Strip Intercropping Corn and Alfalfa

M. A. Smith and P. R. Carter

Research Question

Strip intercropping helps conserve soil and has the potential to increase economic returns from row cropping systems, but little is known in the USA about intercropping annual crops with perennial forage legumes. Objectives of this research were to determine the effects of strip intercropping corn and alfalfa on the growth and yield of each crop, on alfalfa forage quality, and to identify an economically optimum strip width.

Literature Summary

Strip intercropping is the production of more than one crop in strips that are narrow enough for the crops to interact, yet wide enough to permit independent cultivation. Agronomically beneficial strip intercropping systems have usually included corn or sorghum, which readily respond to higher light intensities. Studies with corn and soybean strips four to 12 rows wide have demonstrated increased corn yields (+5 to +26%) and decreased soybean yields (–8.5 to –33%). Little has been documented in the USA about strip intercropping of annual species with perennials.

Study Description

Alternating corn and alfalfa strips of three widths (10, 20, and 40 ft) were compared with sole cropping for crop yields and profitability in a field study from 1988 to 1990 in south central Wisconsin. Alfalfa was harvested three times in 1988 and four times in 1989 and 1990. Sole crop yield estimates were taken from the center four rows of corn and center alfalfa harvest strip of the 40-ft wide treatment. Corn growth and yield data were obtained for each row within treatments. Alfalfa yield and forage quality estimates were determined for alfalfa center and plot border harvest strips. Gross dollar returns per acre were calculated for each strip width.

Applied Questions

How did corn and alfalfa yields compare for intercropping and sole cropping?

Crop yield responses to strip intercropping varied depending on climatic conditions. In drought (1988), neither corn nor alfalfa yields differed due to strip width or from the sole crop yield (Fig. 1 and 2). In 1989, corn yields were lowest for the sole crop (146 bu/acre), increased 3% in 40-ft strips, and 10% in 10- and 20-ft strips (Fig 1). In 1990, corn yields were also lowest for the sole crop (123 bu/acre), and increased 6% in 40-ft, 11% in 20-ft, and 17% in 10-ft strips. Alfalfa yields did not differ due to strip width or from the sole crop yield in 1989 (Fig. 2). In 1990, alfalfa yields in strips vs. the sole crop were reduced 10% only for the 10-ft wide plots.

Is this an economical practice? What strip width was most beneficial?

In all years, 20-ft wide strips had the greatest economic advantage, with gross returns per acre over sole crops of $6 in 1988, $29 in 1989, and $18 in 1990 (Table 1). Increases in prices received for crops always increased the advantage of strip intercropping over crops grown in pure stands. Crop producers have to evaluate whether our observed range of $6 to $29/acre per yr additional returns for 20-ft wide strips would cover their labor and management costs to implement the new cropping system. More time and management may be required of farmers to implement a strip intercropping system. Tillage systems that allow controlled traffic and row placement (ridge till and no till) will probably main-

Full scientific article from which this summary was written begins on page 345 of this issue.

tain more uniform alfalfa strips than full-width tillage systems. Annual weed control in corn will probably include both chemical and mechanical means. Herbicide applications may be limited to banded granules or require spray shields for banding liquids. In addition, hay grown in strips may dry more slowly than that in an open field. In this study, forage was green chopped and mechanically dried.

Table 1. Gross returns per acre for sole crops and three widtbs of alternating corn and alfalfa strips for 3 yr, 1988 to 1990.

Year and crop	Sole crops	Strip width, ft 10	20	40
	$/acre			
1988				
Corn†	102	77	102	96
Alfalfa‡	122	127	128	127
Total	224	204	230	223
Difference from sole crops	--	−20	+6	−1
1989				
Corn	172	191	188	177
Alfalfa	169	169	182	184
Total	341	360	370	361
Difference from sole crops	--	+19	+29	+20
1990				
Corn	145	170	161	154
Alfalfa	209	188	212	214
Total	355	358	373	368
Difference from sole crops	--	+3	+18	+13
3 yr average				
Corn	140	146	150	142
Alfalfa	167	161	174	175
Total	307	307	324	317
Difference from sole crops	--	0	+17	+10

† Based on a corn price of $2.35/bu.
‡ Based on an alfalfa hay price of $75/ton.

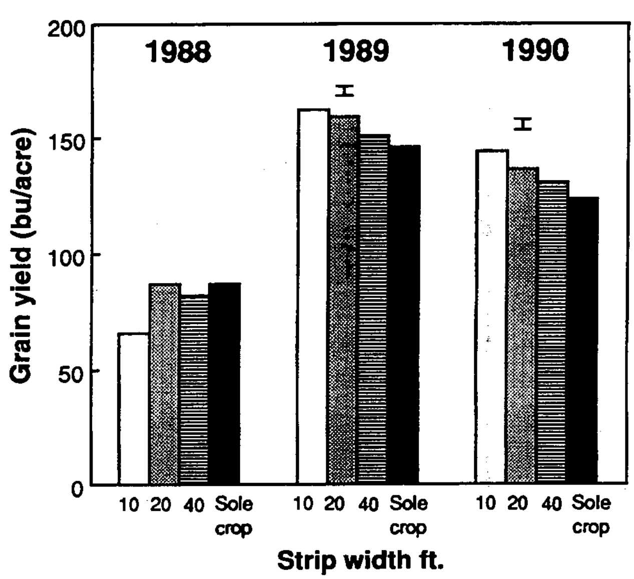

Fig. 1. Corn grain yields for 10-, 20-, and 40-ft wide strips (grown with alternating alfalfa strips of similar width) and the sole crop for 3 yr, 1988 to 1990. The vertical bar represents the $LSD_{0.05}$ for strip widths within each year. Where no bar is shown, there were no differences among treatments.

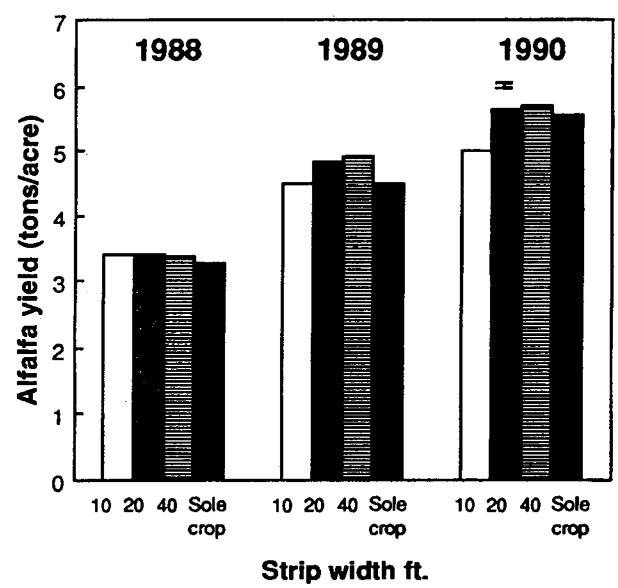

Fig. 2. Alfalfa hay yields expressed at 12% H_2O for 10-, 20-, and 40-ft wide strips (grown with alternating corn strips of similar width) and the sole crop for 3 yr, 1988 to 1990. The vertical bar represents the $LSD_{0.05}$ for strip widths in 1990. Where no bar is shown, there were no differences among treatments.

