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Simulation of Spring-Seeded Smother Plants for Weed Control in Corn (*Zea mays*)[1]

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Abstract. **Field experiments were conducted to determine the effect of a short-term spring-seeded smother plant on corn development and weed control. Yellow mustard was managed to provide interference durations of 2, 4, 6, or 8 wk, and maximum height of 10 or 20 cm. Three yellow mustard planting patterns and eight seeding rates were evaluated during 1989 and 1990 at St. Paul and Rosemount, MN. Yellow mustard seeded at 2120 seeds m^{-2} with an interference duration of 4 wk and a maximum height of 10 cm decreased corn yield 17% and reduced weed dry weight 4 wk after yellow mustard emergence an average of 66%. Yellow mustard with a 2-wk interference duration did not reduce weed dry weight. Yellow mustard seeded at 2120 seeds m^{-2} with a 6- or 8-wk life cycle and 10-cm height reduced weed dry weight at the end of the interference period an average of 82% but delayed corn silk emergence an average of 5.3 d and reduced average grain yield 19%. Increasing yellow mustard height from 10 to 20 cm delayed corn silk emergence and reduced grain yield but did not decrease weed dry weight. Yellow mustard with an interference duration of 4 wk and a maximum height of 10 cm, seeded over the corn row at 530 seeds m^{-2}, reduced weed dry weight 4 wk after mustard emergence an average of 51%, and resulted in an average corn grain yield reduction of 4%, compared with corn grown in monoculture averaged over weedy and weed-free treatments. These results suggest that it may be possible to develop spring-seeded smother plants that reduce weed biomass up to 80% but have only a small impact on corn yield. Nomenclature: Corn, *Zea mays* L. 'Funks G 4256 and 4234'; Yellow mustard, *Brassica hirta* Moench 'Kirby'.**

Additional index words. **Competition, cover crops, densities, living mulch, interference.**

INTRODUCTION

Many corn producers are interested in development of alternative weed control options. This interest has been stimulated by a heightened level of environmental awareness among producers and the general public, by fears of more restrictive regulations on herbicide use in the future, and by the desire to reduce production costs. Smother plants, specialized cover crops selected for their ability to suppress weeds, are one of many alternative weed control methods being investigated (27). An effective smother plant could provide a nonchemical weed control option and also reduce soil erosion (19).

Smother plants evaluated previously have drawbacks that limit their use in the north-central region of the United States. Many of the plant species investigated are not winter hardy, and most do not represent completely nonchemical forms of weed control since a herbicide must be used to suppress or kill the smother plant before planting corn in the spring (20, 24, 28). In addition, use of currently available cover crops as smother plants generally requires increased management, compared to chemical weed control (16).

Plant species that have been evaluated for suitability as smother plants in corn production systems include winter rye (*Secale cereale* L.), hairy vetch (*Vicia villosa* Roth), crownvetch (*Coronilla varia* L.), and subterranean clover (*Trifolium subterraneum* L.) (8, 10, 11, 19, 27). Enache and Ilnicki (7, 8) reported that subterranean clover, suppressed with a herbicide in the spring, effectively controlled annual weeds, but that unusually cold weather in New Jersey caused winter injury. In another study, winter rye, killed with a herbicide applied in the spring, provided fair control of summer annual weeds (27), but its spring growth in dry years reduced soil moisture, caused seedling desiccation and mortality, and reduced crop yield (6, 26).

The use of short-term spring-seeded smother plants may avoid the problems associated with previously tested species. A spring-seeded smother plant would not need to be winter hardy, and management inputs would not be as great as with perennial or winter annual species, provided a herbicide application to regulate smother plant growth was not necessary.

Feasibility of short-term spring-seeded smother plants is supported by plant competition research. Studies indicate that weed interference with corn for the first 2 to 8 wk after corn emergence may not be detrimental to crop yield, depending on the weed species present, soil fertility, moisture availability, and corn cultivar used (3, 9, 17, 23, 30). Therefore, it is possible that a spring-seeded smother plant could compete with corn for a similar period of time without reducing crop yield. Other studies report that weeds that do not emerge until 3 to 6 wk after corn do not reduce corn yield (9, 14, 23, 25). This suggests that annual weeds, is suppressed for about 4 wk by the smother plant, would not compete effectively with corn.

The goal of this research was to define characteristics of an acceptable spring-seeded smother plant, and to examine the feasibility of using spring-seeded smother plants for weed control in corn. Identification of appropriate smother plant life cycle lengths and morphologies would provide necessary background information for plant breeders, molecular geneticists, and other researchers interested in developing spring-seeded smother plants.

