ABSTRACT

Strip intercropping of corn and soybeans can result in improved corn yields but at the cost of reduced soybean yields. Additionally, machinery and labor costs may be increased with strip cropping due to the use of smaller equipment. We present a systematic comparison of the relative net revenue differences for a large-scale corn-soybean operation under conventional and strip intercropping production practices. Although strip intercropping resulted in greater gross receipts than monoculture within a field, costs of machine ownership and operation and labor were much higher, resulting in lower net returns.

Potential Profitability of Strip Intercropping with Corn and Soybeans

By Barry Ward, Brian E. Roe, and Marvin T. Batte

Introduction

Agronomic trials suggest that planting narrow strips of corn and soybeans side by side in the same field can generate greater total revenue than planting the equivalent number of acres in large, monoculture fields (Lesoing and Francis, 1999; West and Griffith, 1992; Verdelli, Acciaresi, and Leguizamon, 2012). This approach, which is referred to as strip intercropping, may improve the efficiency of light reception for the taller crop (corn), though at the expense of shading the shorter soybean crop.



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Recently, trials reporting the effects of strip intercropping on corn yields in industry publications (Winsor, 2011) have sparked the imagination of many farmers and affiliated professionals in the North American field crop sector, leading to increased interest in the potential profitability of such a change in cultivation practices. However, these trials did not consider the full cost-side ramifications of altered cropping systems for modern, large-scale corn and soybean production systems nor did these studies explore sensitivity of results to crop prices. Both are crucial for understanding the relative appeal of this cropping system to commercial US farmers and are the focus of this work.

We systematically compare the relative net revenue differences for a large-scale (5,330 acre) corn-soybean operation under two cultivation systems: (1) traditional cultivation practices where each field involves monoculture cultivation of either corn or soybeans; and (2) a strip intercropping system featuring narrow strips of corn and soybeans in each field. We begin by comparing farm-level gross revenue differences between the two systems under a range of relative corn and soybean prices, weather conditions and strip widths. Relative prices for corn and soybeans are critical as the existing agronomic trials suggest that, as the shorter crop, soybean yields suffer at the expense of improved corn yields. Hence, the strip intercropping regime is more attractive when relative corn prices are higher. Weather conditions are critical as some agronomic trials reveal that dry weather alters the competition for water among the edge rows of the two crops and that soybean edge rows suffer proportionally greater yield losses in dry conditions (Bullock et al., 2015; Lesoing and Francis 1991; Verdelli, Acciaresi, and Leguizamon, 2012). Finally, the agronomic research suggests that yield effects are concentrated in the outer two rows of strips where light and water competition between the two crops is most intense (Bullock et al., 2015). Implementing wider strips implies that a smaller proportion of each crop will be subject to changes in yield. However, while enhancing the yield effect for corn, smaller strips require more passes for planting, spraying and harvesting operations and smaller width equipment. Each has implications for the labor and capital expenses associated with the strip intercropping approach, which we explore for corn production.

Literature Review

Past studies have focused primarily on yield impacts and yield components in a strip intercropping system (see Table 1 for a summary). Gross revenues of strip intercropping systems and monoculture control systems have been compared as a way to evaluate the economic impact of the intercropping systems approach. A Purdue Study (West and Griffith, 1992) examined the yield effects by row for an 8-row strip intercropping system compared to a conventional mono-crop system over a five- year period (1986-1990). With regular management, the outside row of corn in the intercrop system yielded 20 percent higher than the mono-crop control plot. Corn rows next to the border rows did yield higher as expected (5%) although the yield increases were much lower than the border rows. Outside border soybean rows yielded 22 percent lower than inner rows. This study also examined the potential for an increased level of management ("high management") to produce larger corn yield responses. "High management" in this study consisted of increased seeding rates and nitrogen application amounts. The two outside rows in this study produced 27 percent higher corn yields than inner rows. Consistent with the "regular management" system, rows adjacent to the border rows yielded more than the inner rows but much less than the border rows. These rows adjacent to the border rows yielded two percent more than inner rows.

Corn strips in the intercropping system averaged nine percent higher yields than monoculture corn while soybean yields in the strip intercropping system averaged twelve percent less than the monoculture check. West and Griffith found that the value of the additional corn yield in the intercropped system was almost entirely offset by the reduced value of lower soybean yields. Gross return improvements to a strip intercropping system in their study were $1.32/acre for "regular management" plots and $3.65/acre for "high management" plots relative to crop monoculture in field units.