Strip Intercropping Corn and Alfalfa

M. A. Smith and P. R. Carter*

Strip intercropping annual row crops can improve productivity, but the effect of strip cropping grain and perennial forage crops has not been thoroughly investigated. This study was conducted to evaluate the productivity and profitability of strip intercropping corn (*Zea mays* L.) and alfalfa (*Medicago sativa* L.). Alternating strips of corn and alfalfa of three widths (10, 20, and 40 ft) were compared in a field trial conducted from 1988 through 1990. Corn silking dates, heights, grain yields, and moisture were determined for each row within strips. Alfalfa yields and forage quality were determined for harvest strips within plots and for whole plots. Land equivalent ratios (LER) and gross returns to both strips and sole crops were calculated. In the drought of 1988, neither corn nor alfalfa yields differed due to strip width or from the sole crop yield. In 1989, corn yields were lowest for the sole crop (146 bu/acre), increased 3% in 40-ft strips, and 10% in 10- and 20-ft strips. In 1990, corn yields were also lowest for the sole crop (123 bu/acre), and increased 6% in 40-, 11% in 20-, and 17% in 10-ft wide strips. Alfalfa yields did not differ due to strip width or from the sole crop yield in 1989. In 1990, alfalfa yields in strips vs. the sole crop were reduced 10% only for the 10-ft wide plots. Land equivalent ratios were lowest in 1988, with values below 1.00 for 10- and 40-ft strips. All strip widths had values above 1.00 in subsequent years. Maximum LERs were 1.02, 1.08, and 1.06 for 20-ft strips in 1988, 1989, and 1990, respectively. In all years, 20-ft wide strips had the greatest economic advantage, returning $6, $29, and $17/acre over sole crops in 1988, 1989, and 1990, respectively. Increases in prices received for crops always increased the advantage of strip intercropping.

INTERCROPPING is a type of multiple cropping in which two or more crops are grown simultaneously on the same field. Plants of different species can be closely arranged to optimize positive plant growth interactions. In the USA, mechanized agriculture limits the possible spatial arrangements for intercrops.

Strip intercropping is the production of more than one crop simultaneously in different strips that are narrow enough for the crops to interact and wide enough to permit independent cultivation of the different crops (Whigham, 1985). Narrow crop strips compatible with available machinery can improve crop yields with no additional out-of-pocket costs, though more time and management may be required of farmers (N. Kleiber, 1991, personal communication).

Intercropping systems are most often evaluated on the basis of their LER, which is the sum of the ratios of intercrop yields to sole crop yields of each component crop (Oyejola and Mead, 1982). Land Equivalent Ratio values greater than 1.00 indicate greater land-use efficiency from intercropping than from sole cropping. To compare economic returns of strip intercropping and sole cropping systems, market values must be assigned to the component crops and dollar returns per unit area calculated.

Agronomically beneficial strip intercropping systems in the midwestern USA have included corn or sorghum [*Sorghum bicolor* (L.) Moench], C_4 species that readily respond to higher light intensities (Crookston, 1976). Studies with corn and soybean [*Glycine max* (L). Merr.] strips wide enough to accommodate field machinery (four to 12 rows) have generally demonstrated increased corn yields (+5 to 26%) and decreased soybean yields (–8.5 to –33%), which resulted in LER values near 1.00 (Crookston and Hill, 1979; Pendleton et al., 1963). Research in Illinois and Pennsylvania with 4-, 6-, or 8-row alternating strips indicates LER values of 1.10 to 1.18 (Francis et al., 1986).

Welch and Ottman (1983) proposed that increased corn yields in strips with a shorter crop were primarily due to extra light available to outside rows. Cripps (1987) found that outside rows of corn strips received 95% of incident light, regardless of strip width. Second rows from the border row received 76% of incident light; third rows, 49%; and fourth and fifth rows in from the border, 37%. Photosynthesis rates also declined as less light penetrated the canopy.

Yield reductions of soybean in strips bordered by corn appear largely due to shading and reduction of available light. Cripps (1987) found that light (estimated by photosynthetic photon flux density) interception, measured at solar noon at the top of the soybean canopy, was reduced in outer rows 75, 60, and 41% when bordered by 10-, 6-, and 4-row strips of corn, respectively. Competition for soil moisture may also affect soybean when strip intercropped. Nebraska researchers found that, with irrigation, there was no soybean yield reduction in rows bordering corn (Dolezal, 1983).

Little research has been conducted to evaluate strip intercropping of corn and forage legumes. Studies in the 1950s addressed interseeding forage legumes into corn planted in 40 to 80 in. row spacings (Pendleton et al., 1957; Schaller and Larson, 1955; Tesar, 1957). Volak et al. (1981) in Pennsylvania measured increased corn yields compared with sole cropping when double corn rows (10 in. spacing) were alternated with 20-ft strips of alfalfa. But, there were no yield differences compared with sole cropping for corn planted in 2-, 4-, or 6-row (30 to 36 in. spacing) corn strips. Alfalfa yields were not affected by differences in width of alternating corn strips.

Wide contour crop strips (minimum 60 ft wide) are still common in parts of the upper Midwest. Although their erosion control benefits have been quantified, possible yield benefits of corn and alfalfa in these and narrower strips have

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Abbreviation: LER, land equivalent ratio; PAR, photosynthetically active radiation; TPAR, transmitted photosynthetically active radiation.

not been thoroughly studied. It is likely that response to strip intercropping would be different for an annual/perennial crop combination than for two annual crops. Crops differ in their rooting depth, time of nutrient and moisture uptake, and growth patterns that may affect productivity. In a strip intercropping system including small grains, Ghaffarzadeh et al. (1994) observed higher oat (*Avena sativa* L.) yields at the corn/oat interface than in the middle of strips. Because forage can be harvested twice before corn is tall enough to shade alfalfa, we postulated that strip intercropping might increase yields of both crops compared with sole cropping.

Objectives of this study were to determine the effects of strip intercropping of corn and alfalfa on the growth and yield of each crop and on alfalfa forage quality, and to identify an economically optimum strip width.