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MATERIALS AND METHODS

General methods. Two field experiments were conducted at the University of Minnesota St. Paul and Rosemount Agricultural Experiment Stations during 1989 and 1990. Soil at St. Paul and Rosemount was a Waukegan silt loam (fine-silty, mixed, mesic Typic Hapludoll). Soil pH was 6.9 and 6.5 in St. Paul, and 5.5 and 5.8 for Rosemount in 1989 and 1990, respectively. Soil organic matter at all sites ranged from 3.1 to 4.5%. Soil fertility was adjusted in accordance with the University of Minnesota Soil Testing Laboratory recommendations for corn production. The experimental sites were moldboard plowed or chisel plowed in the fall and then field cultivated and/or disked in the spring before planting. Hybrid field corn ('Funks G 4256' in 1989 and 'Funks G 4234' in 1990) was planted at 64000 seeds ha^{-1} in 76-cm-wide rows during the first 10 d in May using a four-row corn planter. Kirby yellow mustard was used to simulate smother plants with various life histories and growth habits and was seeded over the corn row within 24 h of corn planting. A 50-cm area between corn rows was maintained weed free using a hand-operated wheel hoe. Propachlor [2-chloro-*N*-(1-methylethyl)-*N*-phenylacetamide) was applied preemergence at 3.4 kg ai ha^{-1} to the weed-free plots. Propachlor was effective in controlling annual grass and some small-seeded broadleaf weeds but was not phytotoxic to yellow mustard. The most abundant weeds were yellow foxtail [*Setaria glauca* (L.) Beauv #[3] SETLU], green foxtail [*Setaria viridis* (L.) Beauv. # SETVI], common lambsquarters (*Chenopodium album* L. # CHEAL), and redroot pigweed (*Amaranthus retroflexus* L. # AMARE). Weed free plots were handweeded as needed throughout the growing season.

The experimental design for both experiments was a randomized complete block with a split-split-plot restriction on randomization and four replications. Main plot treatments were weedy or weed free. Yellow mustard interference duration was manipulated with an application of 2,4-D amine [(2,4-dichlorophenoxy) acetic acid] at 0.28 kg ai ha^{-1}, followed by a second treatment 1 wk later to ensure complete yellow mustard mortality. Control plots without yellow mustard were also sprayed. The 2,4-D treatment killed broadleaf weeds in the weedy plots, leaving only annual grasses to compete for the remainder of the growing season.

Corn and mustard height, and an estimate of mustard ground cover were recorded weekly for the first 12 wk. Dry weight of aboveground plant tissue from grass and broadleaf weeds, mustard, and corn was obtained from a 0.09-m^2 area of each plot immediately prior to the 2,4-D treatment. The number of days from corn emergence to emergence of silks on 50% of the plants in each sub-subplot was recorded. At harvest, two ears from each sub-subplot were dried to determine ear moisture content. Whole ear fresh weight was converted to grain yield at 15.5% moisture.

[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133.

Data from each site were analyzed separately and in combination, using analysis of variance and multiple linear regression procedures.

Yellow mustard height and interference duration. Weedy or weed-free main plots were 4.6 m long and 12 corn rows wide. Yellow mustard was seeded at 2120 seeds m^{-2} in a 25-cm band over the corn row with a small-plot granular herbicide applicator (1), and incorporated to a depth of approximately 0.5 cm with a drag chain.

Subplots were 2, 4, 6, or 8 wk of yellow mustard interference and were 4.6 m long and three corn rows wide. Interference was assumed to begin at the time of mustard emergence. A bicycle sprayer with a single shielded nozzle was used to apply 2,4-D to subplots with 2- and 4-wk interference durations. For the 6- and 8-wk interference durations, 2,4-D was applied from both sides of the row with a hand-held wand and directed at the lower part of the corn plant. The corn showed very little herbicide injury.

Sub-subplots were one corn row 4.6 m long. Sub-subplot treatments were yellow mustard heights of 0 (no mustard), 10, or 20 cm. Yellow mustard was clipped to 10 or 20 cm on a weekly basis using manually operated grass shears.

At harvest, corn ears from the center 2.4 m of each sub-subplot were harvested and fresh weight recorded.

A significant interaction between yellow mustard interference duration and yellow mustard height was observed. In order to examine the relationship among treatments, three-dimensional surfaces were constructed by plotting interference duration and height on the x and y axes, and the dependent variable of interest on the z axis.

Yellow mustard planting pattern and seeding rate. Weedy or weed-free main plots were 6.1 m long and 24 corn rows wide. Subplot treatments in this experiment were three yellow mustard planting patterns and were 6.1 m long and eight corn rows wide. To create the first pattern, a wheel-driven cone-type hand planter was used to seed a single row of yellow mustard 0.5 to 1 cm deep directly over the corn row. The second pattern was created using the same planter to seed a row of yellow mustard 10 cm to the left and another 10 cm to the right of the corn row in addition to seeding directly over the corn row. The small-plot granular herbicide applicator was used to create the third pattern, and a 25-cm band of yellow mustard seeds was broadcast over the corn row and incorporated to a depth of approximately 0.5 cm using a drag chain.

Sub-subplots were yellow mustard seeding rates of 0, 132, 265, 530, 1060, 2120, 4240, and 8480 seeds m^{-2}. Sub-subplots were one corn row 6 m long. Yellow mustard interference duration was limited to 4 wk. Yellow mustard was clipped to 10 cm on a weekly basis, with the first clipping done 2 to 3 wk after yellow mustard emergence.

An error in herbicide rate calculation resulted in an application rate of 1.3 kg ai ha^{-1} of 2,4-D to the 1990 plots. The Rosemount-grown corn appeared to be unaffected by the higher rate, but corn grain yield data from St. Paul showed increased variability when compared with the other experimental environments and therefore are not presented.

At harvest, corn ears from the center 3.7 m of each sub-subplot were harvested and fresh weight recorded.