A similar study by Lesoing and Francis examined the effects of strip intercropping on yield and yield components of corn, grain sorghum and soybeans in eastern Nebraska. Conducted from 1988 through 1990, this research examined corn-soybean intercropping systems and grain sorghum-soybean intercropping systems under both rain-fed and irrigated conditions. Corn border rows showed significant yield improvement over inner rows in all years in both rain-fed and irrigated conditions. Corn border row yield improvement ranged from a high of 23 percent in the 1989 rain-fed plots to a low of 3 percent improvement in the 1988 rain-fed plots. In line with predictions, soybean border rows in intercropped plots showed marked declines in yield. Soybean border rows had yields zero to twenty-four percent lower than inner rows depending on year and moisture conditions. The system with the largest border row soybean loss was the 1989 rain-fed system with a 24 percent yield loss. The intercropped systems from the drought year of 1988 featured the smallest soybean yield loss; the rain-fed and irrigated plots each featured no soybean yield loss.

Lesoing and Francis found that corn-soybean strip intercropping returned $5.67 to $10.12 more gross revenue per acre than monoculture systems in this study, although these differences were not statistically significant. Based on this three-year study, there is no revenue advantage to the strip intercropping system.

In Argentina, Verdelli, Acciaresi, and Leguizamon (2012) evaluated corn and soybeans grown in 12-row strips for three crop seasons, 2006-2008. They found that corn outer rows yielded 35-46 percent more than the center row of the strip. They found no significant difference in the yield between the center row in the strip and the center row in a corn monoculture. They found that border row soybean yield decreased relative to the center row of the soybean strip. Soybean yield decreases in outer rows ranged from 12 to 33 percent of center row yields. They also found no statistically significant difference in the yield for the center row in the strip and the center row in a soybean monoculture.

An Illinois study by Bullock et al. (2015) evaluated the performance of a corn-soybean strip intercropping system in 2009-10. Normal moisture in 2009 and below normal moisture in 2010 allowed these researchers to evaluate these systems under two different moisture environments. This research found significant improvement in border row corn yields. Under normal moisture conditions (2009), border row corn yields were 37 percent higher than inner rows in this 8 row corn intercropped strip. Rows adjacent to border rows had a yield increase of eight percent over inner rows. Soybean yields on the other hand, showed marked decreases.

Border row soybeans yielded 23 percent less than inner rows while rows adjacent to border rows yielded 2 percent less than inner rows. In the below normal moisture environment in 2010, border row corn yields again showed marked increases of 55 percent over inner rows while yields of rows adjacent to border rows were 18 percent higher than inner rows. Soybean yields in this below normal moisture setting were 29 percent lower than inner rows while rows adjacent to border rows were 12 percent lower than inner rows.

Gross Revenue Impacts

In this section, we compare the value of the corn yield premiums and soybean yield penalties based on data from the literature review for alternative strip widths and commodity price differentials. Differences in the costs of production between the cultivation systems will be considered in the next section. Our analyses are based on data from Bullock et al. (2015). We focus on these results because these experimental results span two recent years with modern seed genetics featuring typical growing conditions one year and dryer than normal conditions the next. Table 2 summarizes the yield impacts for corn and soybeans from these trials. Corn yield in the outer rows of the strip averaged 37 percent higher than the center row yields in the normal weather year, and 55 percent higher than the center row yields in the dry weather year. The second row corn yield was eight percent and eighteen percent higher than the center row yields for the normal and dry year, respectively. Soybeans, on the other hand, realized lower yields in the outer two rows: outer row yields were 23 percent and 29 percent less than center row yields in normal and dry years, respectively, whereas second row yields were 2 percent and 12 percent less than center row yields in normal and dry years.

Assuming that yield effects are limited to the outer two rows of the strip as described in Table 2, we estimate the gross revenue values for strip intercropping using various strip widths by assuming that any rows other than the two outside match the yield of the center rows from the Bullock et al. (2015) trials. We then compare this to the gross revenue for the conventional case – two fields of equal acreage, one of which is planted entirely in corn and the other in soybeans where all rows have a yield equivalent to the center rows from Table 2. For the moment we ignore the requirement of differing sized planting, spraying, and harvesting equipment: we simply assume that the farm has sufficient equipment of appropriate size to allow the strips to be planted within the same time window as for the conventional case. That is, in this analysis we are not allowing for the possibility of delayed field operations and possible planting-delay yield penalties.

We make gross revenue calculations for strip widths of 4, 6, 8, and 16 rows for both typical and dry weather conditions where corn is planted in 30-inch rows, soybeans are planted in strips of width equal to the corn strips, and headlands involve soybeans planted two strips wide where headland strips match strip width for the rest of the field. We also explore two levels of base crop prices (high and low) and three levels of relative crop prices (soy/corn price ratios of 2.0, 2.5, and 3.0). The base corn price under the low price scenario is $4/bu while the base corn price under the high price scenario is $7/bu for corn; soybean prices will be 2.0, 2.5 or 3.0 times the given corn price.

