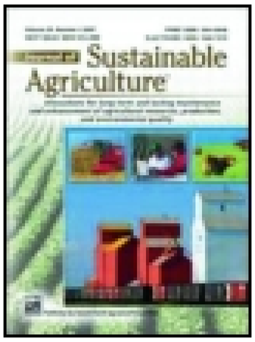

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Corn, Soybean, and Weed Responses to Spring-Seeded Smother Plants

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ABSTRACT. Field and greenhouse research was conducted to better define the characteristics of a spring-seeded smother plant system for weed control in corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr.). In the greenhouse, emergence and early growth of two medic (*Medicago*) species was greatest when planted 1.5 cm deep. In the field, Berseem clover (*Trifolium alexandrinum* L.), four medic species, and yellow mustard (*Brassica hirta* Moench) were planted immediately after corn or soybean planting in a 25-cm-wide band centered over the crop row. All species achieved 45% or more ground cover by 72 days after planting and yellow mustard often generated ground cover more quickly than other species. Weed suppression varied, with yellow mustard and Sava medic (*Medicago scutellata* L.) often providing greater weed suppression than other species. However, weed suppression was highly variable and crop yields were usually reduced compared with weed-free plots. Killing Sava medic 30 days after planting reduced weed suppression and did not increase corn yield compared with allowing the medic to survive until maturity. Delaying seeding of Sava medic until rotary hoeing increased weed suppression compared with rotary hoeing alone. *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-342-9678. E-mail address: <getinfo@haworthpressinc.com> Website: <http://www.HaworthPress.com> 2001 by The Haworth Press, Inc. All rights reserved.]*

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KEYWORDS. Cover crops, clover, integrated weed management, intercropping, medic, mustard

