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Higher Population and Twin Row Configuration Does Not Benefit Strip Intercropped Corn

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Increased corn (*Zea mays* L.) grain yield with strip intercropping, made possible because of increased edge effects, makes this soil-conserving crop production system appealing to farmers. The objective of this study was to determine the population and row configuration needed to optimize the additional yield potential in each outside corn row. Treatments included: 74, 99, and 124 thousand plants ha^{-1} were grown in twin rows and 74 thousand plants ha^{-1} grown in single rows. Single rows or twin row centers were spaced 0.76 m. The experiment was conducted at four central Iowa sites during 1996 and 1997. Grain yield was not increased by increasing population, nor did it respond consistently to the twin row configuration. There was little interaction between row position in the strip and treatment response. Higher plant population decreased the number of ears per plant, kernels per row, and kernel weight. The twin row configuration increased the number of ears per plant, but this was offset by a decrease in the number of kernels per row and kernel weight. Farmers should follow current cropping recommendations until this optimum is determined. Given the inconsistent grain yield response to twin rows, there is no current rationale for investing in twin row planting equipment.

INDEX DESCRIPTORS: strip intercropping, population, plant density, row configuration, twin row, corn.

Farmers generally know how to produce crops sustainably and to conserve soil (Tisdale et al. 1993), but there is concern about how they can afford to do so in the short term (3–5 years) with narrow profit margins and global food demands. Farmers require new farming systems that maintain profits and conserve soil. One option may be to use a strip intercropping system with small grain acting as a vegetative filter strip.

Intercropping is a time-tested practice of growing multiple plant species in close proximity, as compared with the monocrop design of industrial agriculture. The arrangement of crops in strips allows both interaction between and the independent mechanical management of different plant species. Appropriately paired species differ in spatial and temporal use of growth factors, as well as resource requirement and timing of light interception. For example, plants may draw water and nutrients from different soil depths, experience peak growth at different times during their growing cycle, or have a height differential that benefits both species. Such differences can be used to reduce interplant competition when compared with monocultures (Trenbath 1986).

In the proposed strip intercropping system, small grain serves both as a crop for forage or grain and as a vegetative filter strip. Generally, vegetative filter strips are bands of dense vegetation in or adjacent to crop production fields. They have been shown to reduce sediment loads in runoff by 84% and chemical loads more than 50% (Dillaha et al. 1989, Parsons et al. 1990, Daniels and Gilliam 1996, Robinson et al. 1996). The challenge for conservation-minded farmers is whether they can afford to take this land out of corn and soybean [*Glycine max* (L.) Merr.] production. One option may be to incorporate the filter strip concept into the strip intercropping system of corn, soybean and small grain, such as oat (*Avena sativa* L.). The densely-seeded oats then act similarly to a filter strip in terms of canopy and resiliency of vegetation (Gilley et al. 1997).

Corn is sensitive to shading and therefore optimum population recommendations have been developed to maximize grain yield in monocropping systems (Cummins and Dobson 1973, Alessi and Power 1974). Intercropped corn, however, receives relatively more sunlight when paired with a shorter species such as soybeans than when sole-cropped. This is especially true at the interface between corn and soybean strips (Francis et al. 1986). Separate population recommendations may, therefore, be needed for intercropped corn, but limited research has been conducted to address this need (Gliessman 1986).

Row configuration can also increase light interception by corn, with the physiologically optimum configuration being one that uniformly spaces plants both within and between corn rows (Hoff and Mederski 1960). Thus, increased plant populations require the use of narrower row spacing. The cost of reconfiguring equipment, from planters to combines, however, can be prohibitive to farmers' adoption of narrow rows. A twin row planting configuration can be created and managed with conventional equipment and can provide yield benefits similar to the use of narrow rows (Karlen et al. 1985, Karlen and Camp 1985, Karlen et al. 1987). Twin row configurations, however, have not been investigated in the north central United States, nor within a narrow strip intercropping system.