Table 3 displays the results of the gross revenue comparisons for the case of typical weather and lower commodity prices for five strip widths. The conventional system assumes center row yields for the entire acreage, and is displayed in the table with a constant gross revenue ($750/ac) for all strip width comparisons. For the strip intercropping case, gross revenue was greatest ($806/ac) for the 4-row strip width, declining to $751/ac for the 16-row strip width. Because the yield premiums for strip intercropped corn were relatively larger than the yield penalty for soybeans, the intercropping practice generated more value per unit land than the same crops grown in monoculture within the field. For the case displayed in Table 3, the gross revenue advantage ranged from $56/ac (7.4%) for the 4-row strips, to a modest $1/ac (0.1%) advantage for 16-row strips. Although it would be appealing to farmers to utilize existing large-sized equipment to strip crops of 16 to 24 rows, these analyses suggest that the gross value of yield improvements in that width of strip would be negligible.

Table 4 shows the advantage of strip intercropping at a 6-row width relative to conventional plantings for both normal and dry weather conditions, for higher and lower base commodity prices and for different ratios of soybean to corn prices. Although all yields are higher in the normal weather event, under dry conditions monoculture corn yields decrease by a greater percentage than do strip corn yield averages. Soybean yields perform in the opposite manner – six row soybean yield average decreases by a greater percentage with dry weather than does monoculture soybeans. Still, the corn yield increase outweighs the soybean decrease in all four scenarios of Table 4. Obviously, this advantage is greatest when soybeans are relatively "cheap" (e.g., Soybean/Corn price ratio is smaller). The most favorable constellation of conditions features dry weather conditions, high base prices for crops and low soy/corn price ratios. In this setting strip intercropping yields $75 more gross revenue per acre than the conventional system. This gross revenue advantage shrinks to $32 per acre if base prices are low and the soybean/corn price ratio is high. Notice that for a given price level the differential gross revenues for low and high moisture conditions are equal at the 3.0 ratio of soybean to corn prices. It happens that a soybean / corn price ratio of 3.0 equilibrates the differential increases in corn yield and the differential decreases in soybean yields.

Cost Impacts

Revenue is only one side of the ledger when considering such a substantial change in cultivation practices. We explore differences in labor and machine costs for a 5,330 acre corn/soybean operation to implement 15-foot strips of corn (6 rows). All other costs, including seed, chemical, and marketing costs, are assumed to be identical between the systems. Further, in the present analysis, we detail cost differences for corn only and assume soybean cost differences will follow in fixed proportion.

Several practical differences between the cultivation systems have cost implications that are immediately apparent. First, in many areas, corn and soybeans are often planted, sprayed, and harvested at different times of the year, necessitating that each field in an operation will have to be visited twice in a year for each operation. The alternative would involve planting either corn or soybeans outside of its ideal planting window. This would likely affect yield potential and is not considered in this analysis.

Second, great economies of size have been gained by farmers who utilize large-scale planters, sprayers and harvesters capable of covering swaths of crop considerably wider than the 15 feet/6-row strips considered in this analysis of strip intercropping. Hence, additional labor and machinery is required to sustain production at the large scale and narrow widths considered. Table 5 outlines the machinery requirements for traditional tillage while Table 6 provides an equivalent view for strip intercropping. Each system features many items with identical functions: tractor, chisel plow, field cultivator, fertilizer spreader, planter, anhydrous ammonia applicator, chemical sprayer, combine harvester with corn head, grain carts, and semi-trailer truck.

The difference between the systems is in the number of items needed and the width of each item. The inventory for the traditional system is chosen to meet the timeliness needs for planting, spraying, and harvesting windows given the area covered. The strip intercropping inventory was chosen to replicate the timeliness of production obtained under the traditional cultivation system. For example, under both systems, we assume the corn requires spraying three times during the growing season. In the traditional system, the 90-foot self-propelled boom sprayer, which has an assumed field efficiency of 0.65, operational speed of 5.6 mph and an associated field capacity of 39.6 acres per hour, accomplishes its three passes in 201.65 hours. In the strip intercropping system, we assume sprayer width matches strip width (15 feet). These smaller tractor-pulled sprayers are assumed to have a greater field efficiency due to narrow width (0.80) and an identical operational speed (5.6 mph).[1] However, the significantly narrower width drives down field capacity to 8.1 acres per hour, about one-fifth the capacity of the 90-foot self-propelled boom sprayer. To ensure the same three passes occur during the same time window, the strip intercropping machinery inventory includes five of the smaller tractor-pulled boom sprayers. Similar calculations were used to arrive at the need for three chisel plows, three field cultivators, two fertilizer spreaders, three planters, three anhydrous applicators, two combines, and four grain carts. Five tractors were needed to allow all pull sprayers to be used simultaneously, though the tractors are substantially smaller as the narrower machinery implements require fewer horsepower for operation.[2]