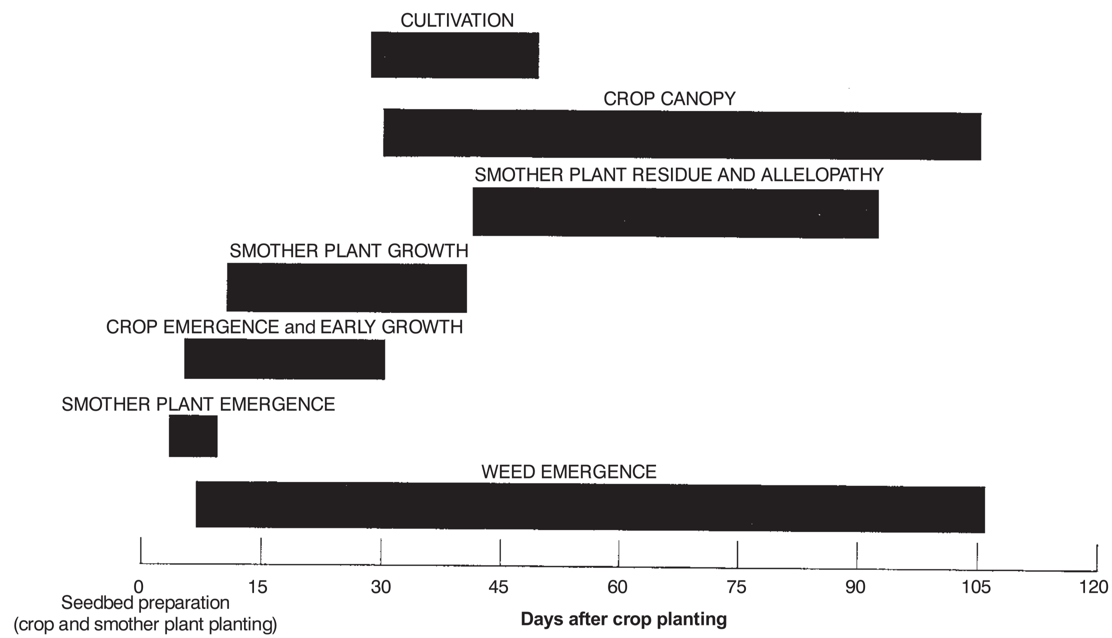
INTRODUCTION

Weeds pose a recurrent and ubiquitous threat to agricultural productivity. In the United States, weeds and weed control have an estimated annual economic cost of more than $15 billion (Bridges, 1994) with even greater relative costs in developing countries (Akobunudu, 1991). Concern over the economic costs, environmental impacts, and long-term efficacy of current practices has reinforced the need for new methods for weed management (Gressel, 1992; Wyse, 1992). Herbicides are important tools for weed control and have improved production efficiency and facilitated reduced tillage production systems. Because of their effectiveness, herbicides and tillage are the dominant practices in many production systems. While the efficacy of these practices is evident, they may also lead to environmental contamination, human health problems, and soil erosion. In addition, weeds persist by adapting to production practices (Buhler, 1999; Liebman and Gallandt, 1997) and herbicide resistance continues to develop and spread (Heap, 1999). Nevertheless, it will be difficult for farmers to reduce dependance on herbicides until new weed control options are developed (Buhler, 1999; Wyse, 1992).

Smother plants are cover crops grown simultaneously with a grain or forage crop to suppress weeds (Buhler et al., 1998; DeHaan et al., 1994; Williams and Wicks, 1978). The use of growing plants and plant residue to suppress weeds is not a new concept. Winter rye (*Secale cereale* L.), vetches (*Vicia* spp.), and clovers *(Trifolium* spp.) were evaluated as smother plants in corn and soybean (Enache and Ilnicki, 1988; Hartwig and Loughran, 1989; Palada et al., 1983; Williams and Wicks, 1978). However, these plant species have proven to be less than ideal smother plants because of their need to be eliminated by tillage or herbicide, excessive competition with the grain crop, soil moisture depletion, or poor winter survival (Triplett, 1985; Worsham, 1991).

A classic example of a successful smother plant in an agronomic system is the use of a small grain as a companion crop for the establishment of perennial forage legumes. The small grain and forage legume are planted simultaneously with the small grain providing rapid early growth to compete with weeds and protect the soil from erosion while the slower growing forage legume becomes established. Later in the growing season the small grain is removed and the forage legume becomes the dominant plant. A spring-seeded smother crop system for corn and soybean might follow these same principles (Figure 1). The sequence of smother plant, grain crop, and weed emergence; interspecies competition; smother plant senescence; and canopy development is key to the success of such a system. The

FIGURE 1. A temporal model for weed suppression with smother plants seeded simultaneously with corn or soybean.



smother plant must emerge rapidly after planting to compete with early emerging weed species and be competitive until the crop canopy is capable of suppressing weed growth. Following senescence, the residue of the smother plant should continue to contribute to weed control. Interrow cultivation may also be used to control weeds between crop rows and to diversify the selection pressures applied to the weed community.

Weed interference for the first 2 to 8 weeks after corn emergence did not reduce grain yield (Hall, Swanton, and Anderson, 1992; Zimdahl, 1988). Therefore, it is possible that a spring-seeded smother plant could grow concurrently with corn for a similar period without reducing yields. Other studies showed that weeds that emerge 3 to 6 weeks after crops do not reduce yields (Hall, Swanton, and Anderson, 1992; Knake and Slife, 1965). This suggests that if establishment of annual weeds were prevented for the first 4 to 6 weeks of the growing season by smother plants, crop yields should not be reduced by weeds. These same principles are the basis for using postemergence herbicides.

Yellow mustard planted at 500 to 1000 seed m^{-2} in a 25-cm band over the corn row at planting suppressed weeds (DeHaan et al., 1994). DeHaan et al. (1994) proposed that a model for spring-seeded smother plants for weed control in corn in the North Central United States would have rapid seedling emergence under cool soil conditions, horizontal leaf angle, mature leaf size of 2 by 3 cm, rooting depth of 2.5 cm, maximum height of 10 cm, a life cycle of 5 weeks or less, and nondormant seed. While they presented this as one model for a smother plant system, they also concluded that to develop smother plant systems for corn and soybean it would be necessary to determine the effects of various smother plant growth rates and morphologies on crop development and weed control over a wide geographic area. They also suggested the need to identify or develop appropriate plant species based on the ideotype, and investigate the environmental and economic impacts of adoption of smother plant technology.