The objectives of this study were: 1) to determine the response of strip intercropped corn in twin rows to conventional and higher plant populations; and 2) to evaluate single and twin row configurations at the conventional plant populations.

METHODS

On-farm research was conducted at four central Iowa sites in 1996 and 1997. Treatments differed among sites. Sites near Union and Plainfield contained four treatments: plant densities of 74,000 (74-T), 99,000 (99-T), and 124,000 (124-T) plants ha^{-1} grown in a

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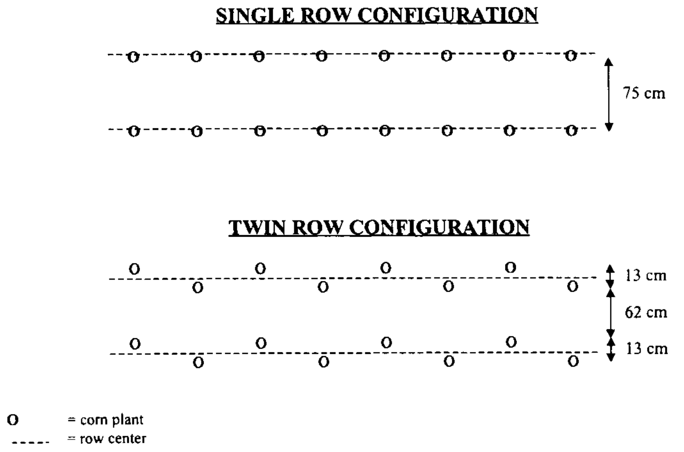

Fig. 1. Single and twin row configurations. "O" represents corn plant. Single row configuration shows two single rows. Twin row configuration shows staggered geometry in two twin row sets.

twin row configuration and 74,000 (74-S) plants ha^{-1} grown in single rows. The effect of twin rows was tested only at the lowest plant density. Sites near Yale and Bayard contained two treatments: plant densities of 74,000 (74-T) and 89,000 (89-T) plants ha^{-1} in twin rows.

The sites were owned and managed by individual farmer-cooperators in Union and Plainfield and by farmer cooperatives in Yale and Bayard. The Union and Plainfield sites were planted at the rate of 148,200 plants ha^{-1} and the Yale and Bayard sites were planted at the rate of 108,000 plants ha^{-1}, which allowed the individual plots to be thinned as necessary to form the plant densities and row configurations listed for each site. Single rows or twin row centers were spaced 0.76 m. Each row within a twin-row set was spaced about 0.16 m, with 0.6 m between sets.

Corn was overplanted in a twin row configuration using two planter passes. This planting method produced minor variations in the spacing between twin rows. Plots were located, however, in sections of the strip where row spacing matched the desired configuration. Corn was thinned during the V4 to V6 growth stage (Ritchie et al. 1997) to establish desired densities and an offset geometry (Fig. 1) between seedlings where necessary. The goal was to create a staggered spacing between individual plants within each row. Corn was not thinned until these growth stages to insure that undesired plants were severed below their growing points. Corn was thinned in and adjacent to measured rows.

Plots were 10.7 m long and ranged from 4.5 to 9.0 m in width, depending on farmer practice. The timing and type of preplant tillage, fertilization, planting, harvest, thinning, and other operations varied between sites (Table 1). The five measured rows were the two edge rows (rows 1 and 5), two adjacent interior rows (rows 2 and 4), and one of the two middle rows of the strip (row 3). Note that the numbering system for measured rows does not reflect the actual number of rows in the strip.

Site Characteristics

The Union site used for research in 1996 and 1997 was predominantly a Tama (fine-silty, mixed, mesic Typic Argiudoll) silty clay loam. Strip intercropping had been used at this site since 1994. Crop strips were 12 rows wide and from southeast-northwest. Corn, soybean, and an oat/berseem clover (*Trifolium alexandrinum* L.) mixture were grown so that the oat/berseem strips were always to the southwest and the soybean strips were to the northeast of the corn strips (Fig. 2).