The combined analysis of variance tables were utilized to compare weedy and weed-free treatments and the three planting patterns. To generate predictive equations for corn height, silk emergence, and ear moisture response to yellow mustard seeding rate, the data (averaged across locations, weed treatments, and planting patterns) from each variable were fit to various equations, and those with the highest adjusted R^2 were used to describe the relationships. The response of yellow mustard dry weight at 4 wk (averaged across weed treatments and planting patterns) to a range of yellow mustard seeding rates was best described by the nonlinear equation for a hyperbolic response:

$$Y = \frac{(A \times d)}{(B + d)}$$

where Y is yellow mustard dry weight, A and B are estimated parameters, and d is the yellow mustard seeding rate in seeds m^{-2}. Responses of weed dry weight and corn grain yield (averaged across weed treatments and planting patterns) to yellow mustard seeding rate were estimated using the hyperbolic model of Cousens (4):

$$Y = Y_{mf}\left[1 - \frac{Id}{(1 + Id/C)}\right]$$

where Y is actual weed weight or corn grain yield, d is yellow mustard seeding rate, and Y_{mf}, I, and C are estimated parameters denoting yellow mustard free weed weight or corn grain yield, yield loss (in weed weight or corn grain) per unit yellow mustard seeding density as d approaches 0, and maximum yield loss as d approaches infinity, respectively. Predicted weed weight in g m^{-2} was converted to percent reduction in weed biomass due to large differences in yellow mustard free weed weight from year to year.

RESULTS AND DISCUSSION

Yellow mustard height and interference duration. Weed presence resulted in small but significant effects on corn development (Table 1). Response to weedy versus weed-free treatments was similar across environments, except that the 1990 Rosemount site showed a larger increase in ear moisture and a greater decrease in grain yield than the other sites, due to heavy populations of yellow and green foxtail. Response of corn to weeds was similar across yellow mustard lengths of interference and yellow mustard maximum height. Corn height at 8 wk was reduced 6.8% by weed presence, and silk emergence was delayed by approximately 1 d. At the end of the growing season, weed presence increased corn ear moisture content 1.3% and decreased corn grain yield 6.7% compared with weed-free plots. Weed presence may have had a larger impact on corn development and yield if the broadleaf weeds had been allowed to compete for the entire growing season, instead of being killed by the 2,4-D used to manipulate yellow mustard interference duration. Bunting and Ludwig (3) reported similar reductions in corn yield when natural weed infestations were allowed to compete with the crop for 2 to 6 wk before being removed.

Table 1. Influence of weeds on corn development and yield averaged across yellow mustard height treatments, interference duration, and two locations in 1989 and 1990 (n = 192).

Treatment	Corn ht at 8 wk[a]	Corn silk emergence[b]	Corn ear moisture	Corn grain yield
	cm	d	%	kg ha^{-1}
Weed-free	101.5	68.5	28.6	8630
Weedy[c]	94.6	69.4	29.9	8050
Significance[d]	**	*	**	*

[a]Time after yellow mustard emergence.

[b]Time from seedling emergence to silk emergence on 50% of the plants.

[c]Natural stands of annual broadleaf and grass weeds were allowed to compete for the first 2, 4, 6, or 8 wk after yellow mustard emergence, then the plots were treated with a herbicide that killed the broadleaf weeds and the yellow mustard, leaving annual grasses to compete with the corn for the remainder of the growing season.

[d]** = significant at 1% level, * = significant at 5% level.

Corn height 8 wk after yellow mustard emergence was very sensitive to changes in yellow mustard interference duration and yellow mustard height. The 2-wk yellow mustard interference duration reduced corn height at 8 wk by 15 cm (Figure 1a). Corn height reduction can be partially explained by emergence of the yellow mustard seedlings about 7 d ahead of the corn, giving the yellow mustard a competitive advantage. In addition, 2,4-D kills yellow mustard over a period of 3 to 4 d, so the yellow mustard was alive for more than 2 wk. Six or 8 wk of yellow mustard interference did not reduce corn height more than 4 wk of interference. This probably occurred because yellow mustard reached its maximum height of 10 or 20 cm in 2.5 or 3.5 wk, respectively. Once the vertical growth of yellow mustard was stopped by clipping, the plants appeared to lose their ability to compete effectively with corn, even though they were still living. Conversely, an increase in yellow mustard height from 10 to 20 cm resulted in decreased corn height over all but the 2-wk interference duration. Yellow mustard did not attain a height of 20 cm until 3 wk after emergence, and therefore the 20-cm yellow mustard treatment did not reduce corn height more than the 10-cm yellow mustard treatment after 2 wk of growth.

The response surface (Figure 1a) indicates that to minimize negative effects of yellow mustard on corn height, yellow mustard interference duration should be limited to 2 to 3 wk, or yellow mustard height should be restricted to less than 10 cm. It is important to note that while most yellow mustard growth was stopped by the clipping treatment, a smother plant with a less erect growth habit might continue growing without exceeding 10 cm in height, and thus could have a different effect on corn height.