MATERIALS AND METHODS

A field study was conducted in 1988, 1989, and 1990 at the Arlington Agricultural Research Station near Madison, WI, on a Plano silt loam (fine-silty, mixed, mesic Typic Argiudoll). Corn was planted into strips arranged to alternate with strips of previously established alfalfa. Three treatments, each occupying 0.07 of an acre, contained a total of 16 30-in rows (40 ft wide) of corn and strips of alfalfa totalling 40 ft wide. Treatments were: (i) four rows (10 ft wide) of corn alternated with 10-ft wide strips of alfalfa, the pattern repeated four times; (ii) eight rows (20 ft wide) of corn alternated with 20-ft wide strips of alfalfa, the pattern repeated twice; (iii) sixteen rows (40 ft wide) of corn beside a 40-ft wide strip of alfalfa. This experiment was conducted in a randomized complete block design with three replicates in 1988 and four replicates in 1989 and 1990. All plots were 40 ft long.

'Arrow' alfalfa was established in the spring of 1987. Each subsequent fall, strips corresponding to planned corn plantings were chisel plowed and plots were disked or field cultivated in the spring before planting. Corn hybrid LH74 × LH51 (110 d relative maturity) was planted 1 May 1988 at a rate of 31 000 seeds/acre with rows oriented east/west. Alfalfa did not survive the following winter, so in the spring of 1989, plots were reestablished adjacent to the 1988 plot with rows oriented north/south. The same hybrid was planted 2 May 1989 but the plant stand was sparse due to poor seed quality. Plots were replanted with Dekalb brand 524 (105 d relative maturity) at a rate of 31 000 seeds/acre on 22 May. In 1990, Dekalb brand 524 at the same seeding rate was planted 30 April. Counter (chloropyrifos) was applied with the planter at 1 lb/acre a.i. for corn rootworm [*Diabrotica longicornus* (Say)] control in 1990.

Weed control options in corn were limited due to bordering alfalfa. Lasso II (alachlor) granules were applied with the planter at 3 lb/treated acre a.i. in a 10 in. band over corn rows. Corn was also rotary hoed twice and cultivated twice.

Soil test results were: pH 6.4, 113 lb/acre P (excessively high), and 292 lb/acre K (high) (Kelling et al, 1991). At planting, corn received 9+16+30 lb/acre of $N+P_2O_5+K_2O$ as row-applied starter fertilizer. In addition, 125 lb/acre N in 1988 and 1989 and 150 lb/acre N as ammonium nitrate in 1990 was sidedressed at approximately crop stage V6 (Ritchie and Hanway, 1984).

Gravimetric soil water content was measured three or four times each growing season just after alfalfa harvests. At first alfalfa harvest (early June), sample depths were 0 to 6, 6 to 12, and 12 to 18 in., and at subsequent sample dates, 0 to 12, 12 to 24, and 24 to 36 in. depths. In 1988 and 1989, all strip widths were sampled in the center of corn plots, the center of alfalfa plots, and at both interfaces (north and south in 1988, east and west in 1989) midway between the two crops. Because no differences were observed due to strip width, in 1990 soil water content was only measured in 20-ft wide strips. That year, in addition to the previous sample locations, samples were also taken in each corn row.

Light transmission was measured with a LI-COR (LI-COR, Lincoln, NE) line quantum sensor with an interception surface of 39.4 by 0.51 in. Measurements were taken three or four times each growing season at the time of alfalfa harvests on cloudless days at solar noon. Photosynthetically active radiation (PAR) was measured outside the corn plots just before taking measurements within plots. Transmitted PAR (TPAR) was measured at the ground surface and at 3.3 ft (approximately ear level). The sensor was placed level and perpendicular to each corn row to measure TPAR. Transmitted PAR was expressed as a percentage of full sun (Gallo and Daughtry, 1986).

Variables measured for each corn row included days to silk, plant height, plant population, grain moisture, and grain yield. For plant height, 10 plants per row were measured. Data for all other variables were collected for all plants in each row. Days after planting to silk was determined when 50% of corn plants had silks visible. Mature plant height (in to flag leaf collar) and final plant population (plants per acre) were measured just before harvest. In years when conditions warranted, lodging, broken stalks, and barren plants were also counted.

Each row of corn was harvested on 8 Oct. 1988, 31 Oct. 1989, and 13 Oct. 1990. Rows bordering alfalfa were hand-picked to avoid driving on bordering alfalfa and were combined-shelled. Remaining rows were harvested individually with a plot combine equipped with scale and moisture meter. Yields were adjusted to 15.5% moisture.

Alfalfa was harvested on 27 May, 30 June, and 27 July in 1988; 1 June, 29 June, 1 Aug., and 12 Sept. 1989; and 1 June, 2 July, 1 Aug., and 10 Sept. 1990. Harvest strips, each 3 ft wide, were taken from the plot center and both plot edges, (parallel to corn rows) with a flail-type harvester to evaluate the corn border effects. Remaining forage was chopped and weighed for each plot to calculate whole plot yields. Alfalfa yields were adjusted to 12% moisture. Sole crop yield estimates were taken from the center four rows of corn and center alfalfa harvest strip of the 40-ft wide treatment.

Subsamples from each harvest strip were weighed wet, dried at 140°F, and reweighed to determine moisture content of the forage. Dried samples were ground through a 1 mm screen in a Wiley mill. Total N content of the forage was measured with a Leco Model FP-428 Nitrogen Determinator (Leco Corp., St. Joseph, MI.). Crude protein concentration was calculated by multiplying total N by 6.25. Neutral detergent fiber and acid detergent fiber were determined using the procedure of Robertson and Van Soest (1980).

Table 1. Precipitation and mean air temperatures for the 1988 to 1990 growing seasons at Arlington, WI.

	1988	1989	1990
	in.		
April	3.3 (0.2)†	1.4 (−1.6)	2.5 (−0.5)
May	1.0 (−2.1)	1.8 (−1.2)	4.2 (1.3)
June	1.5 (−2.1)	2.0 (−1.6)	6.3 (2.9)
July	1.6 (−2.0)	3.8 (0.2)	1.6 (−1.9)
August	2.9 (−1.4)	4.3 (−0.2)	5.4 (0.7)
September	3.9 (−0.2)	3.8 (−0.3)	1.2 (−2.5)
6 month total	14.2 (−7.6)	17.1 (−4.7)	21.2 (0)
	°F		
April	55.0 (8.1)	45.2 (0.7)	48.7 (4.1)
May	62.6 (4.1)	57.6 (−0.9)	54.8 (−3.5)
June	71.6 (4.9)	66.3 (−0.8)	67.7 (0.6)
July	75.0 (3.3)	72.8 (0.9)	69.9 (−1.9)
August	74.7 (5.3)	69.5 (0.1)	70.0 (0.7)
September	64.4 (3.1)	59.4 (−1.8)	64.0 (2.7)

† Number in parentheses is deviation from the 20 year moving average.