The Plainfield site used in 1996 was abandoned in 1997 because the twin rows were not adequately spaced during planting. The Plainfield site was predominantly Kenyon (fine-loamy, mixed, mesic Typic Hapludoll) loam and Floyd (fine-loamy, mixed, mesic Aquic Hapludoll) loam. Strip intercropping was first used at this site in 1996, with corn and soybean strips six rows wide and rows from west-east.

The Yale site used in 1997 was predominantly Nicollet (fine-loamy, mixed mesic Aquic Hapludoll) loam. Strip intercropping was first used at this site in 1996, with corn and soybean strips 12 rows wide and rows from west-east.

The Bayard site was also used in 1997. Soil was predominantly Webster (loamy, mixed, noncalcareous, mesic Cumulic Haplaquoll) silty clay loam. Strip intercropping was also first used at this site in

Table 1. Details of the field operations used at each site-year.

OPERATION	1996 UNION	1996 PLAINFIELD	1997 UNION	1997 YALE	1997 BAYARD
Corn Variety	Pioneer 3395	Pioneer 3394	Pioneer 3395	NK 5857	NK 5857
Preplant herbicide	Dual II[a], 0.57 L ha^{-1}.	Harness Extra[b], 0.57 L ha^{-1}.	Dual II, 0.57 L ha^{-1}.	Dual, 0.57 L ha^{-1}.	Dual, 0.57 L ha^{-1}.
Planting Date	1 May	1 May	1 May	19 April	19 April
Postemergence herbicide	Pursuit[c], applied at 47.9 ml ha^{-1}.	none	Pursuit, applied at 47.9 ml ha^{-1}.	none	none
Nitrogen application	160 kg ha^{-1} as urea, pre-plant;	160 kg ha^{-1} as urea NH_4 - NO_3	160 kg ha^{-1} as urea, pre-plant;	160 kg ha^{-1} as NH3	179 kg ha^{-1} as urea NH_4 - NO_3
Manure	28,000 L ha^{-1} hog manure	none	28,000 L ha^{-1} hog manure	none	none
Tillage	reduced tillage	no-till	reduced tillage	chisel plow, field cultivator	no-till
Thinning date	2 June	12 June	5 June	25 June	25 June
Harvest date	2 November	11 November	11 October	25 September	25 September

[a] Dual, Dual II = metolachlor: 2-chloro-N-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetemide
[b] Harness Exrra = acetochlor: 2-chloro-N-ethoxy mehtyl-N-(2-ethyl-6-methylphenyl) acetemide
[c] Pursuit = imazethapyr (±)-2-[4,5-dihydro-4-methyl-4-(1 methyethyl-5-oxo-1*H*-imidazol-2-yl)]-5ethyl-3-pyridine carboxolic acid

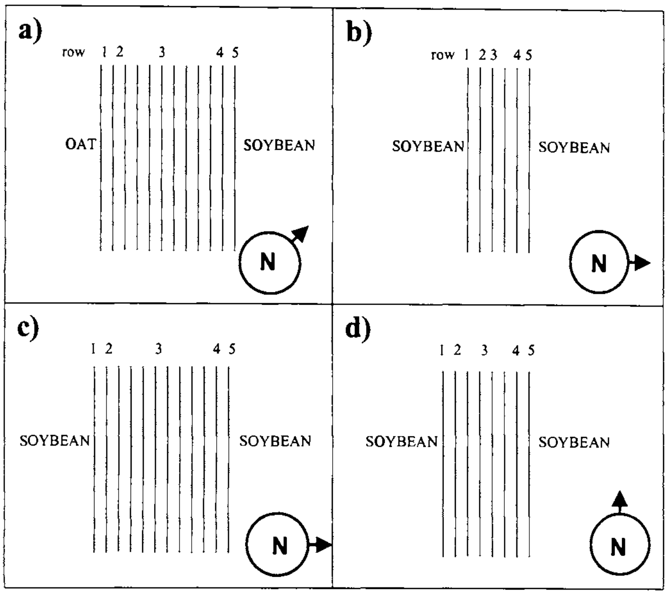

Fig. 2. Strip width, row numbering and geographical orientation by site: a) Union, b) Plainfield, c) Yale and d) Bayard. Vertical lines represent corn rows and measured rows are numbered. Circled N points towards true north.