Reproductive development of corn, as measured by days from corn emergence to emergence of silks in 50% of the plants, showed a response similar to corn height at 8 wk (Figure 1b). An 8-wk interference duration delayed silk emergence only slightly

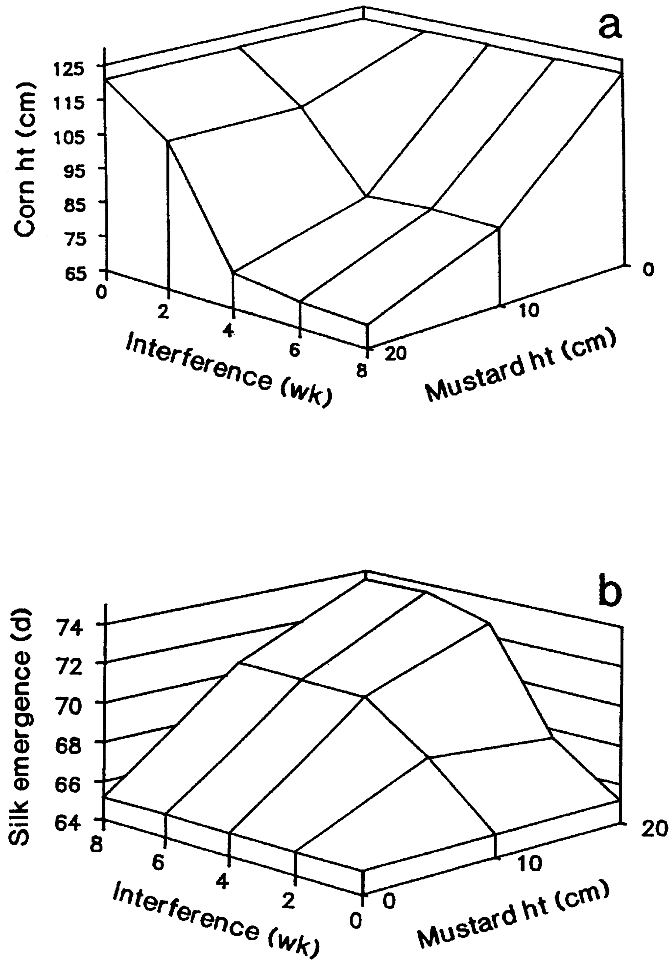

Figure 1. Corn height 8 wk after yellow mustard emergence (a), and number of days from corn seedling emergence to silk emergence (b) as affected by length of yellow mustard interference and yellow mustard height, averaged across weed treatments and two locations in 1989 and 1990 (n = 32).

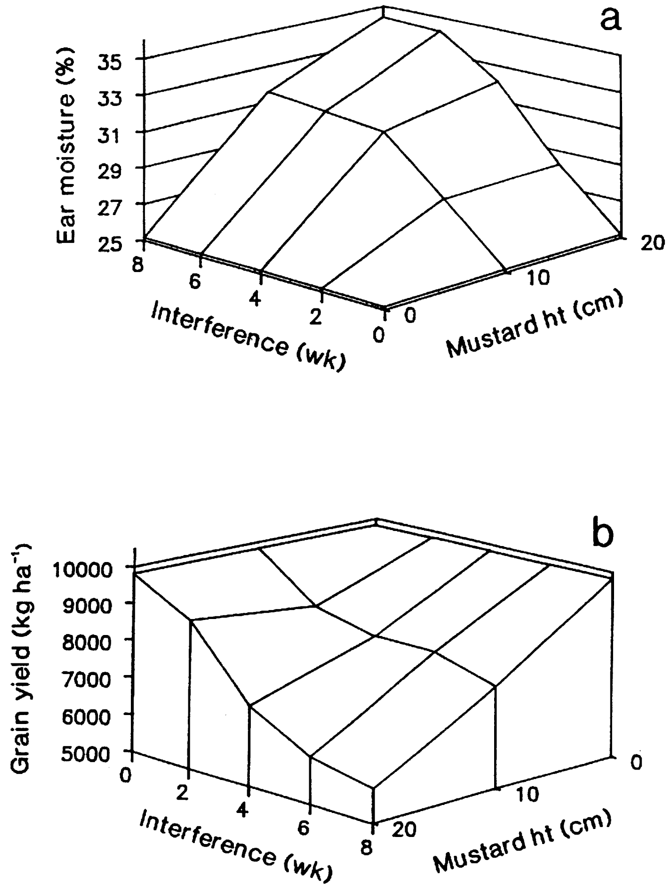

Figure 2. Corn ear moisture at harvest (a), and corn grain yield (b) as affected by length of yellow mustard interference and yellow mustard height, averaged across weed treatments and two locations in 1989 and 1990 (n = 32).

more than 4 wk of interference. Increasing yellow mustard height from 10 to 20 cm resulted in a significant delay in corn silk emergence. These data support the use of smother plants with a 2- to 3-wk period of interference if height is not restricted, or a 4- to 6-wk period of interference when height is less than 10 cm.

Corn ear moisture and corn grain yield at the 20-cm height were influenced more by the 6- and 8-wk periods of yellow mustard interference than the 4-wk interference duration (Figure 2a and 2b). This is in contrast to corn height and silk emergence data which indicated that 6 and 8 wk of yellow mustard interference did not influence corn more than 4 wk of interference. There are two possible explanations for this apparent discrepancy. Longer periods of interference may have had a delayed impact on the corn plants, and corn height and silk emergence may have been measured too soon after the 8-wk interference duration for a response to be detected. Alternatively, end of season corn maturity and yield could be more sensitive to interference duration than the midseason parameters of corn height at 8 wk and days to silk emergence. In any case it would appear advisable not to extend the interference duration beyond what is necessary for effective weed suppression.

Increasing yellow mustard maximum height from 10 to 20 cm increased corn ear moisture at harvest and decreased corn grain yield. Knake and Slife (13) allowed giant foxtail (*Setaria faberii* Herrm.) to reach 7 to 30 cm while competing with corn for 2 to 4.5 wk, and reported that longer periods of interference and taller plants resulted in larger corn yield reductions than shorter periods of interference and shorter plants. These results are in agreement with the simulated smother plant data obtained from this experiment.

