POTENTIAL PROFITABILITY OF STRIP INTERCROPPING WITH CORN AND SOYBEANS

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Abstract

Strip intercropping, the planting narrow strips of different crops side by side in the same field, can generate greater crop yields and total revenue than planting the equivalent number of acres in large, monoculture fields. Although experimental data have shown yield advantages are possible, few studies have considered the cost implications of intercropping implementation. We develop a systematic comparison of the relative net revenue differences for a large-scale (2,157 hectare) corn-soybean operation under conventional and strip intercropping production practices. Results suggest that because the yield premiums for strip intercropped corn were relatively larger than the yield penalty for soybeans, the intercropping practice generated more revenue per unit land than the same crops grown in monoculture within the field. When costs of machine ownership and operation were incorporated into the analyses, the total wage bill estimate was nearly double for strip intercropping, and machinery ownership costs were 90% higher with strip intercropping. 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 normal moisture conditions with the most favorable result occurring when corn has the highest relative price, wages are lowest and fuel is most expensive.

Keywords: strip intercropping, Partial Budget Analysis, farm management, cultivation practices

1. 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 1991, West and Griffith 1992). 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. 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 U.S. farmers and are the focus of this work.

We develop a systematic comparison of the relative net revenue differences for a large-scale (2,157 hectare) 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 (Lesoing and Francis 1991; Bullock and Bullock 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 and Bullock 2012). Implementing wider strips implies that a smaller proportion of each crop will be subject to changes in yield. However, while enhancing 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.

2. Literature review

Past studies have focused primarily on yield impacts and yield components in a strip intercropping system. 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 5 year period (1986-1990). With regular management, the outside row of corn in the intercrop system yielded 20% higher than the mono-crop check. 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% 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% 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 2% more than inner rows.

Corn strips in the intercropping system averaged 9% higher yields than monoculture corn while soybean yields in the strip intercropping system averaged 12% 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. Returns to a strip intercropping system in their study were $3.26 per hectare for “regular management” plots and $9.02 per hectare for “high management” plots.

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 31% in the 1989 irrigated plots to a low of 10% 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 2 to 31% lower than inner rows depending on year and moisture conditions. The system with the largest border row soybean loss was the 1989 irrigated system with a 31% yield loss. The plot intercropped system with the smallest soybean yield loss was the 1988 rain-fed system with a 2% yield loss.

Lesoing and Francis found that corn-soybean strip intercropping returned $14 to $25 more gross revenue per hectare 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.

An Illinois study by Bullock and Bullock evaluated the performance of a corn-soybean strip intercropping system in 2009-10. The two year study encountered two distinct moisture environments. 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 41% higher than inner rows in this 6 row corn intercropped strip. Rows adjacent to border rows had a yield increase of 14% over inner rows. Soybean yields on the other hand, showed marked decreases. Border row soybeans yielded 15% less than inner rows while rows adjacent to border rows yielded 8% less than inner rows. In the below normal moisture environment in 1990, border row corn yields again showed marked increases of 51% over inner rows while yields of rows adjacent to border rows were 17% higher than inner rows. Soybean yields were more severely affected in this below normal moisture setting. Border row soybean yields in 1990 were 57% lower than inner rows while rows adjacent to border rows were 16% lower than inner rows.

Table 1. Yield Effects for Corn and Soybean from the Extant Literature

Source	Moisture Status/ Management	Crop Year	Unit	Corn Outer Row	Corn 2nd Row	Corn Inner Rows	Soy Outer Row	Soy 2nd Row	Soy Inner Row
Leosing and Francis 1991	Below normal moisture	1988	Mg/ha	6.77 (+10%)	NR	6.13	1.43 (-5%)	NR	1.51
Leosing and Francis 1991	Below normal moisture	1989	Mg/ha	9.13 (+30%)	NR	7.01	1.86 (-22%)	NR	2.39
Leosing and Francis 1991	Near normal moisture	1990	Mg/ha	8.7 (+16%)	NR	7.48	1.89 (-23%)	NR	2.46
Leosing and Francis 1991	Irrigated	1988	Mg/ha	11.0 (+19%)	NR	9.23	1.69 (-2%)	NR	1.73
Leosing and Francis 1991	Irrigated	1989	Mg/ha	15.3 (+31%)	NR	11.7	1.86 (-31%)	NR	2.70
Leosing and Francis 1991	Irrigated	1990	Mg/ha	13.8 (+28%)	NR	10.8	1.66 (-26%)	NR	2.25
West and Griffith 1992	Normal Moisture-Regular Mgt.	1986 - 1990	Mg/ha	13.41 (+20%)	11.68 (+5%)	11.15	2.34 (-22%)	2.91 (-3%)	2.99 (3.2)[a]
West and Griffith 1992	Normal Moisture-High Mgt.	1986 - 1990	Mg/ha	14.3 (+27%)	11.5 (+2%)	11.24	2.34 (-22%)	2.91 (-3%)	2.99 (3.2)[a]
Bullock and Bullock 2013[b]	Normal moisture	2009	Mg/ha	19.5 (+41%)	15.7 (+14%)	13.8	3.3 (-15%)	3.6 (-8%)	3.9
Bullock and Bullock 2013[b]	Below normal moisture	2010	Mg/ha	15.7 (+51%)	12.2 (+17%)	10.4	2.1 (-57%)	3.1 (-16%)	3.7