Buhler, Kohler, and Foster (1998) evaluated Berseem clover, Caliph medic (*Medicago truncatula* Gaerth.), Santiago medic (*Medicago polymorpha* L.), Sava medic, and yellow mustard as smother plants in Iowa. Weed suppression ranged from 20 to 90% among smother plant species. The effect of smother plants on corn and soybean yields varied among locations, years, smother plant species, and weed pressure. In some instances, yields with smother plants were equal to weed-free conditions, while at other times yields were as low as those in unweeded plots.

Smother plants may provide weed control options for some growers. Management will present new challenges, but we may be able to replace weed populations with manageable smother plants by exploiting the dynamics of weed/crop interactions (Figure 1). Smother plants could be combined with other control tactics in an integrated system to help reduce selection pressure on weeds by diversifying the cropping environment and by consuming resources (water, nutrients, and light) currently available to weeds. Spring-seeded smother plants may be easier to manage than the previously evaluated winter annual and perennial species because selection of planting patterns and rates can be made in response to environmental conditions and other factors at the time of planting. The objectives of this research were to further define the characteristics of a spring-seeded smother plant system for corn and soybean by evaluating emergence dynamics, growth, and ground cover of potential smother plant species and to evaluate the effects of altering spatial and temporal dynamics of a smother plant on weed suppression and crop yield.

MATERIALS AND METHODS

Smother Plant Planting Depth

An experiment was conducted in a greenhouse at Iowa State University in Ames, IA to determine the effect of species and planting depth on medic seedling establishment and early growth. Temperature in the greenhouse ranged between a minimum night temperature of 14 C and a maximum day temperature of 28 C. Supplemental lighting provided a 12-hr photoperiod of at least 260 μE m^{-2} s^{-1} photosynthetic photon flux density. The experiment used a factorial treatment design of two medic species by three planting depths in a randomized complete block design with four replications and was conducted twice.

The medic species were Sava (large seeded, 1.7 g 100 $seeds^{-1}$) and Santiago (small seeded, 0.4 g 100 $seeds^{-1}$) and each was planted 0.5, 1.5, and 3 cm deep in a soil-filled bench. The bench was 20 cm deep and contained a mixture of Webster clay loam (50%), sand (25%), and compost (25%). Each experimental unit was a row 45 cm long by 5 cm wide containing 100 seeds. The soil was surface watered daily.

Seedling counts were taken daily until no new seedlings were recorded for 5 consecutive days. Seedlings were considered emerged when the cotyledons were above the soil surface and free of the seed coat. After 28 days, a final seedling count was taken and fresh weight was measured. Data were converted to seedlings m^{-2}.

Smother Plant Growth, Weed Suppression, and Crop Yields

Field experiments were conducted near Sioux Center (northwest) and Ames (central), IA in 1995, 1996, and 1997; and near Crawfordsville (southeast), IA in 1997. Corn or soybean plus smother plant combinations were planted on two dates at each location. The first planting was targeted as early for local conditions and the second planting was about two weeks later. The early planting for corn was April 20 at Crawfordsville, about May 1 at Ames, and about May 10 at Sioux

Center. The early planting date for soybean was about May 15 regardless of location. The soil type at Ames was Clarion loam and at Crawfordsville it was Mahaska silty clay loam. Fertility adjustments were made according to recommendations of the Iowa State University Soil Testing Laboratory for a corn/soybean rotation. The Sioux Center soil was Galva silty clay loam, with a manure application made each autumn. The research areas were in long-term corn/soybean rotation and chisel plowed in the autumn, then disked and field cultivated in the spring before planting.

The design of the experiments was a randomized complete block, split plot design. Planting dates were whole plot treatments and smother plant species the subplot treatments. Separate experiments were conducted for corn and soybean. Subplots were five 76-cm-wide rows by 10 m at Ames, four 94-cm-wide rows by 10 m at Sioux Center, and four 76-cm-wide rows by 10 m at Crawfordsville. These row widths are the standard practices in these areas of Iowa. All treatments were replicated four times. Locally adapted corn hybrids were planted at 69,200 seeds ha^{-1} at Ames and at 74,100 seeds ha^{-1} at Crawfordsville and Sioux Center. Locally adapted soybean varieties were planted at 435,000 seeds ha^{-1} at all locations. Planting depth was set according to soil moisture levels at planting. Smother plants were seeded immediately following the planting of corn or soybean in a 25-cm-wide band centered over the crop row. Seeds of smother plants were incorporated into the upper 1.5 cm of soil with a garden rake. Berseem clover, Caliph medic, Santiago medic, and Sava medic were planted at 200 seeds m^{-2} and yellow mustard was planted at 500 seeds m^{-2}. Seeding rates were based on previous research (Buhler, Kohler and Foster, 1996; DeHaan et al., 1994). All plots received interrow cultivation at about 30 and 45 days after planting (DAP) to control weeds between crop rows. Weedy and weed-free control treatments were included in all experiments. Weed-free control plots were maintained by biweekly hoeing and hand weeding for the entire growing season.