Corn development was affected not only by the maximum height of yellow mustard but also by yellow mustard height relative to corn height. Yellow mustard in the 10-cm treatment did not grow taller than the corn, whereas yellow mustard in the 20-cm treatment was taller than the corn between 2.5 and 4 wk after mustard emergence (data not shown). This may have been the primary reason that the 20-cm yellow mustard treatment delayed corn development more than the 10-cm treatment. The important role that relative plant height plays in competitive

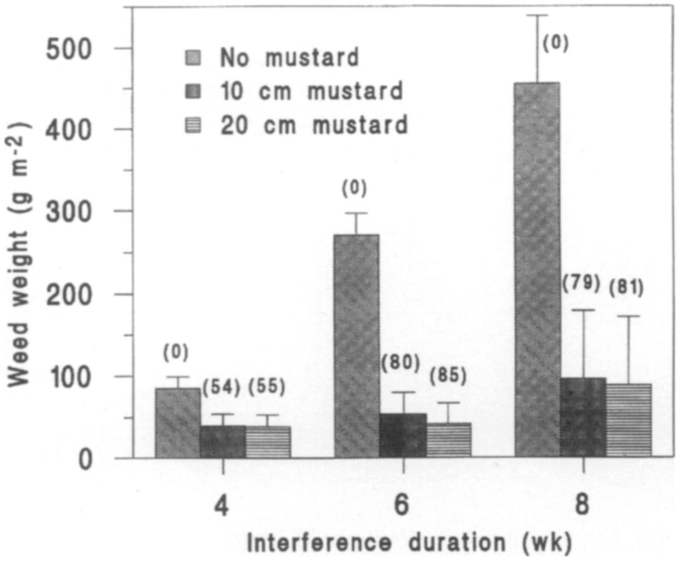

Figure 3. Weed dry weight in 1989 as affected by yellow mustard interference duration and yellow mustard height, averaged across two locations. Bars indicate standard errors for comparison of means (n = 8) at each time interval. Numbers in parenthesis indicate percent reduction in weed dry weight due to yellow mustard presence.

Table 2. Influence of weeds on yellow mustard dry weight and corn development and yield averaged across yellow mustard seeding rates, yellow mustard planting patterns, and two locations in 1989 and 1990 (n = 384).

Treatment	Mustard wt at 4 wk[a]	Corn ht at 8 wk[a]	Corn silk emergence[b]	Corn ear moisture	Corn grain yield
	gm^{-2}	cm	d	%	kg ha^{-1}
Weed-free	118	101	67.7	28.0	9210
Weedy[c]	122	97	68.3	28.8	8760
Significance[d]	NS	*	**	*	**

[a]Time after yellow mustard emergence.

[b]Time from seedling emergence to silk emergence on 50% of the plants.

[c]Natural stands of annual broadleaf and grass weeds were allowed to compete for the first 4 wk after yellow mustard emergence, then the plots were treated with a herbicide that killed the yellow mustard and the annual broadleaf weeds, leaving the annual grasses to compete with the corn for the remainder of the growing season.

[d]** = significant at 1% level, * = significant at 5% level.

interactions between species may be the key to smother plant weed control selectivity where light is the most limiting resource (12, 29). In this experiment, yellow mustard in both the 10- and 20-cm treatments was much taller than the annual grass and broadleaf weeds early in the growing season, suggesting that a shorter or later emerging smother plant might provide effective weed suppression.

In 1989 yellow mustard reduced weed dry weight 4 wk after yellow mustard emergence (Figure 3). A similar response was recorded in 1990. The 10-cm mustard treatment reduced weed weight by 54, 80, and 79% for 4, 6, and 8 wk of yellow mustard interference, respectively. Data for the 2-wk interference duration were not taken in 1989. The 10-cm yellow mustard treatment was as effective in reducing weed dry weight as the 20-cm treatment (Figure 3). In 1990 yellow mustard with a 2-wk interference duration did not reduce weed dry weight, since both the yellow mustard and the weeds were small and very little competition occurred (data not shown).

These data indicate that yellow mustard can reduce weed dry weight. They also suggest that a successful smother plant, one that can control weeds without having a negative impact on corn, will have an interference duration (or life cycle length) of 4 to 6 wk, a maximum height of less than 10 cm, and vertical growth intermediate between that of the crop and annual weeds.

Yellow mustard planting pattern and seeding rate. Weed presence or absence did not have a major effect on the variables measured, due to the natural variability in weed densities, weed species present, and the experimental protocol which prevented broadleaf weeds from competing throughout the growing season. Response of corn and yellow mustard to weedy versus weed-free treatments was similar across locations, planting patterns, and yellow mustard densities. Mustard weight at 4 wk was not affected by weeds (Table 2). Weed presence reduced corn height at 8 wk by 4% and delayed silk emergence by 0.6 d. At harvest, weeds reduced grain yield by 5% and increased ear moisture by 0.8%.