Notes: NR – not reported. Numbers in parentheses are the percent deviation from inner row yield, [a] Average of 8 row monoculture control over this period, [b] Awaiting publication

3. 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. 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 and Bullock (2012). 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 141% of the center row yields in the normal weather year, and about 151% of center row yields in the dry weather year. The second row corn yield was about 114 and 117% of 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 84 and 57% of center row yields in normal and dry years, respectively, whereas second row yields were 92 and 85% of center row yields in normal and dry years.

Table 2. Yield by Row from Bullock and Bullock's Strip Intercropping Field Trials

	Corn		Soybeans	
Row	Normal	Dry	Normal	Dry
1st (edge)	19.5	15.7	3.3	2.1
2nd	15.7	12.2	3.6	3.1
Center	13.8	10.4	3.9	3.7

Notes: Yields in metric tons/hectare from field trials in Illinois during 2009 and 2010. Source: personal communication with authors

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 and Bullock 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 and soybeans are planted in strips of width equal to the corn strips. 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 $157/T while the base corn price under the high price scenario is $275/T for corn; soybean prices will be 2.0, 2.5 or 3.0 times the given corn price.

Table 3. Intercropping Gross Revenue Comparisons ($/hectare)

System	Strip Width in Rows				
	4	6	8	12	16
Conventional	$1,852	$1,852	$1,852	$1,852	$1,852
Strip Intercrop	$2,044	$1,972	$1,933	$1,891	$1,866
Absolute Difference	$191.66	$119.49	$81.30	$38.89	$13.46
% Difference	10.35	6.45	4.39	2.10	0.73

Notes: Headlands planted to soybeans and encompass two times the number of rows in each strip. Soy and corn prices are $368 and $157/metric ton, respectively (2.5 price ratio). Scenario captures normal moisture and lower absolute prices. No cost differences incorporated

Table 4. Sensitivity of Gross Revenue Differences to Price Ratio, Price Level and Moisture

	Soy/Corn Price Ratio		
Price Level/Moisture	2.0	2.5	3.0
Low Price, Low Moisture	$70 (5.0%)	$49 (3.2%)	$25 (1.5%)
Low Price, Normal Moisture	$125 (7.4%)	$119 (6.4%)	$112 (5.6%)
High Price, Low Moisture	$123 (4.0%)	$85 (3.2%)	$45 (1.5%)
High Price, Normal Moisture	$219 (7.4%)	$208 (6.4%)	$197 (5.6%)

Notes: All figures compare gross revenue per hectare from 6-row strips to conventional cultivation. Low prices are based on $157/T for corn while high prices are $276/T for corn. Soy prices are 2.0, 2.5 or 3.0 times the price of corn as indicated in the column heading

Table 3 displays the results of the gross revenue comparisons for the case of typical weather and lower commodity prices for 5 strip widths. The conventional system assumes center row yields for the entire acreage, and is displayed in the table with a constant gross revenue ($1,852/ha) for all strip width comparisons. For the strip intercropping case, gross revenue was greatest ($2,044/ha) for the 4-row strip width, declining to $1,866/ha 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 $192/ha (10.4%) for the 4-row strips, to a modest $13/ha (0.7%) advantage for 16-row strips.

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 soy to corn prices. The most favorable constellation of conditions features normal weather conditions, high base prices for crops and low soy/corn price ratios. In this setting strip intercropping yields $219 more gross revenue per hectare than the conventional system. This gross revenue advantage shrinks to $25 per hectare if base prices are low, the soy/corn price ratio is high and moisture is low.