1996, with corn and soybean strips eight rows wide and oriented north-south.

Measurements

At each site, corn ears from 10m of row length were hand-harvested soon after physiological maturity and shelled using a one-row plot combine. Grain moisture and weight were recorded and the number of harvested ears was counted for all sites. Six sample ears were retained from each single- or twin-row set for analysis of grain yield components. The kernel rows per ear, kernels per row, weight of kernels, and weight per hundred kernels were measured.

Several measurements were used to confirm that soil fertility levels were adequate for maximum plant growth. Soil samples were collected at harvest in each site-year to measure P, K, and pH. Late spring soil nitrate and stalk nitrate tests were used to evaluate availability of N. Weather data were collected at the NOAA weather station nearest each site.

Statistical Design

The statistical design used for data analysis was a split-block with the row position as the main effect and plant density and row configuration as the blocked sub-unit effect. The split-block model was necessary because row position could not be randomized among experimental units. At least four replications were used for each site. Analysis of variance F-tests were conducted using PROC MIXED to identify significant treatment and row position effects, as well as any interactions (SAS Instititue, INC). The linear model used to test the row position and treatment effect was:

$$Y_{ijk} = \mu + B_i + \delta_{(i)} + R_j + BR_{ij} + \omega_{(ij)} + T_k + BT_{ik} + \lambda_{(ik)} + RT_{jk} + BRT_{ijk}$$

where B is the block effect, R is the row position effect, and T is the treatment effect. Block effects were treated as random, whereas row position and treatment effects were treated as fixed. Row position, treatment, and the interaction of row position and treatment were each tested using their interaction with the block effect.

When the F-test indicated significant effects, means were separated using pre-planned orthogonal contrasts between treatments and rows. Main treatment contrasts were: 124-T vs. the average of the other three; 99-T vs. the average of 74-S and 74-T; and 74-S vs. 74-T. Row position contrasts for yield and ears per plant were: row 3 (middle) vs. the average of the other four rows; average of rows 1 and 2 vs. average of rows 4 and 5; row 1 vs. row 2; and row 4 vs. row 5 (Fig. 1). The row position contrast for yield components was: row 1 or row 5 (whichever had the greatest yield) vs. row 3. Least significant differences (LSDS) were used to separate other differences. A probability level of $P \leq 0.05$ was used to identify significant differences.

RESULTS AND DISCUSSION

Weather

Weather during 1996 was cooler than normal at both sites during several months (Table 2). The 1997 season was also cooler than normal during spring, but temperatures approached normal during the summer months. Moisture was limiting during the crucial pollination and grain-fill stages during July and August in 1997.

Grain Yield

There was no obvious advantage to planting our corn hybrids at densities greater than that of the 74-T treatment. At the Yale and Bayard sites, there were no significant differences among treatments. At the Union and Plainfield sites, the 74-T treatment produced a yield equivalent to or greater than that at higher plant densities (Table 3).

Yield did increase about 9% more when planted in twin rows (74-T) compared with single rows (74-S) at Union, but these results were reversed at Plainfield. Because of these inconsistencies, along with equipment modifications or additional labor involved in planting twin rows, we defer to the farmer's own judgment whether to experiment with this alternative row configuration.