Tables 5, 6, and 7 capture the differential fuel use required to undertake corn operations between the two systems. More total hours spread across multiple implements are needed to complete field operations for strip intercropping (3135 vs. 1664, or about 88% more). However, the smaller widths imply that each propulsion unit uses significantly fewer horsepower to accomplish each operation. Indeed, the total horsepower brought to bear for the strip intercropping operation is 30 percent less, with 850 (50 hp tractor x 5 + 300 hp combine x 2) versus 1,210 for the conventional approach (250 hp tractor + 310 hp tractor + 400 hp combine + 250 hp sprayer). This results in nearly 50 percent less fuel use per acre for strip intercropping.

In our assessment we assume that 2,665 acres of corn are planted under both a traditional and under a strip intercropping system. Under traditional cultivation corn is planted in half of the 40 fields, while under strip intercropping corn is planted on half the area in each of the 40 hypothetical fields. In both cases, a 1.25 miles travel distance between fields is assumed, though we assess the sensitivity of cost results to changes in the assumption of between-field distance.

Table 7 provides a side-by-side comparison of machinery and labor costs associated with corn production under the two systems. The table reveals the core results of this partial budgeting exercise: labor and machinery ownership costs are higher under strip intercropping though fuel costs are less. The total wage bill is nearly double, as both field hours and hours spent in transition are considerably higher with strip intercropping. Machinery ownership costs, which consist of repairs, depreciation, interest, insurance and housing, are 90 percent higher with strip intercropping. While the smaller equipment may require less fuel, the sheer quantity of items means a dramatically higher ownership cost.

For all elements of this partial budget, we find strip intercropping to cost $63.26 more per acre than the conventional approach, representing a 53 percent increase in these core costs. Table 8 documents how three key assumptions – wage rate, fuel price, and distance between fields, alters the core cost finding. We explore a wage rate change from base of +/- 30 percent, a fuel cost change of +/- 21 percent, and reduction in distance between fields from 1.25 to 0.12 miles. The ratio of costs between strip intercropping and conventional systems is most sensitive to fuel price changes, followed closely by sensitivity to wage changes and is nearly insensitive to changes in the distance between fields. The combination that makes the cost of strip intercropping most competitive is the scenario with lower wages and higher fuel costs. In this case strip intercropping is only 47 percent more costly than conventional. For the highest wages and lowest fuel cost, strip intercropping is about 60 percent more expensive than conventional.

Overall Impacts

Tables 9 and 10 bring together gross revenue changes and cost changes affiliated with a change from the conventional system to a strip intercropping system, where negative figures are denoted in parentheses and represent situations where strip intercropping would result in a decrease in net revenue compared to a conventionally cultivated operation. In Table 9, we assume that cost differences for soybeans are identical to the cost differences for corn detailed in the previous section. The table presents changes in net revenue per acre for an array of assumptions concerning crop price levels, crop price ratios, moisture conditions, wage rates and fuel costs. The critical result is that strip intercropping would lead to net revenue improvements over a conventional production system only for high base prices for crops and for low soil moisture conditions, with the most favorable result occurring when corn has the highest relative price, wages are lowest and fuel is most expensive. In this setting strip intercropping would return $17 more per acre than the conventional operation. In any scenario featuring low base crop prices, strip intercropping results in lower net revenue than a conventional operation, with the least favorable scenarios generating up to $37 less per acre.

Table 10 calculates the same results under the assumption that the relative cost of production for soybeans under strip intercropping versus conventional is not as much as it is for corn. Specifically we look at a setting where the cost increases for strip intercropping soybeans are 15 percent less than the cost increases for strip intercropping corn. Given that soybeans would not require an anhydrous ammonia application, and may require one less spray pass, such an assumption may be reasonable. Even with this more favorable assumption for strip intercropping, the general pattern of results is similar in Table 10 as in Table 9 – only scenarios with high base crop prices lead to higher net revenue under strip intercropping. Each entry is approximately $4-5 per acre more favorable to strip intercropping under the assumptions maintained in Table 10.

Discussion and Conclusions

Strip intercropping is viewed as an opportunity to increase total crop production primarily because of greater efficiency of sunlight capture. Our analyses show that because the yield premiums for strip intercropped corn were relatively larger than the yield penalty for soybeans, the intercropping practice generated more value per unit land than the same crops grown in field-level monoculture.