The three-row yellow mustard planting pattern was more competitive with corn and weeds than the one-row or the 25-cm band, but differences were small (Table 3). Response to planting pattern was similar across locations, weedy or weed-free treatments, and yellow mustard planting densities. The three-row pattern increased mustard dry weight at 4 wk and delayed silk emergence compared to the other planting patterns (Table 3). Grain yield was not affected by planting pattern; however, grain moisture was increased by both the three-row treatment and the 25-cm band compared to the single row pattern. Weed suppression was not different among treatments in 1989, but in 1990 the three-row pattern reduced weed dry weight at 4 wk compared to the other planting patterns. The one-row planting pattern was less competitive with corn and weeds than the three-row pattern. This may have been due to an increase in intraspecific yellow mustard competition and a resulting decrease in yellow mustard dry weight at 4 wk compared to the other patterns. The 25-cm band seeding method did not allow for precise yellow mustard seed placement or seeding depth and resulted in less uniform stands with fewer plants than the other patterns. The three-row pattern combined a relatively precise seeding method with an even spatial arrangement and therefore was the most competitive planting pattern.

Changes in yellow mustard seeding rate affected all variables. Yellow mustard populations 1 wk after emergence were approximately 90% of the seeding rate for the one-row and three-row planting patterns, and 55% of the seeding rate for the 25-cm band. Yellow mustard dry weight per unit area, however, was similar across planting patterns (Table 3). Yellow mustard dry weight at 4 wk increased asymptotically with seeding rate, suggesting

Table 3. Influence of yellow mustard planting pattern on weed dry weight in 1989 and 1990 (n = 64), and on yellow mustard dry weight, and corn development and yield averaged across weed treatments and two locations in 1989 and 1990 (n = 256).

Seeding pattern	Mustard wt at 4 wk[a]	Corn ht at 8 wk[a]	Corn silk emergence[b]	Corn ear moisture	Corn grain yield	Weed wt at 4 wk 1989	Weed wt at 4 wk 1990
	gm^{-2}	cm	d	%	kg ha^{-1}	gm^{-2}	gm^{-2}
One-row[c]	110	101	67.7	27.8	9160	54.8	2.4
Three-row[d]	136	100	68.4	28.6	8900	36.5	1.0
25-cm band[e]	113	96	67.9	28.5	8890	40.0	2.2
LSD (0.05)	8	2	0.3	0.6	NS	NS	1.1

[a]Time after yellow mustard emergence.

[b]Time from seedling emergence to silk emergence on 50% of the plants.

[c]One row of yellow mustard seeded directly over the corn row.

[d]Three rows of yellow mustard, one seeded directly over the corn row and a row 10 cm to either side of the corn row.

[e]Yellow mustard seed broadcast in a 25-cm band over the corn row.

intraspecific yellow mustard competition at the higher seeding rates (Figure 4). Although the shape of the fitted lines was similar across environments, the specific response of yellow mustard dry weight at 4 wk was different in each of the environments, as shown by the parameter coefficients (Table 4) and determined by full versus reduced model F-tests (18). In all environments, a yellow mustard seeding rate of 2120 seeds m^{-2} produced nearly as much yellow mustard dry weight at 4 wk as yellow mustard seeding rates of 4240 or 8480 seeds m^{-2}. Conversely, a relatively small increase in seeding rate between 0 and 1060 seeds m^{-2} produced a large increase in yellow mustard dry weight m^{-2} at 4 wk.

Corn vegetative growth, represented by corn height at 8 wk, was inversely related to yellow mustard seeding rate (Figure 5a).

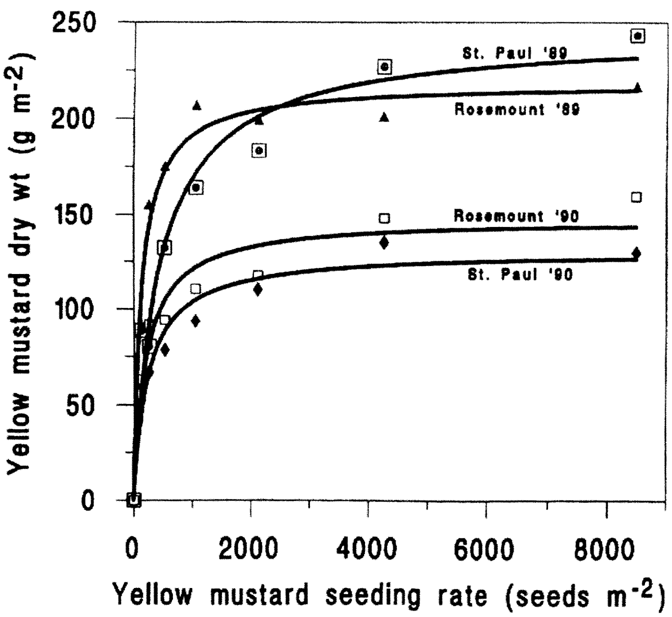

Figure 4. Yellow mustard dry weight 4 wk after emergence as influenced by yellow mustard seeding rate, and fitted lines. Symbols indicate means (n = 24) averaged across planting patterns and weed treatments.