Row position significantly affected grain yield at all sites in all years. The outside rows of each strip typically yielded more than interior rows. Exceptions included: the 1996 Union site, where oat was planted too close to the corn strip and competed with the outer corn row (row 1) for early season light and N; and the 1997 Yale site, where the northern border row (row 5) in the east-west strips yielded less than the adjacent interior row. Perhaps, there was more shading in the northern border row compared with the southern border row, as observed by Pendleton et al. (1962), but this was not measured in our study. The benefits of additional sunlight did not extend into the strips, as shown by the frequent differences between outside and the adjacent interior rows. This underscores the advantage of using narrower strips when intercropping to create a greater number of border rows compared with wider strips or sole-cropped corn (Crookston and Hill 1979).

Plant density and row position interacted significantly at Union in 1996, with the 99,000 plants ha^{-1} density yielding more than the lower density in the outer rows. This effect was not observed in data from any other site-year, suggesting little long-term advantage for varying seeding rates by row.

Ears per Plant

The number of ears per plant partially accounts for the yield difference between treatments at Union. Contrasts indicate that the number of ears per plant was greatest in the 74-T treatment and declined with increasing population (Table 4). The number of ears

Table 2. Temperature and precipitation data recorded during the growing season at each site-year.

	SITES						
	UNION[a]			PLAINFIELD[b]		YALE AND BAYARD[c]	
MONTH	1996	1997	NORMAL	1996	NORMAL	1997	NORMAL
Temperature (°C)							
April	8.0	7.7	9.1	7.4	8.8	6.6	9.1
May	13.9	13.1	15.4	13.0	15.5	12.1	15.7
June	21.0	21.7	20.7	20.4	20.7	21.9	20.8
July	21.6	23.9	22.9	20.9	22.8	23.9	23.3
August	21.1	20.9	21.2	20.3	21.5	21.2	21.6
September	16.0	17.9	16.6	15.8	16.8	18.1	16.8
October	10.8	11.1	10.2	10.4	10.5	11.2	10.4
Precipitation (mm)							
April	3.7	4.0	8.0	3.1	8.3	6.4	7.9
May	16.8	12.8	10.1	12.3	10.1	8.0	10.6
June	17.7	15.1	11.9	14.6	11.6	9.5	12.0
July	10.2	4.9	10.8	4.8	10.3	3.3	9.5
August	4.4	4.2	11.6	12.9	9.6	2.7	9.8
September	9.6	11.7	9.2	4.7	9.5	9.0	8.4
October	7.7	10.3	6.3	7.4	6.6	9.1	6.1

[a] Data for Union was taken at Marshalltown, IA (National Climatic Data Center, 1996; National Climatic Data Center, 1997)
[b] Data for Plainfield was taken at Charles City, IA (National Climatic Data Center, 1996)
[c] Data for Yale and Bayard was taken at Perry, IA (National Climatic Data Center, 1997)

Table 3. Average corn grain yields expressed by treatment and row for each site-year. Orthogonal contrasts (bottom) were used to further separate means.

	CORN GRAIN YIELD (Mg ha^{-1})				
SITES	1996 UNION	1996 PLAIN-FIELD	1997 UNION	1997 YALE	1997 BAYARD
Treatment					
74-S	8.3	11.0	8.4	N/A	N/A
74-T	9.0	10.1	9.2	11.6	11.7
99-T (89-T)	9.0	9.8	8.2	(11.8)	(12.3)
124-T	7.7	10.0	7.3	N/A	N/A
LSD	0.7	0.7	0.7	0.7	1.0
Row					
1	7.6	11.5	10.7	12.6	13.0
2	9.2	9.7	7.9	12.0	11.5
3	7.6	9.4	6.6	11.8	10.9
4	8.5	9.5	7.9	11.4	11.3
5	10.3	10.9	8.2	10.6	13.2
LSD	0.8	0.8	0.8	1.2	1.6
Contrasts					
124-T vs. others	**	ns	**	N/A	N/A
74-S and 74-T vs. 99-T	ns	*	ns	N/A	N/A
74-T vs. 74-S	**	*	*	N/A	N/A
Row 3 vs. others combined	**	**	**	ns	*
Row 1 and 2 vs. 4 and 5	*	ns	**	**	ns
Row 1 vs. 2	**	**	**	ns	ns
Row 4 vs. 5	**	**	ns	ns	*

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

Table 4. Average number of ears per corn plant were expressed by treatment and row for each site-year. Orthogonal contrasts (bottom) were used to further separate means.