Projecting from yield effects in recent Illinois field trials, we find the gross farm revenue improvements involved in implementing strip intercropping ranged from less than one percent to 9.2 percent. Narrower strips yielded substantially larger gross revenue relative to monoculture. Expansion to wider strip widths increasingly dilutes the higher-yield edges with wider center row segments, resulting in lower average yields and gross revenues. For example, in a year with normal rainfall and prices ($4/bu corn and $10/bu soybeans), implementing 4-row corn strips yields an increase in gross revenue per acre of $56 (7.4%) over monoculture, while a 6-row corn strip yields only a $34/acre improvement. The gross revenue advantage of strip intercropping all but disappears with strip widths of 16 rows.

Commodity price also is important, both in terms of absolute level and the relative level of prices for the crops in strips. A drop in commodity prices from $7/bu corn, $17.50/bu soybeans to $4/bu corn, $10/bu soybeans results in a decline in the 4-row strip advantage of $41.90/ac, assuming normal moisture. Because corn yields increase while soybean yields decline over the strip cropped area, an increase (decrease) in the soybean/corn price ratio decreases (increases) the revenue advantage of strip intercropping.

Of course, revenue is only one side of the ledger when considering such a substantial change in cultivation practices. We explore differences in labor and machine costs for a 5330 acre corn/soybean operation to implement 6 row crop strips. All other costs, including seed, chemical and marketing costs, are assumed to be identical between the systems. More total hours spread across multiple implements are needed to complete field operations for strip intercropping, nearly doubling the total wage bill for strip intercropping. Machinery ownership costs are 90 percent higher with strip intercropping as more, smaller implements and tractors are required to accomplish operations in a timely fashion. A key conclusion is that strip intercropping would lead to net revenue improvements over a conventional production system only for high base prices for crops and for dry soil moisture conditions, with the most favorable result occurring when corn has the highest relative price, wages are lowest, and fuel is most expensive. In this scenario, strip intercropping would return a modest $17 more per acre than the conventional operation. In other less favorable scenarios, increased costs of strip intercropping typically exceeded improvements in revenues.

These analyses do not consider the one-time costs of altering the machinery complement to allow the strip production system with narrow strips. Such transitional investment requirements might be a significant deterrent to farmer adoption of strip intercropping. On the other hand, our analyses also ignores possible yield boosts from decreased compaction resulting from the smaller equipment used in strip intercropping. Compaction related yield penalties are well documented, but their effect has not been isolated or the accumulated effect traced over time in current agronomic and pilot tests of strip intercropping yield comparisons. Further, additional work is needed to consider the potential profitability for smaller operations that currently possess smaller capacity equipment and may have the capability to expend additional time to plant, spray and harvest smaller strips without risking timeliness of each operational step. Also, we do not consider how row-specific management approaches within a strip intercropped system might affect yields or net revenues, where different planting populations and fertilizer levels for edge rows could spur further yield boosts for corn. Finally, all analyses here assume the prevailing machinery technology is employed for both monoculture and strip intercropping production systems. The advent of radical new technologies, for instance, small supervised autonomous (robotic) equipment, might greatly alter the cost calculus for farming small strips, allowing capture of yield advantages of very narrow strips without the much higher machine and labor costs calculated in this study.

End Notes

[1] Field efficiency is defined as the ratio of theoretical productivity of a machine to its actual productivity (White, 1978). Smaller machines have a higher field efficiency due to a smaller turning radius (less time required to turn), greater maneuverability around obstacles, and greater speed of movement from field to field, among other things. This simply says that a 16 foot implement can accomplish less than twice as much productive work as an 8 foot implement. We utilize these numbers, along with implement width and travel speed to determine the amount of time that each machine size will require to accomplish a given field operation.

[2] This analysis included investment in a complement of small equipment only. Consideration may be given to a mix of small and large equipment to accomplish field activities (i.e. large chisel plow and sprayer, small planters and combines) however a complement of small and large equipment will increase the necessary complement of power equipment and increase the machinery costs of the strip-intercropping system in this analysis. This type of equipment mix will cause the inter-cropping system to be less competitive with the conventional system.

Consideration may be also given to hiring custom farm operators to complete certain tasks (i.e. spreading dry fertilizer and tillage). While this may create some cost savings over the inter-cropping system analyzed, there are other considerations with this approach. Hiring custom operators to perform tillage on the entire acreage with larger equipment will interrupt rotational tillage if producers choose to engage in this type of production.

Hiring custom operators to broadcast spray fertilizer on a larger scale may also decrease costs to the inter-cropping system, however there may be continued environmental concerns in the future that may cause producers to limit this type of fertilizer application.