Corn height at 8 wk was reduced by yellow mustard seeded at 130 seeds m^{-2}, the lowest seeding rate tested. Corn vegetative

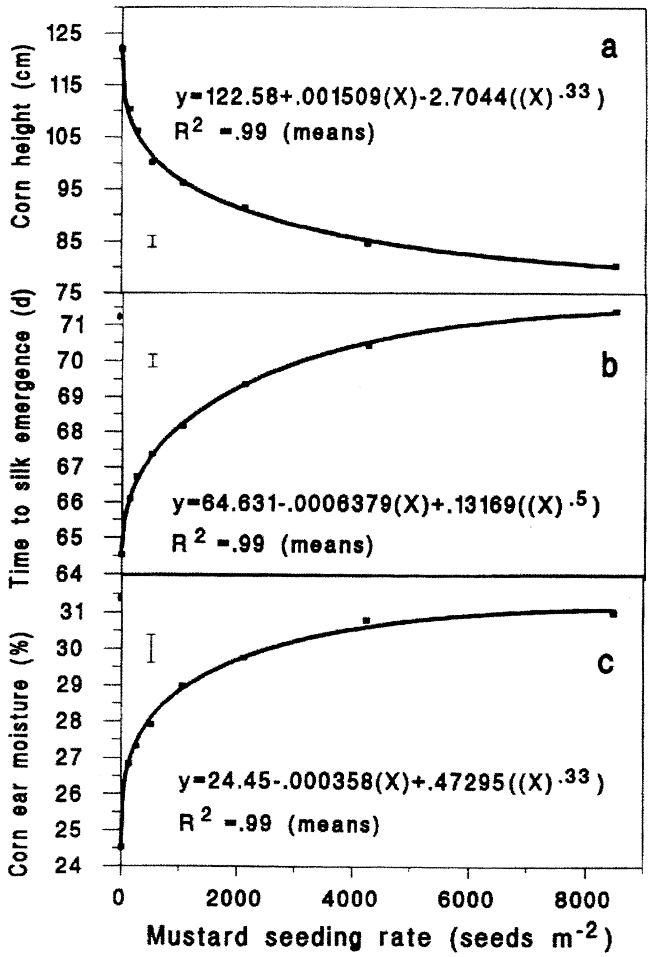

Figure 5. Corn height 8 wk after mustard emergence (a), days from corn seedling emergence to 50% silk emergence (b), and corn ear moisture at harvest (c) as affected by yellow mustard seeding rate. Bars indicate standard error of the means (n = 96) averaged across planting patterns, weed treatments, and two locations in 1989 and 1990.

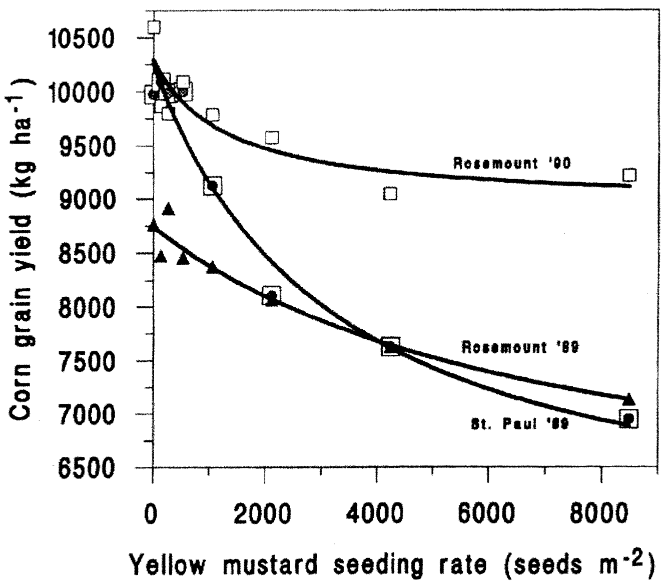

Figure 6. Corn grain yield as affected by yellow mustard seeding rate, and fitted lines. Symbols indicate means (n = 24) averaged over planting patterns and weed treatments.

growth early in the season, therefore, was very sensitive to yellow mustard competition.

Corn reproductive development, as measured by days to 50% silk emergence, was delayed by yellow mustard interference at all seeding rates (Figure 5b). Later silking dates generally result in later maturing corn that is more susceptible to frost damage and has a higher grain moisture at harvest.

Yellow mustard interference increased grain moisture at harvest (Figure 5c), with even the lowest seeding rate (130 seeds m^{-2}) resulting in a 2.3% increase.

Corn grain yield was reduced by yellow mustard presence when the seeding rate exceeded 530 seeds m^{-2} (Figure 6). The response of corn grain yield to yellow mustard interference was not different between Rosemount in 1989 and 1990, except for y intercept; however, the response at the 1989 St. Paul experiment was different from the Rosemount plots, as suggested by the parameter estimates (Table 4), and as determined by full versus reduced model F-tests. Moisture competition early in the growing season may have contributed to this difference, since June rainfall was 8.41, 11.9, and 24 cm for St. Paul in 1989 and Rosemount in 1989 and 1990, respectively. A yellow mustard seeding rate of 530 seeds m^{-2} resulted in a predicted yield loss of 204 kg ha^{-1} (2.3%) at Rosemount in 1990, a 655 kg ha^{-1} (6.4%) yield loss at St. Paul in 1989, and an average yield loss over all three environments of 416 kg ha^{-1} (4.2%). Corn grain yield was less affected by increasing yellow mustard seeding rates than corn vegetative growth or reproductive development. Results from previous studies of weed competition with corn (2, 12, 15, 22) report a similar corn development and yield response.