	EARS PER PLANT				
SITES	1996 UNION	1996 PLAIN-FIELD	1997 UNION	1997 YALE	1997 BAYARD
Treatment					
74-S	0.96	0.82	0.87	N/A	N/A
74-T	1.05	0.79	0.94	0.81	0.80
99-T (89-T)	0.91	0.80	0.78	(0.80)	(0.68)
124-T	0.82	0.77	0.69	N/A	N/A
LSD	0.06	0.05	0.06	0.05	0.06
Row					
1	0.92	0.77	0.88	0.74	0.73
2	0.97	0.79	0.80	0.88	0.79
3	0.93	0.77	0.78	0.85	0.81
4	0.90	0.89	0.83	0.85	0.68
5	1.00	0.76	0.81	0.73	0.68
LSD	0.06	0.05	0.07	0.08	0.09
Contrasts					
124-T vs. others	**	ns	**	N/A	N/A
74-S and 74-T vs. 99-T	**	ns	**	N/A	N/A
74-T vs. 74-S	**	ns	*	N/A	N/A
Row 3 vs. others combined	ns	ns	ns	ns	*
Row 1 and 2 vs. 4 and 5	ns	*	ns	ns	*
Row 1 vs. 2	ns	ns	*	**	ns
Row 4 vs. 5	**	**	ns	**	ns

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

Table 5. Average number of kernels per row of corn ear expressed by treatment and row for each site-year. Orthogonal contrasts (bottom) were used to further separate means. The inside row measurement corresponds to the middle row (measured row 3), whereas the outside row measurement refers to the higher yielding of rows 1 and 5.

	KERNELS PER ROW				
SITES	1996 UNION	1996 PLAIN-FIELD	1997 UNION	1997 YALE	1997 BAYARD
Treatment					
74-S	34	33	30	N/A	N/A
74-T	31	31	29	38	38
99-T (89-T)	28	29	28	(34)	(38)
124-T	24	25	22	N/A	N/A
LSD	1.9	2.3	2.7	2.0	2.6
Row					
Outside	34	31	31	40	41
Inside	27	28	23	31	35
LSD	1.3	1.7	1.9	2.0	2.6
Contrasts					
124-T vs. others	**	**	**	N/A	N/A
74-S and 74-T vs. 99-T	**	*	ns	N/A	N/A
74-T vs. 74-S	**	ns	ns	N/A	N/A
Outside vs. inside row	**	**	**	**	**

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

Table 6. Average total kernel weights per corn ear expressed by treatment and row for each site-year. Orthogonal contrasts (bottom) were used to further separate means. The inside row measurement corresponds to the middle row (measured row 3), whereas the outside row measurement refers to the higher yielding of rows 1 and 5.

	TOTAL KERNEL WEIGHT PER EAR (g)				
SITES	1996 UNION	1996 PLAIN-FIELD	1997 UNION	1997 YALE	1997 BAYARD
Treatment					
74-S	147	159	136	N/A	N/A
74-T	132	139	128	175	167
99-T (89-T)	111	124	114	(142)	(158)
124-T	94	94	91	N/A	N/A
LSD	8.4	13.6	12.6	10.8	15.0
Row					
Outside	141	142	138	180	181
Inside	112	122	97	137	146
LSD	6.0	9.6	8.9	10.8	15.0
Contrasts					
124-T vs. others	**	**	**	N/A	N/A
74-S and 74-T vs. 99-T	**	**	ns	N/A	N/A
74-T vs. 74-S	*	ns	ns	N/A	N/A
Outside vs. inside row	**	**	**	**	ns

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

Table 7. Average weights per 100 corn kernels expressed by treatment and row for each site-year. Orthogonal contrasts (bottom) were used to further separate means. The inside row measurement corresponds to the middle row (measured row 3), whereas the outside row measurement refers to the higher yielding of rows 1 and 5.