There are also timeliness issues to consider when hiring custom operators to complete field tasks but hiring custom operators to complete certain field tasks that may be done with larger equipment may decrease the machinery equipment costs in a strip-intercropping system and make it more economically competitive when compared to a conventional cropping system.

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Table 1. Yield effects for corn and soybean from the extant literature.

Source	Soil Moisture Status/Management	Crop Year	Corn Outer Row	Corn 2nd Row	Corn Inner Rows	Soy Outer Row	Soy 2nd Row	Soy Inner Row
Lesoing and Francis 1991	Below normal moisture	1988	78 (+3%)	NR	76	22 (-0%)	NR	22
Lesoing and Francis 1991	Below normal moisture	1989	102 (+23%)	NR	83	29 (-24%)	NR	38
Lesoing and Francis 1991	Near normal moisture	1990	127 (+7%)	NR	119	27 (-16%)	NR	32
Lesoing and Francis 1991	Irrigated	1988	145 (+7%)	NR	135	25 (-0%)	NR	25
Lesoing and Francis 1991	Irrigated	1989	200 (+14%)	NR	175	34 (-8%)	NR	37
Lesoing and Francis 1991	Irrigated	1990	197 (+13%)	NR	174	23 (-23%)	NR	30
West and Griffith 1992	Normal Moisture-Regular Mgt.	1986 - 1990	213.7 (+20%)	186.1 (+5%)	177.6 (+3%)[a]	34.75 (-22%)	43.2 (-3%)	44.45 (-7%)[a]
West and Griffith 1992	Normal Moisture-High Mgt.	1986 - 1990	227.8 (+27%)	183.2 (+2%)	179.2 (-7%)[a]	34.75 (-22%)	43.2 (-3%)	44.45 (-7%)[a]
Verdelli et al. 2012	Corn + Soybean Variety #1	2006-2007	311.5 (+35%)	NR	230.9	50.2 (-33%)	NR	74.5
Verdelli et al. 2012	Corn + Soybean Variety #1	2007-2008	294.9 (+40%)	NR	211.2	37.1 (-17%)	NR	44.5
Verdelli et al. 2012	Corn + Soybean Variety #1	2008-2009	319.1 (+43%)	NR	222.6	38.6 (-17%)	NR	46.3
Verdelli et al. 2012	Corn + Soybean Variety #2	2006-2007	342.5 (+46%)	NR	235	56.2 (-12%)	NR	64.1
Verdelli et al. 2012	Corn + Soybean Variety #2	2007-2008	308 (+43%)	NR	214.9	46.3 (-28%)	NR	64.1
Verdelli et al. 2012	Corn + Soybean Variety #2	2008-2009	319.1 (+43%)	NR	222.6	39.5 (-30%)	NR	56.4
Bullock et al 2015[b]	Normal moisture	2009	301 (+37%)	237 (+8%)	220	48 (-23%)	61 (-2%)	62
Bullock et al 2015[b]	Below normal moisture	2010	255 (+55%)	195 (+18%)	165	42 (-29%)	52 (-12%)	59

Notes: NR – not reported. All yields are reported as bushel per acre. Numbers in parentheses are the percent deviation from inner row yield.

a Average of 4 inner rows relative to monoculture control over this period.

b Awaiting publication

Table 2. Yield by row from Bulluck et al. strip intercropping field trials.

	Corn		Soybeans	
Row	Normal	Dry	Normal	Dry
1st (edge)	301	255	48	42
2nd	237	195	61	52
Center	220	165	62	59

Notes: Yields in bushel/acre from field trials in Illinois during 2009 and 2010.
Source: Bullock et al., 2015

Table 3. Intercropping gross revenue comparisons ($/acre)

	Strip Width in Rows				
System	4	6	8	12	16
Conventional	750	750	750	750	750
Strip Intercrop	806	784	772	759	751
Absolute Difference	56	34	22	9	1
% Difference	7.4	4.5	3.0	1.2	0.1

Notes: Headlands planted to soybeans and encompass two times the number of rows in each strip. Soy and corn prices are $10 and $4/bushel, respectively (2.5 Soy/Corn price ratio). Scenario captures normal moisture and lower absolute prices. No cost differences incorporated.

Table 4. Sensitivity of gross revenue differences to price ratio, prices level, and moisture.

	Soy/Corn Price Ratio		
Price Level/Soil Moisture	2	2.5	3
Low Price, Low Soil Moisture	43	37	32
	(7.6%)	(6.0%)	(4.6%)
Low Price, Normal Soil Moisture	37	34	32
	(5.3%)	(4.5%)	(3.9%)
High Price, Low Soil Moisture	75	65	55
	(7.6%)	(6.0%)	(4.6%)
High Price, Normal Soil Moisture	64	60	55
	(5.3)	(4.6%)	(3.9%)

Notes: All figures compare gross revenue per acre from 6-row strips to conventional cultivation. Low prices are based on $4/bu for corn while high prices are $7/bu for corn. Soy prices are 2.0, 2.5 or 3.0 times the price of corn as indicated in the column heading.