Yellow mustard was effective in reducing weed dry weight at 4 wk (Figure 7). Standard errors for the parameter estimates were large due to variation in natural weed populations but were significant in most cases (Table 4). Response of weed weight to yellow mustard presence in each environment was not different,

Table 4. Observed yellow mustard free weed weight and corn grain yield averaged across two locations in 1989 and 1990, and the parameter estimates used in the nonlinear equations to generate the fitted lines for weed weight, corn grain yield, and yellow mustard weight.[a]

Variable	Location and year	Mustard free yield	Parameter estimates[b] Y_{mf}	I	C
			gm^{-2}		
Weed wt 4 wk	St. Paul '89	32.4	34.3 (4.9)	.0012 (.0007)	1.12 (.21)
	Rosemount '89	147.1	150.5 (18.3)	.0030 (.0016)	.84 (.09)
	St. Paul '90	5.7	5.7 (.6)	.0175 (.0114)	.86 (.06)
	Rosemount '90	3.1	3.0 (.6)	.0010 (.0010)	.66 (.23)
	Pooled	—	—	.0023 (.0009)	.88 (.07)
			kg ha^{-1}		
Corn grain yield	St. Paul '89	9978	10259 (223)	.00014 (.00005)	.45 (.09)
	Rosemount '89	8764	8744 (139)	.00005 (.00002)	.34 (.18)
	Rosemount '90	10600	10294 (224)	.00010 (.00009)	.13 (.04)
			A	B	
			gm^{-2}		
Mustard wt 4 wk	St. Paul '89	—	243 (8.6)	439 (60.9)	—
	Rosemount '89	—	218 (7.4)	139 (26.2)	—
	St. Paul '90	—	130 (4.0)	253 (35.2)	—
	Rosemount '90	—	147 (6.4)	217 (45.0)	—

[a]Standard errors of the parameter estimates are in parenthesis.

[b]Y_{mf} is the mustard free yield of weeds or corn grain, I is the yield loss per unit of yellow mustard seeding density as density approaches 0, and C is the yield loss as seeding rate approaches infinity, based on the model by Cousens (4).

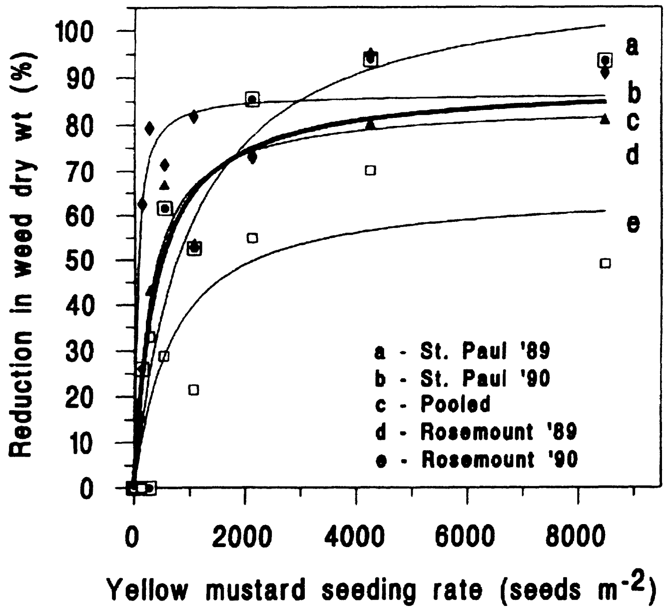

Figure 7. Percent reduction in weed dry weight 4 wk after yellow mustard emergence as a function of yellow mustard seeding density, and fitted lines. Symbols represent means (n = 12) averaged across planting patterns.

based on a reduced versus full-model F-test, and therefore the pooled or mean response is probably the best predictor of reduction in weed dry weight. Qualitative differences in the fitted lines, however, suggest that real differences may have been masked by variability in the data. A yellow mustard seeding rate of 430 seeds m^{-2} reduced predicted annual grass and broadleaf weed dry weight at 4 wk 29% at Rosemount in 1990, 79% at St. Paul in 1989, and by an average, over all environments, of 51%. Yellow mustard seeding rates of 1060 and 8480 seeds m^{-2} reduced the average predicted dry weight of annual weeds at 4 wk 65 and 85%, respectively.

The three-row yellow mustard seeding pattern was the most effective in suppressing weeds, and the optimum yellow mustard seeding rate was in the range of 500 to 1000 seeds m^{-2}. Manipulated yellow mustard was not an ideal smother plant because rapid growth during the first 2.5 wk after emergence enabled it to compete with corn, and the clipping treatment opened the yellow mustard canopy reducing the shading effect on weeds.

These studies provide the initial information needed to develop a model spring-seeded smother plant for weed control in corn production systems. Ideotypes, hypothetical plants described in terms of traits that are thought to enhance genetic performance potential, have been proposed as useful tools for plant improvement (5, 21). A spring-seeded smother plant ideotype would be especially helpful as researchers begin breeding new smother plant species. An ideotype is developed by selecting certain traits and then specifying a phenotypic goal for each trait.

We propose the following ideotype for spring-seeded smother plants in corn production systems in the north central region of the United States: rapid seedling emergence (4 to 5 d) under cool conditions, horizontal leaf angle, mature leaf size of 2 by 3 cm, rooting depth of 25 cm, maximum height of 10 cm, life cycle of 5 wk or less, nondormant seed, and seed production potential of at least 500 kg ha^{-1}. This ideotype represents a starting point for plant breeders, weed scientists, and other researchers interested in development of spring-seeded smother plants for weed control in corn production systems.

Research is needed in three general areas to facilitate development and introduction of successful spring-seeded smother plants. First, effects of various smother plant growth rates and morphologies on corn development and weed control need to be examined to more accurately define the ideotype. Second, appropriate spring-seeded smother plant species must be identified or developed based on the refined ideotype. Finally, environmental and economic impact of adoption of smother plant technology in corn production systems needs further investigation.

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