	WEIGHT PER 100 KERNELS (g)				
SITES	1996 UNION	1996 PLAIN-FIELD	1997 UNION	1997 YALE	1997 BAYARD
Treatment					
74-S	29.0	31.2	28.4	N/A	N/A
74-T	28.6	28.7	27.8	25.5	25.5
99-T (89-T)	28.3	28.6	26.9	(25.0)	(23.8)
124-T	27.0	27.6	27.8	N/A	N/A
LSD	0.9	1.0	1.2	0.8	0.9
Row					
Outside	28.1	29.2	27.9	25.5	25.4
Inside	28.4	29.0	27.7	25.0	24.0
LSD	0.7	0.7	0.9	0.8	0.9
Contrasts					
124-T vs. others	**	**	ns	N/A	N/A
74-S and 74-T vs. 99-T	ns	**	ns	N/A	N/A
74-T vs. 74-S	ns	**	ns	N/A	N/A
Outside vs. inside row	ns	ns	ns	ns	ns

*Significant at the 0.05 probability level
**Significant at the 0.01 probability level

per plant was also significantly higher in the 74-T than 74-S treatment, suggesting that barrenness was less frequent in twin rows than in single rows. This was probably the result of better light distribution in the twin-row configuration, although light distribution was not measured.

Row position did not have a significant effect on the number of ears per plant (Table 4). Lodging was not a widespread problem at these sites, but this difference may have been caused by the wind exposure of outer rows and resulting ear drop. An attempt was made to locate and match dropped ears with rows, but not all ears were recovered. No interaction between treatment and row position was observed.

Yield Components

Yield components were examined to determine if they could explain yield differences or serve as indicators of stress during reproductive growth stages (Claassen and Shaw 1970, Westgate and Boyer 1985). The number of kernels per row was highest at the lower plant density and in single rows. Differences, however, were not always significant (Table 5). In addition, a difference between the single and twin-row configuration was only observed in one site-year. Row position consistently affected the number of kernels per row, with higher values occurring in border rows than in middle rows. This suggests that there was less stress in plants at lower plant densities and in outside rows during the early grain-fill period.

The total weight of kernels per ear was also affected by treatment and row position, being highest for the low plant density and single rows, when present (Table 6). Row position consistently affected total weight, with higher values occurring in border rows than middle rows. Hundredweight, or the weight of one hundred kernels, reacted similarly to changes in plant density, as shown in the contrasts (Table 7). Both observations suggest that there was less stress in plants at lower densities and in outside rows during the middle of the grain fill period (Claassen and Shaw 1970, Westgate and Boyer 1985). No interactions for any yield component were observed between treatment and row position.

The increase in number of ears per plant with twin rows seems to be offset by a decrease in the number and weight of kernels produced by the plant. Corn planted in the twin-row configuration may receive more light and be prompted to produce a second ear per plant; many small "nubbin" ears were observed at harvest. These tiny ears, however, contained no kernels and were, therefore, not included in this study. In retrospect, these additional ears may divert resources and reduce grain fill in the main ear, thereby decreasing the grain yield of the plant.

Therefore, we found no advantage to planting these corn hybrids at plant densities greater than 74,000 plants ha^{-1}, even when corn is planted in a strip intercropping configuration. It should be noted, however, that no densities between 74,000 and 99,000 (89,000 in Yale and Bayard) plants ha^{-1} were tested, and that an optimum plant density may exist in this range.

Finally, there seems to be no great advantage to planting in twin rows rather than single rows at the populations studied. Such a configuration may prove beneficial, however, at reducing crowding at higher populations. It may also be more appealing to farmers if the twin rows could be established in a single operation.

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