Table 5. Machinery inventory assumptions for corn operations for conventional cropping practices.

Inventory List	Width (ft)	List Price	Field Efficiency	Operational Cost/acre	Field Capacity (ac/hr)	Fuel use (gal/ac)	Total fuel use per machine (gal)	Total Machine Use (hr/ yr)	Fixed transition time b/w fields (hr)	Total Transit time b/w fields (hr/ machine)	Labor cost ($/yr)
Chisel Plow	24	22,500	0.85	1.15	13.79	1.11	2,949	192.75	0.5	10.1	2,637
Field cultivator	47	70,500	0.8	3.59	25.50	0.60	1,600	104.58	0.5	10.1	1,491
Boom Sprayer, Self Prop	90	211,500	0.65	10.78	39.61	0.34	918	201.65	0.5	10.1	2,752
Fertilizer Spreader'	45	40,500	0.7	2.06	21.30	0.72	1,910	124.83	1	20.1	1,884
16 Row Planter	40	85,500	0.75	4.36	20.31	0.75	2,005	131.07	2.5	50.1	2,355
Anhydrous Applicator	40	27,000	0.8	1.38	21.70	0.71	1,880	122.88	1.5	30.1	1,989
Combine 400 HP	20	247,500	0.65	12.62	8.80	2.48	6,611	302.47	2	40.1	4,454
Corn Head 8 Row	20	45,000	0.65	2.29	8.80			302.47			
Semi Tractor/Trailers (2x)		70,000		3.57							
Grain Cart, 900 bu		22,500		1.15		1.74	4,628	302.47	0.5	10.1	4,063
310 HP Tractor		193,500		19.73				338.06			
250 HP Tractor		156,048		15.91				338.06			

Notes: Assumes 5.6 miles/hr field operation speeds for all practices, 12.4 miles/hr transportation speed between fields, except for the combine, which is 9.3 miles/hr, labor cost of $13/hr for all machine operation time. Assumes three passes with boom sprayer. Fuel use is a function of horsepower and field capacity. Assumes machinery visits 20 fields as corn is planted in half of farm's fields. Assumes all fields are 1.25 miles apart for transport. Each field assumed to be 133 acres for a total of 2665 acres of corn.

Table 6. Machinery inventory assumptions for corn operations for strip intercropping practices.

Inventory List	Width (ft)	List Price	Field Efficiency	Non-fuel Operational Cost/ac	Field Capacity (ac/hr)	Fuel use (gal/ac)	Total fuel use per machine (gal)	Total Machine Use (hr/ yr)	Fixed transition time b/w fields (hr)	Total Transit time b/w fields (hr/ machine)	Labor cost ($/yr)
Chisel Plow (3x)	6.9	6,563	0.9	1.00	4.3	0.64	568	208.05	0.5	6.8	2,793
Field cultivator (3x)	15	22,500	0.85	3.44	8.6	0.32	281	102.8	0.5	6.8	1,424
Boom Sprayer, pull (5x)	15	17,625	0.8	4.49	8.11	0.34	179	65.54	0.5	4.1	905
Fertilizer Spreader (2x)	22	32,063	0.85	2.02	12.7	0.22	287	105.14	1	20.1	1,628
6 Row Planter (3x)	15	32,063	0.9	4.90	9.09	0.3	265	97.09	2.5	33.4	1,697
Anhydrous Applicator (3x)	15	10,125	0.9	1.55	9.09	0.3	265	97.09	1.5	20.1	1,523
Combine 300 HP (2x)	15	185,625	0.75	18.92	7.61	2.15	2865	174.77	2	40.1	2,794
Corn Head 6 Row (2x)	15	33,750	0.75	3.44	7.61			174.77			
2 Semi Tractor/Trailers		70,000		8.82							
Grain Cart, 200 bu (4x)		5,000		1.26		0.18	239	87.39	0.5	10.1	1,267
50 HP Tractor (5x)		31,210		19.64				480.52			

Notes: 3x means the farm operates 3 identical units. All data columns are per machine. Assumptions include: 5.6 miles/hr field operation speeds for all practices, 12.4 miles/hr transportation speed between fields, except combine, which is 9.3 miles/hr, labor cost of $13/hr for all machine operation time. Assumes three passes with boom sprayer. Fuel use is a function of horsepower and field capacity. Assumes machinery visits all 40 of the farm's fields as corn is planted in each field as part of the intercropping strategy. Assumes all fields are 1.25 miles apart for transport. Each field assumed to have 66.6 acres of corn (half the field area) for a total of 2665 acres of corn.

