see citation below). Crops were fertilized with ammonium nitrate, monosodium phosphate, and muriate of potash as recommended by the University of Missouri Soil Test Lab.

‘Pioneer 25R37’ soft red winter wheat was no-till seeded at 111 lb/ac in 7.5- and 15-inch rows. Soybeans were no-till planted in 15-inch rows. ‘Hubner 431NRR’ soybeans treated with the Intellicocat Polymer System (Landec Ag Inc., Monticello, IN) were planted in the relay intercrop system. Noncoated ‘Hubner 431NRR’ were planted in the full-season and double-crop production system. Soybean plots were maintained weed-free with two postemergence applications of glyphosate plus diammonium sulfate.

Glyphosate as Roundup WeatherMAX (Monsanto Co., Wheaton, IL) spaced 20 inches apart and 19 inches above the canopy. Wheat development stage was determined on June 20 and 24 of each year at the Novelty sites. Soybean plots were maintained weed-free with two postemergence applications of glyphosate.

At Novelty, wheat samples were collected from each plot to determine test weight. Double-crop soybeans were planted the same day wheat was harvested, and soybean population was determined before harvest in each plot. All plots were harvested with a small-plot combine. Moisture and grain yield were determined at Novelty and Albany, and yield adjusted to 13% moisture before analysis.

An economic analysis evaluated gross margins of wheat and soybean production systems, using the product of yield and average receipts for wheat and soybean over the past three years minus input costs to calculate gross margins for the different cropping systems. Discounts from reduced test weights among treatments were not included in the analysis due to variability among locations in the Midwest. Gross margins for full-season soybean and selected relay intercrop or double-crop production systems were evaluated for different wheat and soybean price scenarios based on market fluctuations over the past years.

### Results and discussion

Glyphosate applied as a harvest aid to wheat caused necrosis of the entire plant approximately five to seven days after application. Wheat maturity was faster with a preharvest application of glyphosate on June 10 or 17 (two to three weeks before wheat harvest) than nontreated wheat. On June 20, wheat treated with glyphosate on June 10 and 17 was in the hard and soft dough stages of development, respectively, while nontreated wheat was between the late milk and early dough stages. Similarly, nontreated wheat four days later (June 24) was between dough and ripening while glyphosate-treated wheat had already developed hard kernels. Premature plant death with glyphosate two to three weeks before harvest (June 10 and 17) in 2003 and three weeks (June 10) before harvest in 2005 reduced grain density (test weight) 3 to 13% compared with the nontreated control. Narrow-row wheat yields were 11 bu/ac greater than wide rows in this study. Wheat grain yield was reduced when glyphosate was applied two to three weeks (June and 17) before harvest compared with nontreated wheat. However, the harvest aid applied one week before harvest (June 24) did not affect wheat yields compared with the nontreated control.

Overall soybean plant population at harvest was greatest for narrow-row wheat–double crop–soybean and wide-row wheat–double crop–soybean followed by full-season soybean. The researchers found no difference in soybean population at harvest among harvest aid treatments in a relay intercrop production system. Relay intercrop soybean grain yield with no harvest aid was 14
to 28% (4–7 bu/ac) greater than all double-crop soybean. Glyphosate applied to wheat for the relay intercrop soybean one, two, and three weeks before wheat harvest increased soybean yields 14 to 23% when compared with relay-intercropped soybean with no harvest aid treatment.

Dry conditions during June caused moisture stress to soybean plants, reduced harvested stand, and reduced the yield of relay-intercropped soybean in other research. The use of a harvest aid reduced interference between wheat and soybean. Subsequently, soybean grain yield when glyphosate was applied to wheat one to three weeks before harvest in a relay intercrop system was greater than double-crop soybean and had no risk of an early fall frost reducing grain quality or yield since relay-intercropped soybean maturity was similar to full-season soybean (visual observation). The integration of new technology and a harvest aid treatment into relay intercrop production systems may allow farmers to avoid the need for specialized equipment and field layouts, reduce mechanical injury to plants due to late seeding, and increase production that was previously limiting adoption.

Gross receipts and expenses were greatest for relay intercrop soybean treated with a harvest aid on June 24, approximately one week before harvest. Cropping system gross margins with wheat at $5.84/bu and soybean at $8.63/bu were similar for full-season soybean, wide-row wheat with a June 24 harvest aid and relay intercrop soybean, narrow-row wheat followed by double-crop soybean, wide-row wheat with a June 17 harvest aid and relay intercrop soybean, wide-row wheat and delay intercrop soybean, narrow-row wheat with a June 24 harvest aid followed by double-crop soybean. All cropping systems in upstate Missouri that included relay intercrop or double-crop soybean were more profitable than wide- or narrow-row wheat alone.

Additional economic analysis evaluated gross margins of full-season noncoated soybean, wide-row wheat and relay intercrop coated-soybean with a June 24 harvest aid application, and narrow-row wheat double-cropped with noncoated soybean over a range of wheat and soybean price scenarios (Fig. 1). At high wheat and soybean prices, the wheat (harvest aid) relay intercrop soybean system had higher gross margins than wheat (no harvest aid) relay intercrop soybean or wheat double-crop soybean systems. However, wheat double-crop soybean gross margins were greater than relay intercrop systems when wheat prices decreased. Gross margins of full-season soybean were less than relay intercrop or double-crop soybean when wheat was $6/bu and soybean was less than $7.62/bu, but full-season soybean gross margins were greater once soybean prices exceeded $7.80/bu. High soybean prices were required for full-season soybean to have gross margins similar to relay intercrop systems when wheat was $9/bu.

A relay intercrop production system could help economically maintain wheat in the crop rotation as demonstrated in other research. Profit and loss margins of full-season, relay intercrop, or double-crop production systems depended on relative wheat and soybean prices.

**Conclusion**

Glyphosate applied to wheat one week before wheat harvest or after the late dough stage of wheat development (Zadok stage 87) in a relay intercrop production system with coated soybean maintained wheat grain yields similar to nontreated wheat and increased soybean grain yields when compared with nontreated wheat relay intercrop or double-crop soybean. Earlier glyphosate application timings (two and three weeks before wheat harvest) reduced wheat grain yields and test weight but increased soybean yield.
Based on these results, farmers could use glyphosate as a harvest aid to reduce the impact of wheat interference on soybean yield in a relay intercrop system. Applicators should carefully follow label restrictions for preharvest wheat applications and be cognizant of the stage of wheat development, minimum preharvest interval, and restrictions on wheat grown for seed.

This research indicated that profitability of relay intercrop soybean depended on relative wheat and soybean prices. A relay intercrop production system on claypan soils prone to drought stress with glyphosate as a harvest aid may allow farmers in the Midwest to profitably maintain wheat in their crop rotation while minimizing risk associated with an early fall frost or dry conditions at seeding that may otherwise decrease double-crop soybean yields.