Analyses of variance were conducted separately for corn and alfalfa each year. Land equivalent ratios were calculated as follows:

$$\frac{\text{corn yield in intercrop/0.5 acre}}{\text{corn yield in sole culture/acre}} + \frac{\text{alfalfa yield in intercrop/0.5 acre}}{\text{alfalfa yield in sole culture/acre}}$$

Gross returns/acre for each strip width and sole crops were calculated each year using a corn price of $2.35/bu and an alfalfa hay price of $75/ton, which were average prices for the two crops for 1988 to 1990. We assumed that input costs for strip intercropping systems and sole crops were identical other than for labor and management. Increased labor or management requirements for strip intercropping were not estimated. Price sensitivity analyses were conducted each year for differences between gross returns for 20-ft wide strips and sole crops, with corn prices ranging from $2.05 to $2.65/bu and alfalfa hay prices ranging from $65 to $85/ton.

RESULTS AND DISCUSSION

Weather and Soil Water Content

Growing seasons in 1988, 1989, and 1990 were different. Rainfall was far below (−7.6 in.) and temperatures far above (4.8°F) average in the 1988 growing season (Table 1). Rainfall was 4.7 in. below average in the 1989 growing season, but temperatures were slightly cooler (−1.8°F) than average. The 1990 season was average for south-central Wisconsin.

Soil water content reflected weather conditions for each year and throughout each growing season. In 1988, soils contained the most water (approximately 16%) in late May at the initial alfalfa harvest and contained only about 12% water at later forage harvests (Table 2). In late May, soil in the center of corn plots contained the most water. Soil was drier at the corn/alfalfa interfaces, and much drier in alfalfa plot centers. At second harvest there were no differences between corn plot edges or centers, but alfalfa plots remained drier. At third harvest there were no differences in soil water content due to sample position.

Table 2. Gravimetric soil moisture in corn/alfalfa strips at four sample positions for 3 yr, 1988 to 1990. Values are averaged over three depths and 10-, 20-, and 40-ft strip widths in 1988 and 1989. Samples in 1990 are only from 20-ft wide plots.

Year	Sample position	Sampling date† 1	2	3	4
		% Soil H_2O			
1988	North corn ‡	17.0§	13.5¶	13.6	--
	Center corn	18.6	11.9	13.1	--
	South corn	16.0	13.0	12.0	--
	Center alfalfa	11.6	10.3	10.3	--
	$LSD_{0.05}$	1.1	1.9	NS	--
1989	East corn	14.9	18.0	14.2	13.9
	Center corn	17.8	19.4	13.7	16.0
	West corn	14.9	18.3	12.1	12.0
	Center alfalfa	10.6	13.2	12.1	15.4
	$LSD_{0.05}$	1.6	1.3	1.0	1.3
1990	East corn	25.1	21.9	13.9	16.4
	Center corn	25.5	22.8	14.2	16.4
	West corn	24.1	22.4	12.8	13.6
	Center alfalfa	24.5	20.9	14.0	16.0
	$LSD_{0.05}$	NS	0.5	NS	2.0

† Soil was sampled after each alfalfa harvest.
‡ Sample positions in 1988 (when corn rows were oriented east and west) were at north and south edges of corn plots at the corn/alfalfa interface, and in corn and alfalfa plot centers. In 1989 and 1990 (when corn rows were oriented north and south), sample positions were at the east and west edges of corn plots and corn and alfalfa plot centers.
§ Samples depths were 0 to 6, 6 to 12, and 12 to 18 in. at the first sampling date and 0 to 12, 12 to 24, and 24 to 36 in. at subsequent sampling dates.
¶ In 1988, extremely dry conditions for the second and third sample dates limited the ability to take soil samples, so only 10-ft wide plots were included.

The pattern of soil water distribution was similar in 1989, with the center of corn plots being wettest (14 to 19% H_2O) through most of the growing season, corn/alfalfa interfaces drier (12 to 18% H_2O) and alfalfa plots the driest (11 to 15% H_2O). Alfalfa probably was using water laterally from adjacent corn plots.

There were fewer differences in soil water content due to sample position in 1990 because of adequate rainfall for both corn and alfalfa growth. Only in early July, after the second alfalfa harvest, were alfalfa plots drier than corn plots (Table 2). In September, after the fourth alfalfa harvest, the west corn/alfalfa interface was drier than elsewhere in the plots (Table 2). Soil water content measured in each corn row of eight row (20 ft) plots at the same sample dates illustrate that westernmost corn rows were drier than all other rows in June, August, and September (Fig. 1). There were no differences among other corn rows.

Corn

Both corn growth and yield were affected by row position within strips and by strip width. Days to silking were affected by corn row position, but response differed with years (data not shown). Dry, hot weather in 1988 resulted in delayed silking by 8 d for plants in outside rows compared with the average (82 d) for all interior rows of all strip widths. Although weather conditions were not as stressful in 1989, silking was still delayed by 2 d (73 vs. 71 d) for outside corn rows compared with interior rows. In contrast, with adequate soil water in 1990, plants in outer corn rows silked 1 d sooner than interior rows (93 vs. 94 d).

Average plant height was shortest in 1988 (59 in), intermediate in 1989 (85 in), and tallest in 1990 (91 in). In all years, corn was shortest in outside rows, taller in second rows from the edge and of equal height in other interior rows (data presented for 1990 in Fig. 2), with similar height responses for corn rows in all plot widths. A comparison of the two outside rows revealed that the south (1988) and west rows (1989 and 1990) were shorter by 1 to 6 in. than north and east rows.

Figure 3 illustrates light (PAR) transmission response to row positions in 1990 at silking, which was typical of responses in other years. Light transmitted at ear height was 60%, 46%, and 32% of full sun, for east, west, and interior rows, respectively. At ground level, there were no differences due to row position in available light, which averaged 13% of full sun. These results differ from Cripps (1987), who measured progressively less light available to rows 1 through 4 from plots edges. Differences may be due to the variation in above-ground heights at which light transmission was measured (3.3 ft vs. 4.9 ft).