Table 7. Machinery and labor cost comparison of standard and strip intercropping system for corn operations.

Measure	Strip Intercrop	Standard
Total field hours	2,752	1,483
Between field transition hours	383	181
Total hours	3,135	1,664
Hours/acre	1.18	0.62
Total wage bill	40,755	21,632
Wage/acre	15.29	8.12
Machinery ownership costs/acre	149.33	78.51
Fuel cost/acre	17.76	32.5
Total Machinery & Labor Costs/acre	182.38	119.13
Ratio: Strip/Standard		1.53
Difference: Strip/Standard ($/acre)		63.26

Notes: Assumes a six-row strip intercropping system, $13/hour wage, $3.48/gallon fuel price and 1.25 miles travel distance between fields

Table 8. Machinery and labor cost comparison of standard and strip intercropping system for corn operations: sensitivity analysis.

	Machinery and Labor Cost Differential		
Scenario	Wage = $9	Wage = $13	Wage = $17
Fuel = $2.76/gal, 1.25 mile between fields	64.10 (1.58)	66.30 (1.59)	68.51 (1.60)
Fuel = $3.48/gal, 1.25 mile between fields	61.05 (1.52)	**63.26** **(1.53)**	65.46 (1.54)
Fuel = $3.48/gal, 0.12 mile between fields	60.43 (1.52)	62.37 (1.53)	64.30 (1.54)
Fuel = $4.24/gal, 1.25 mile between fields	57.88 (1.47)	60.09 (1.48)	62.29 (1.48)

Notes: $/acre difference (strip intercrop – conventional) is top number in each cell. Ratio of strip intercrop to conventional cost in parentheses. Bolded cell reflects base assumptions. All other parameters not listed in a column or row heading match those of the base assumption for a six-row strip interseeding system.

Table 9. Difference in net revenue for corn and soybean operations: soybean cost difference same as corn.

Levels for Output Price, Soil Moisture	Wage = $13, Fuel = $3.48 Soy/Corn Price Ratio			Wage = $17, Fuel = $2.76 Soy/Corn Price Ratio			Wage = $9, Fuel = $4.24 Soy/Corn Price Ratio		
	2	2.5	3	2	2.5	3	2	2.5	3
Low Price, Low Moisture	$ (20)	$ (26)	$ (32)	$ (26)	$ (31)	$ (37)	$ (15)	$ (21)	$ (26)
Low Price, Normal Moisture	$ (27)	$ (29)	$ (32)	$ (32)	$ (34)	$ (37)	$ (21)	$ (24)	$ (26)
High Price, Low Moisture	$ 12	$ 2	$ (32)	$ 6	$ (3)	$ (13)	$ 17	$ 7	$ (2)
High Price, Normal Moisture	$ 1	$ (4)	$ (8)	$ (4)	$ (9)	$ (13)	$ 6	$ 2	$ (3)

Notes: $ per acre: Strip intercropping – conventional from partial budget analysis summing changes in gross revenue and changes in labor and machinery costs from previous tables. Figures in parentheses denote negative values. Assumes cost differences to produce soybeans in strips are the same as the cost differences for producing corn in strips.

Table 10. Difference in net revenue for corn and soybean operations: soybean cost difference 15% less than corn.

Levels for Output Price, Soil Moisture	Wage = $13, Fuel = $3.48 Soy/Corn Price Ratio			Wage = $17, Fuel = $2.76 Soy/Corn Price Ratio			Wage = $9, Fuel = $4.24 Soy/Corn Price Ratio		
	2	2.5	3	2	2.5	3	2	2.5	3
Low Price, Low Moisture	$ (16)	$ (21)	$ (27)	$ (21)	$ (26)	$ (32)	$ (11)	$ (16)	$ (22)
Low Price, Normal Moisture	$ (22)	$ (24)	$ (27)	$ (27)	$ (29)	$ (32)	$ (17)	$ (19)	$ (22)
High Price, Low Moisture	$ 16	$ 7	$ (27)	$ 12	$ 2	$ (8)	$ 21	$ 12	$ 2
High Price, Normal Moisture	$ 6	$ 1	$ (3)	$ 1	$ (4)	$ (8)	$ 11	$ 6	$ 2

Notes: $ per acre: Strip intercropping – conventional from partial budget analysis summing changes in gross revenue and changes in labor and machinery costs from previous tables. Figures in parentheses denote negative values. Assumes cost differences to produce soybeans in strips are 15% less than the cost differences for producing corn in strips.