4. 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 2157 hectare corn/soybean operation to implement 4.6 meter 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 4.6-meter/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

Table 5. Machinery Inventory Assumptions for Corn Operations for Conventional Cropping Practices

Inventory List	Width (m)	List Price	Field Efficiency	Operational Cost/ha	Field Capacity (Ha/hr)	Fuel use (l/ha)	Total fuel use per machine (l)	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	7.3	$22,500	0.85	$2.84	5.58	10.38	11163	192.75	0.5	10.1	2637.09
Field cultivator	14.3	$70,500	0.80	$8.87	10.32	5.61	6057	104.58	0.5	10.1	1490.82
Boom Sprayer, Self Prop	27.4	$211,500	0.65	$26.63	16.03	3.18	3476	201.65	0.5	10.1	2752.31
Fertilizer Spreader’	13.7	$40,500	0.70	$5.09	8.62	6.73	7230	124.83	1.0	20.1	1884.10
16 Row Planter	12.2	$85,500	0.75	$10.77	8.22	7.02	7591	131.07	2.5	50.1	2355.24
Anhydrous Applicator	12.2	$27,000	0.80	$3.41	8.78	6.64	7117	122.88	1.5	30.1	1988.74
Combine 400 HP	6.1	$247,500	0.65	$31.18	3.56	23.20	25025	302.47	2.0	40.1	4453.90
Corn Head 8 Row	6.1	$45,000	0.65	$5.66	3.56	-----		302.47			
Semi Tractor/Trailers (2x)		$70,000		$8.82		-----	-----	-----			
Grain Cart, 900 bu		$22,500		$2.84		16.28	17518	302.47	0.5	10.1	4063.46
310 HP Tractor		$193,500		$48.75			----	338.06			
250 HP Tractor		$156,048		$39.31			----	338.06			

Notes: Assumes 9 km/hr field operation speeds for all practices, 20 km/hr transportation speed between fields, except for the combine, which is 15 km/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 2 km apart for transport. Each field assumed to be 53.9 acres for a total of 1078 hectares of corn

Table 6. Machinery Inventory Assumptions for Corn Operations for Strip Intercropping Practices

Inventory List	Width (m)	List Price	Field Efficiency	Non-fuel Operational Cost/ha	Field Capacity (Ha/hr)	Fuel use (l/ha)	Total fuel use per machine (l)	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)	2.1	$6,563	0.90	$2.47	1.74	5.99	2152	208.05	0.5	6.8	2792.63
Field cultivator (3x)	4.6	$22,500	0.85	$8.50	3.48	2.99	1063	102.80	0.5	6.8	1424.39
Boom Sprayer, pull (5x)	4.6	$17,625	0.80	$11.10	3.28	3.18	678	65.54	0.5	4.1	905.27
Fertilizer Spreader (2x)	6.7	$32,063	0.85	$4.99	5.14	2.05	1087	105.14	1	20.1	1628.09
6 Row Planter (3x)	4.6	$32,063	0.90	$12.11	3.68	2.81	1004	97.09	2.5	33.4	1696.81
Anhydrous Applicator (3x)	4.6	$10,125	0.90	$3.83	3.68	2.81	1004	97.09	1.5	20.1	1523.48
Combine 300 HP (2x)	4.6	$185,625	0.75	$46.75	3.08	20.11	10845	174.77	2	40.1	2793.76
Corn Head 6 Row (2x)	4.6	$33,750	0.75	$8.50	3.08	-----		174.77			
2 Semi Tractor/Trailers		$70,000		$8.82		----	----	-----			
Grain Cart, 200 bu (4x)		$5,000		$1.26		1.68	904	87.39	0.5	10.1	1267.31
50 HP Tractor (5x)		$31,210		$19.64			-----	480.52			

Notes: 3x means the farm operates 3 identical units. Assumptions include: 9 km/hr field operation speeds for all practices, 20 km/hr transportation speed between fields, except combine, which is 15 km/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 2 km apart for transport. Each field assumed to have 26.96 hectares of corn (half the field area) for a total of 1078 hectares of corn 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 27.4 meter self-propelled boom sprayer, which has an assumed field efficiency of 0.65, operational speed of 9 km/hr and an associated field capacity of 16.03 hectares per hour, accomplishes its three passes in 201.65 hours. In the strip intercropping system, we assume sprayer width matches strip width (4.6 meters). These smaller tractor-pulled sprayers are assumed to have a greater field efficiency due to narrow width (0.80) and an identical operational speed (9 km/hr). However, the significantly narrower width drives down field capacity to 3.28 hectares per hour, about one-fifth the capacity of the 27.4 meter 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 a substantially smaller as the narrower machinery implements require fewer horsepower for operation.

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 86% 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% 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% less fuel use per hectare for strip intercropping.

In our assessment we assume that 1078.5 hectares 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 2 km travel distance between fields is assumed, though we assess the sensitivity of cost results to

Table 7. Machinery and Labor Cost Comparison of Standard and Strip Intercropping System for Corn Operations

Measure	Strip intercrop	Standard
Total field hours	2752	1483
Between field transition hours	383	181
Total hours	3135	1664
Hours/hectare	2.91	1.54
Total wage bill	$40,751	$21,626
Wage/hectare	$37.79	$20.05
Machinery ownership costs/ hectare	$369	$194
Fuel cost/hectare	$43.89	$80.32
Total Machinery & Labor Costs/hectare	$450.57	$294.55
Ratio: Strip/Standard	--	1.53
Difference: Strip/Standard ($/ hectare)	--	$156.02

Notes: Assumes $13/hour wage, $0.92/liter fuel price and 2.0 km travel distance between fields 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% higher with strip intercropping. While the smaller equipment may require less fuel, the sheer quantity of items means a dramatically higher ownership cost.