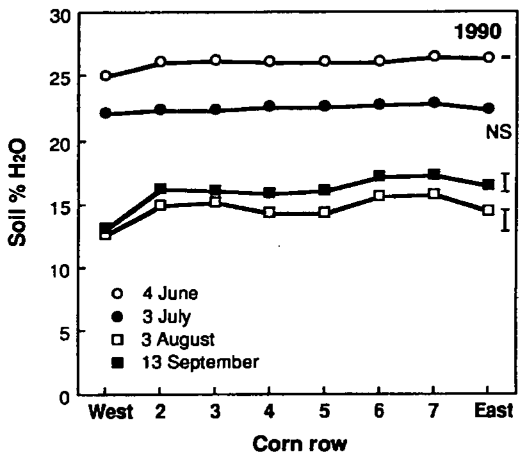

Fig. 1. Gravimetric soil moisture in each corn row in 20-ft wide plots (grown with alternating alfalfa strips of similar width) at four sampling dates in 1990. Values are averaged over soil profile samples of the upper 18 in. (4 June) and 36 in. (3 July, 3 August, and 13 September).Vertical bars represent the $LSD_{0.05}$ for rows within each sampling date.

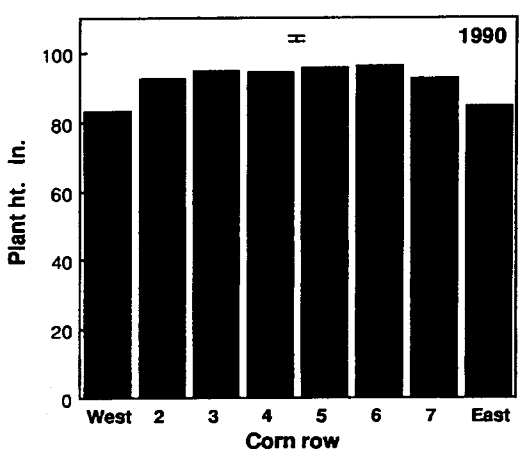

Fig. 2. Corn heights to the flag leaf collar for each corn row in 20-ft wide plots (grown with alternating alfalfa strips of similar width), 1990. The vertical bar above height bars represents the $LSD_{0.05}$.

Despite the differences in days to silking, grain moisture at harvest was affected by corn row position in only a few instances. In 1988 and 1990, grain from outside rows was often drier by 2 to 3 percentage points than grain from interior rows, possibly due to greater exposure to drying winds and sunlight. Grain moisture did not differ among corn rows in 1989. Averaged over all corn rows, grain moisture did not differ among strip widths in 1988 or 1989, but in 1990, grain was wetter by 1 percentage point for 40 ft plots than for narrower strips.

Corn yields differed by row position at every strip width in all years (Fig. 4). In 1988, yields were lowest on the south edge of all plot widths. Averaged over the three strip widths, south rows averaged 39 bu/acre and second rows from the south edge 76 bu/acre. North rows and second rows from the north edge averaged 65 and 93 bu/acre, respectively. Low rainfall and high temperatures (Table 1) resulted in low soil moisture levels (Table 2), visible moisture stress in outer corn rows, delayed silking, and pollination failure in many cases. The percentage of barren plants averaged 47% in south rows, 23% in second rows from the south, and 33% for north rows. All other interior rows averaged 18% barren plants. Although there was some variability for interior row yields, inside row yields were always higher than for outer rows. Interior rows for eight row (20 ft) plots (center 4) and for 16 row (40 ft) plots (center 12) averaged 97 and 88 bu/acre, respectively (Fig. 4).

Corn yields were higher in 1989, but below average rainfall and soil moisture depletion by alfalfa adjacent to corn (Table 2) probably were related to yield responses to row position similar to those in 1988 (Fig. 4). West rows always yielded less than neighboring rows and had lowest yields in 10- and 20-ft wide plots. Averaged over all plot widths, west rows produced 138 bu/acre while east rows averaged 165 bu/acre. All interior rows averaged 177 bu/acre for 10-ft, 164 bu/acre for 20-ft, and 150 bu/acre for 40-ft wide plots. Although the periodic light measurements conducted in this study did not indicate less light in 40-ft plots compared with 10- or 20-ft plot widths, it is likely that, over the growing season, less light was available to interior corn rows in the widest plots. Yields of several interior rows in 40-ft plots

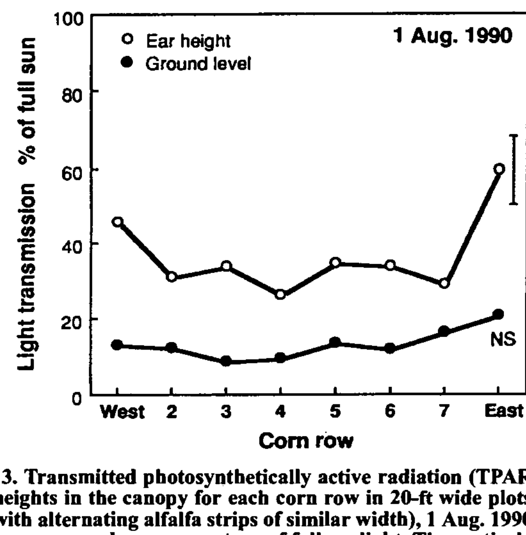

Fig. 3. Transmitted photosynthetically active radiation (TPAR) at two heights in the canopy for each corn row in 20-ft wide plots (grown with alternating alfalfa strips of similar width), 1 Aug. 1990. Values are expressed as a percentage of full sunlight. The vertical bar represents the $LSD_{0.10}$ for differences among rows.

were less than west row yields, which did not occur in 10- or 20-ft plots (Fig. 4). Only in 40- ft plots were there more broken stalks in interior (16%) than in outer rows (9%). Limited light and harvest losses due to stalk breakage may have contributed to lower yields for interior rows of 40-ft plots.

More favorable soil water availability in 1990 (Tables 1 and 2) resulted in yield responses to row position different than those in 1988 and 1989 (Fig. 4). Outer rows for all plot widths always yielded better than interior rows. Only in 40-ft plots did west rows yield more than the east rows (Fig. 4). Outer (border) rows averaged 160 bu/acre for 10-ft, 162 bu/acre for 20-ft, and 162 bu/acre for 40-ft wide plots. All other interior rows averaged 129 bu/acre for 10-ft and 20-ft, and 127 bu/acre for 40-ft wide plots. For all plot widths there were more broken stalks in interior rows (26%) than in outer rows (12%).

Overall, corn yield response to strip width was similar in 1989 and 1990 (Fig. 5), despite contrasting row position effects (Fig. 4). Grain yields in 1989, which decreased pro-

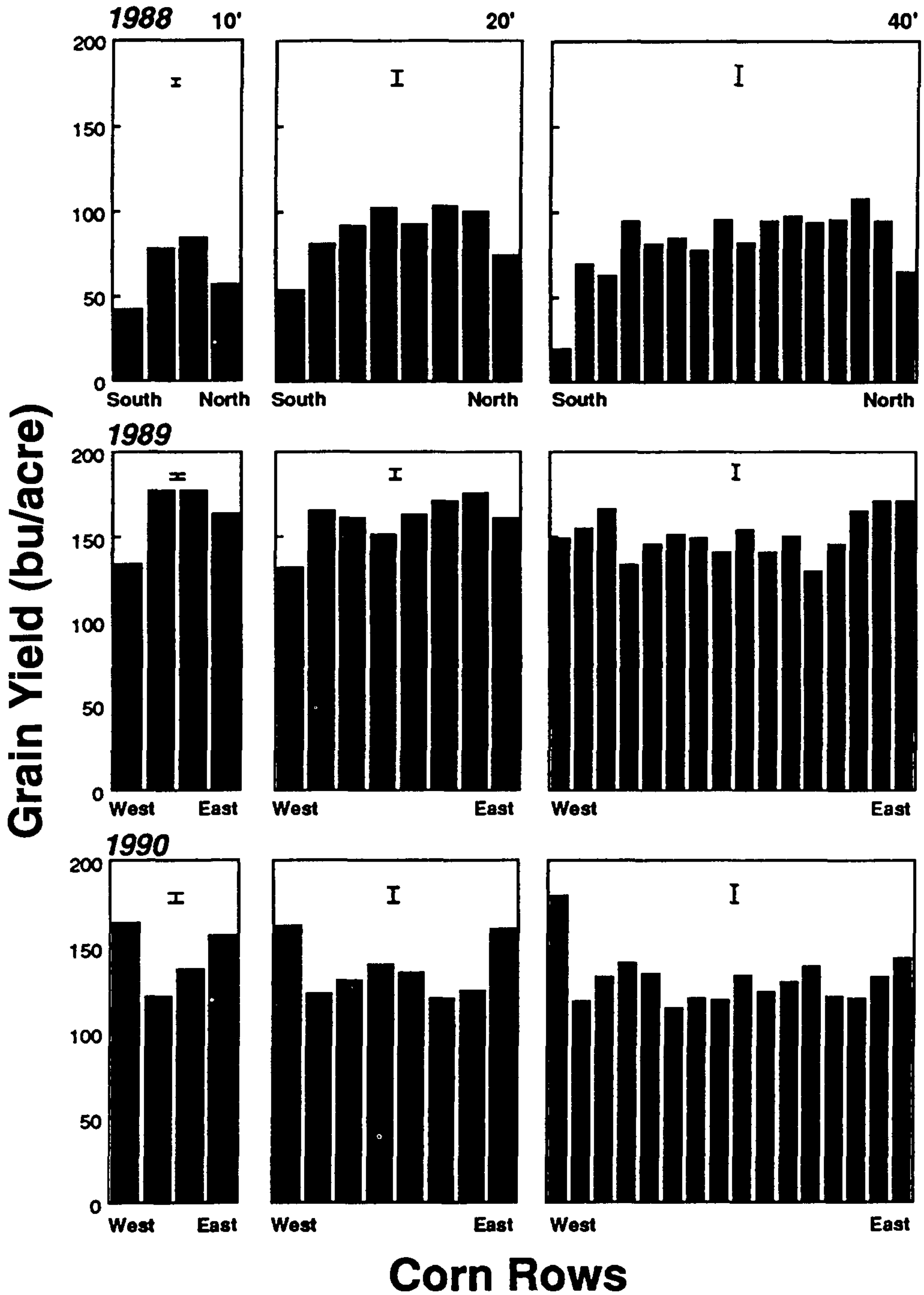

Fig. 4. Grain yields for each corn row in 10-, 20-, and 40- ft strip widths (grown with alternating alfalfa strips of similar width) for 3 yr, 1988 to 1990. The vertical bar above yield bars represents the $LSD_{0.05}$ for rows within each strip. The four center rows in 40-ft wide strips represent the sole-crop yield each year.

gressively as strip widths widened, ranged from 163 bu/acre for 10-ft wide plots to 146 bu/acre for the sole crop (Fig. 5). Yield levels were slightly lower in 1990, ranging from 145 bu/acre for 10-ft strips to 124 bu/acre for the sole crop. There was no yield response to strip width in 1988 (Fig. 5). Drought that year increased variability and kept yields below 100 bu/acre.

Alfalfa

Alfalfa crude protein percentage, acid detergent fiber, and neutral detergent fiber varied only slightly due to harvest strip position for a few harvests during the three growing seasons (data not shown). Differences were not consistent and exhibited no trends for harvests within years or combined over harvests.

Alfalfa yield response to harvest strip position was markedly different in 1988 than in 1989 and 1990. In 1988, when alfalfa was moisture stressed due to both low rainfall and high air temperatures (Table 1), hay yields tended to be higher at plot edges bordering corn plots than in plot centers, especially for the first harvest in 20-ft plots (Fig. 6). Soils were drier in the center of alfalfa plots than at plot edges following first hay harvest (Table 2). Before the first harvest, alfalfa at plot edges had little competition from bordering corn seedlings and probably absorbed water from below the corn rooting zone.

In 1989, alfalfa yield response to harvest strip position was inconsistent across treatment widths at the first hay harvest, nonexistent at second and third harvests, and consistently higher for plot center strips compared with border strips at the fourth hay harvest (Fig. 6). Soil water content following fourth harvest was 1.5 to 3.5 percentage points higher in alfalfa plot centers than corn/alfalfa interfaces (Table 2). After corn reached full height at tasselling, additional sunlight available to outer corn rows probably

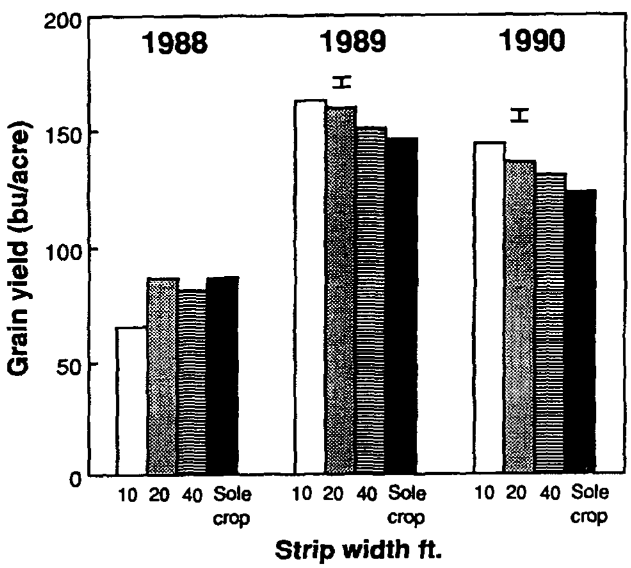

Fig. 5. Corn grain yields for 10-, 20-, and 40-ft wide strips (grown with alternating alfalfa strips of similar width) and the sole crop for 3 yr, 1988 to 1990. The vertical bar represents the $LSD_{0.05}$ for strip widths within each year. Where no bar is shown, there were no differences among treatments.

increased evapotranspiration and water demand. Resulting competition between crops for limited soil water probably depressed yields of both fourth-harvest alfalfa hay (Fig. 6) and corn grain (Fig. 4) at the corn/alfalfa interface. Lower light intensities due to shading of alfalfa plot edges by corn may also have contributed to yield differences (Rhykerd et al., 1960).