Table 8. Machinery and Labor Cost Comparison of Standard and Strip Intercropping System for Corn Operations: Sensitivity Analysis

	Wage = $9	Wage = $13	Wage = $17
Fuel = $0.73/l, 2 km b/w fields	$158.37 (1.58)	$163.83 (1.59)	$169.28 (1.60)
Fuel = $0.92/l, 2 km b/w fields	$150.56 (1.52)	$156.02 (1.53)	$161.47 (1.54)
Fuel = $0.92/l, 0.2 km b/w fields	$150.54 (1.52)	$156.00 (1.53)	$161.45 (1.54)
Fuel = $1.12/l, 2 km b/w fields	$142.75 (1.47)	$148.21 (1.48)	$153.67 (1.48)

Notes: $/hectare 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 all elements of this partial budget, we find strip intercropping to cost about $156 more per hectare than the conventional approach, representing a 53% 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%, a fuel cost change of +/- 21% and reduction in distance between fields by an order of magnitude. The ratio of costs between strip intercropping and conventional systems is most sensitive to fuel price changes, next most sensitive to wage changes and 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% more costly than conventional. For the highest wages and lowest fuel cost, strip intercropping is about 60% more expensive than conventional.

5. 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 hectare 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 normal 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 $76 more per hectare than the conventional operation. In any scenario featuring either low moisture conditions or low base crop prices, strip intercropping would results in lower net revenue than a conventional operation, with the least favorable scenarios generating up to $131 fewer per hectare.

Table 9. Difference in Net Revenue for Corn and Soybean Operations: Soybean Cost Difference Same as Corn

Levels for Output Price, Moisture	Wage = $13, Fuel = $0.92 Soy/corn price ratio			Wage = $17, Fuel = $0.73 Soy/corn price ratio			Wage = $9, Fuel = $1.12 Soy/corn price ratio		
	2.0	2.5	3.0	2.0	2.5	3.0	2.0	2.5	3.0
Low Price, Low Moisture	$(86)	$(107)	$(131)	$(99)	$(121)	$(144)	$(72)	$(94)	$(117)
Low Price, Normal Moisture	$(31)	$(37)	$(44)	$(44)	$(50)	$(57)	$(18)	$(23)	$(30)
High Price, Low Moisture	$(33)	$(71)	$(112)	$(46)	$(84)	$(125)	$(19)	$(57)	$(98)
High Price, Normal Moisture	$63	$52	$41	$50	$39	$27	$76	$66	$54

Notes: $ per hectare: 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, Moisture	Wage = $13, Fuel = $0.92 Soy/corn price ratio			Wage = $17, Fuel = $0.73 Soy/corn price ratio			Wage = $9, Fuel = $1.12 Soy/corn price ratio		
	2.0	2.5	3.0	2.0	2.5	3.0	2.0	2.5	3.0
Low Price, Low Moisture	$(74)	$(96)	$(119)	$(86)	$(108)	$(131)	$(62)	$(83)	$(107)
Low Price, Normal Moisture	$(19)	$(25)	$(32)	$(31)	$(37)	$(44)	$(7)	$(13)	$(20)
High Price, Low Moisture	$(21)	$(59)	$(100)	$(33)	$(71)	$(112)	$(9)	$(47)	$(88)
High Price, Normal Moisture	$75	$64	$52	$62	$52	$40	$87	$76	$65

Notes: $ per hectare: 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

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 are 15% 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 and normal moisture lead to higher net revenue under strip intercropping. Each entry is approximately $10 -$12 per hectare more favorable to strip intercropping under the assumptions maintained in Table 10.

6. 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 12 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 high prices ($276/T corn and $643/T soybeans), implementing 4-row corn strips yields an increase in gross revenue per hectare of $335 (10%) over monoculture, while a 6-row corn strip yields only a $208/hectare improvement. In a dry year, the additional revenue from a 4-row corn strip drops to about $134/ha.

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 $276/T corn, $643/T soybeans to $157/T corn, $367/T soybeans results in a decline in the 4-row strip advantage of $143/ha, assuming typical weather. 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 2157 hectare corn/soybean operation to implement 4.6 meter strips of corn (6 rows). 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. The total wage bill is nearly double for strip intercropping, as both field hours and hours spent in transition are considerably higher. Machinery ownership costs are 90% 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 normal 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 $76 more per hectare 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 be 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.

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