Nearly average rainfall and temperatures in 1990 contributed to highest season-total hay yields of the three study years. That year, yields of alfalfa harvest strips adjoining corn were probably influenced more by light than available soil water. Generally, 1990 alfalfa yields were higher for plot centers than for borders, especially for third and fourth harvests when corn was tall enough to shade adjacent alfalfa (Fig. 6). Whole-plot season-total hay yields did not differ due to plot width in 1988 and 1989 (Fig. 7). Alfalfa yields in strips averaged 3.4 tons/acre in 1988 and 4.75 tons/acre in 1989, with 4 to 5% lower yields for the sole-crop. In 1990, whole-plot season-total hay yields were approximately 9% greater for 20- and 40-ft wide strips than for 10-ft wide strips (Fig. 7). Narrowing of alfalfa strips by tillage equipment in contiguous corn plots in 1990 may have contributed to lower yields per unit area in 10-ft wide strips. Also, a greater portion of 10-ft wide alfalfa strips were shaded by corn during late-season alfalfa growth compared with 20- and 40-ft wide strips (Fig. 6). The sole crop yield was 2% lower than 20- and 40-ft wide treatment yields and 9% higher than the 10-ft wide strip yield (Fig. 7).

Land Equivalent Ratios and Economics

Land equivalent ratios were lowest in 1988, intermediate in 1990, and highest in 1989 (Table 3). In 1988, values were below 1.00 for 10- and 40-ft wide plots and 1.02 for 20-ft wide plots. Values for all strip widths were above 1.00 in both 1989 and 1990. In all years, 20-ft wide plots had the highest LERs (Table 3).

Average gross returns were lowest in 1988, due to both low corn and alfalfa yields, and nearly equal in 1989 and 1990 (Table 4, Fig. 5 and 7). In all years, returns were greatest for the 20-ft wide strips.

Gross returns in 1988 ranged from $204 to $224/acre, with only 20-ft wide strips returning more per acre ($6) than the sole crops (Table 4). In 1989, returns ranged from $341/acre for sole crops to $370/acre for 20-ft wide strips. Increases over sole crop returns were 5% for 10-ft, 8% for 20-ft, and 6% for 40-ft wide strips (Table 4). Rankings were similar in 1990 but differences were smaller, ranging from $355/acre for sole crops to $373/acre for 20-ft wide strips. Increases over sole crop returns were 1% for 10-ft, 5% for 20-ft, and 4% for 40-ft wide strips. Averaged over all three study years, gross returns were increased 0%, 5%, and 3% by 10-, 20-, and 40-ft wide strips, respectively (Table 4).

Because there were only small differences in corn and alfalfa yields between sole crops and those from 20-ft wide strips in 1988 (Fig. 5 and 7), changes in prices received for crops had little effect on the difference in gross returns (Table 5). Within the corn price range of $2.15 to $2.55/bu and hay price range of $65 to $85/ton, differences in gross returns ranged only from $5 to $6.50/acre, with the increase coming from change in alfalfa hay price.

In both 1989 and 1990, hay and corn yields were both higher for 20-ft wide strips than for sole crops (Fig. 5 and 7). Consequently, differences in gross returns for 20-ft strips compared with sole crops increased with both increasing hay prices and increasing corn prices. Within the price ranges illustrated, the advantage for 20-ft wide strips over sole crops ranged from approximately $25.50 to $31.75/acre in 1989 and from $16.50 to $19.80/acre in 1990 (Table 5).

CONCLUSION

Strip intercropping provided greater gross returns than sole crops only for the 20-ft strip width in 1988 ($6/acre). In 1989 and 1990, all strip widths returned more than the sole crops. Twenty-foot wide strips were most advantageous, however, with returns of $29/acre (1989) and $17/acre (1990) over sole crops. Because grain yields in 1989 and

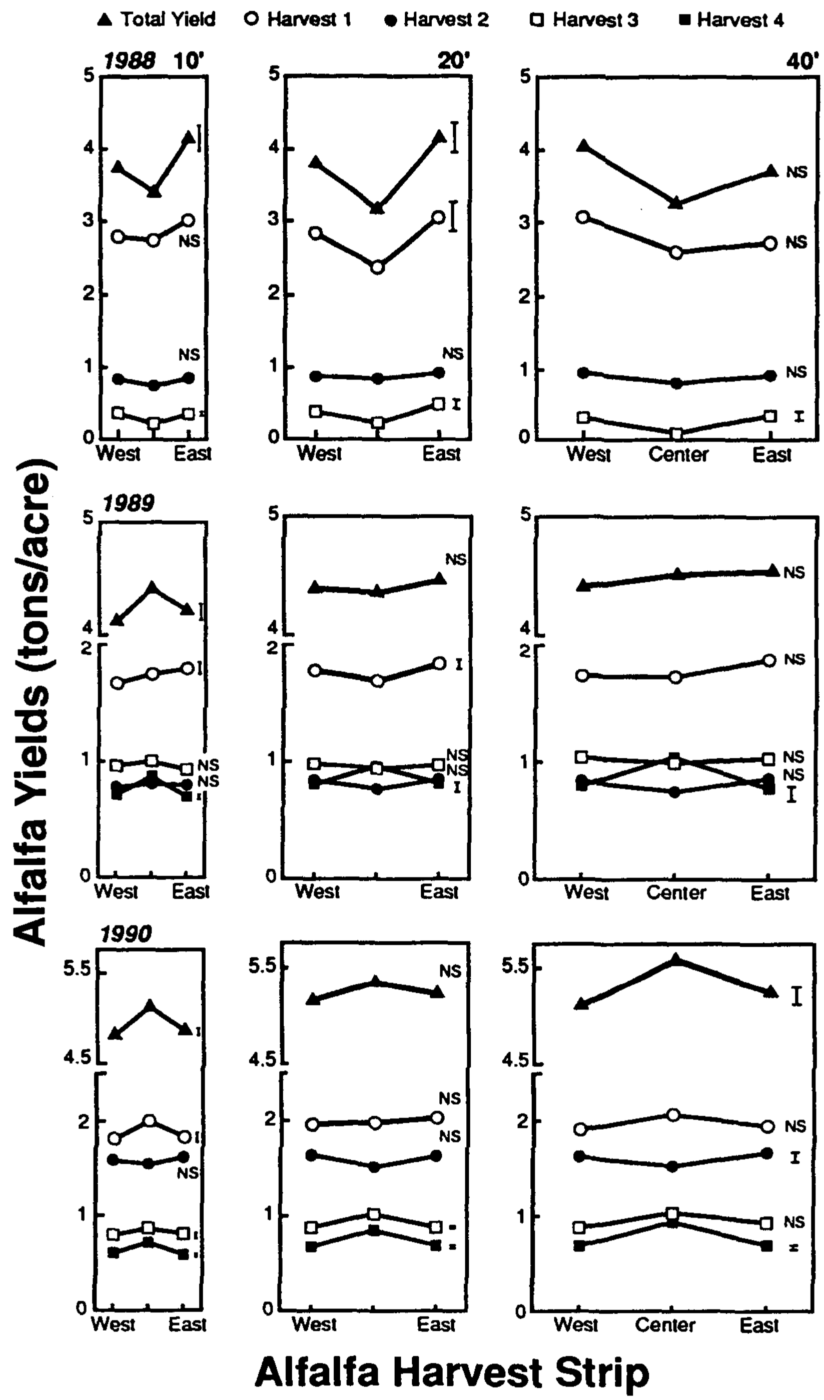

Fig. 6. Alfalfa hay yields expressed at 12% H_2O for three harvest positions within 10-, 20-, and 40-ft wide strips (grown with alternating corn strips of similar width) are illustrated for three (1988) and four (1989, 1990) harvests and for the total season. Vertical bars represent the $LSD_{0.05}$ for comparing harvest strip positions within each strip width for each harvest. The center harvest strip in 40-ft wide strips represents the sole-crop yield each year.

Table 3. Land equivalent ratios (LERs) for three widths of alternating corn and alfalfa strips for 3 yr, 1988 to 1990.

Year	Strip width, ft		
	10	20	40
1988	0.90	1.02	0.99
1989	1.06	1.08	1.05
1990	1.03	1.06	1.04

Table 4. Gross returns per acre for sole crops and three widths of alternating corn and alfalfa strips for 3 yr, 1988 to 1990.

Year and crop	Sole crops	Strip width, ft		
		10	20	40
	$/acre			
1988				
Corn†	102	77	102	96
Alfalfa‡	122	127	128	127
Total	224	204	230	223
Difference from sole crops	--	−20	+6	−1
1989				
Corn	172	191	188	177
Alfalfa	169	169	182	184
Total	341	360	370	361
Difference from sole crops	--	+19	+29	+20
1990				
Corn	145	170	161	154
Alfalfa	209	188	212	214
Total	355	358	373	368
Difference from sole crops	--	+3	+18	+13
3 yr average				
Corn	140	146	150	142
Alfalfa	167	161	174	175
Total	307	307	324	317
Difference from sole crops	--	0	+17	+10

† Based on a corn price of $2.35/bu.
‡ Based on an alfalfa hay price of $75/ton.

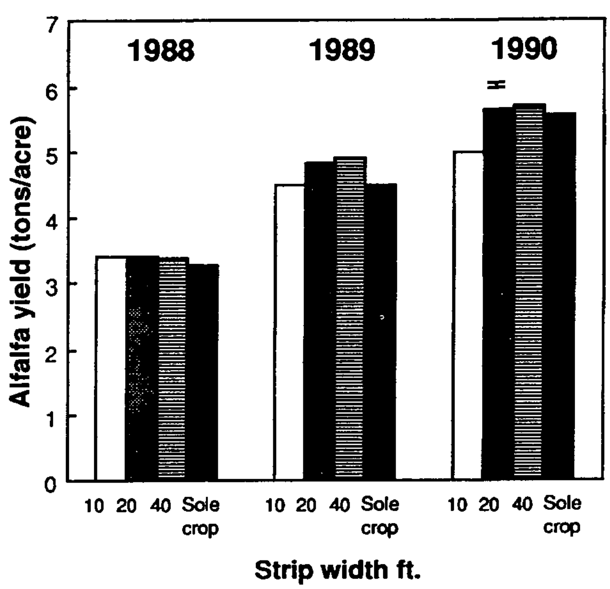

Fig. 7. Alfalfa hay yields expressed at 12% H_2O for 10-, 20-, and 40-ft wide strips (grown with alternating corn strips of similar width) and the sole crop for 3 yr, 1988 to 1990. The vertical bar represents the $LSD_{0.05}$ for strip widths within each year. Where no bar is shown, there were no differences among treatments.

Table 5. Price sensitivity analysis for the difference† in gross returns between (i) 20-ft wide strips of corn and alfalfa and (ii) sole crops for 3 yr, 1988 to 1990.

Corn price	Hay price, $/ton				
	65	70	75	80	85
$/bu	$/acre				
1988					
2.15	4.98	5.36	5.73	6.11	6.48
2.25	4.99	5.36	5.74	6.11	6.49
2.35	4.99	5.37	5.74	6.12	6.49
2.45	5.00	5.37	5.75	6.12	6.50
2.55	5.00	5.38	5.75	6.13	6.50
1989					
2.15	25.67	26.49	27.32	28.14	28.97
2.25	26.36	27.19	28.01	28.84	29.66
2.35	27.06	27.88	28.71	29.53	30.36
2.45	27.75	28.58	29.40	30.23	31.05
2.55	28.45	29.27	30.10	30.92	31.75
1990					
2.15	16.47	16.64	16.82	16.99	17.17
2.25	17.13	17.30	17.48	17.65	17.83
2.35	17.79	17.96	18.13	18.31	18.49
2.45	18.45	18.62	18.80	18.97	19.15
2.55	19.11	19.28	19.46	19.63	19.81

† Gross returns/acre for 20-ft. wide intercrop strips – gross returns/acre for sole crops.

1990 were increased when corn was grown in strips and alfalfa yields reduced only in 10-ft strips in 1990, increases in prices received for crops always increased the advantage of strip intercropping in 20- and 40-ft wide strips.

Crop producers have to evaluate whether our observed range of $6 to $29/acre per yr additional returns for 20-ft wide strips would cover their labor and management costs to implement the new cropping system. Possible differences in hay drying rates for strips and sole crops and an expected reduction in soil erosion due to strip intercropping should be addressed in the future.

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