In 1996 and 1997, two additional experiments were conducted at Ames. In one experiment, Sava medic was either broadcast over the entire plot, seeded in a 25-cm-wide band between corn rows, or seeded in a 25-cm-wide band over corn rows and incorporated as described above. The medic was either allowed to grow with the corn until maturity or killed with dicamba (3,6-dichloro-2-methoxybenzoic acid) at 0.3 kg ha^{-1} 30 days after emergence. The design of the experiment was a randomized complete block, split plot design with 4 replications. Spatial arrangements were whole plot treatments and growth period the subplot treatments. In the other experiment, Sava medic was broadcast seeded either 7 or 14 DAP in conjunction with rotary hoeing. Sava medic was seeded on the soil surface prior to rotary hoeing 7 DAP, seeded on the soil surface following rotary hoeing followed immediately by a second rotary hoeing 7 DAP, or seeded prior to rotary hoeing 14 DAP in plots that were rotary hoed 7 DAP. Plots rotary hoed 7 or 7 and 14 DAP without medic and weedy and weed-free control plots were also included. The design of the experiment was a randomized complete block with 4 replications. All treatments (except the weedy control) in both experiments received interrow cultivation 45 DAP.

The primary weed species encountered over the course of the experiments were giant foxtail (*Setaria faberi* Herrm.), common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), and Pennsylvania smartweed (*Polygonum pensylvanicum* L.). Smother plant densities were monitored daily through initial emergence and then measured 14, 28, and 72 DAP from a 0.1 m^2 area in the seeded band in each of the center two or three rows. Smother plant heights were recorded at 40 DAP. Visual estimation of percent ground cover by smother plants within the seeded areas were conducted at 28, 40, and 72 DAP. Weed control within the crop row area, averaged over species and by individual species, was evaluated by visual estimation of biomass reduction compared with the crop row area of the weedy control 40 and 72 DAP using a scale of 0 (no reduction) to 100% (no weeds present). Evaluations visually integrated the entire plot area and two independent evaluations were made of each plot. Weed density and above ground biomass was determined for each species 72 DAP. The weeds in a 1 m^2 area of the seeded band were counted, clipped at the soil surface, and weighed in the field. Crop height was recorded at 14 day intervals up to 72 DAP. Grain yields were determined by harvesting the two (Crawfordsville and Sioux Center) or three (Ames) center rows from each plot with a combine.

All data were subjected to analyses of variance. Main effects and interactions were tested for significance. For analyses of visual estimates of weed control, data from the weedy and weed-free control treatments were excluded. For analyses of weed density, data from the weed-free treatment were excluded. Means were separated by Fisher's Protected LSD test at $P < 0.05$.

RESULTS AND DISCUSSION

Most of the parameters measured in the field experiments were influenced by planting date, smother plant species, location, and year. Interactions among treatment factors were also significant in most cases. Significant interactions often precluded combining data over locations or years, resulting in a very large data set. Therefore, we have selected a subset of the data to illustrate the major trends in the results and to present some of the concepts involved in smother plant/crop/weed interactions.

Smother Plant Planting Depth

Initial emergence for Santiago and Sava medic (defined as 10% of total emergence) occurred about 4 DAP in the greenhouse for 0.5 and 1.5 cm planting depths (data not shown). Planting the seed 3 cm deep delayed initial emergence until 7 DAP for both species. Final seedling densities were greatest for both species when planted 1.5 cm deep (Table 1). Densities following planting at 3 cm were also greater than at 0.5 cm. At 1.5 and 3 cm, the larger seeded Sava produced greater seedling densities than Santiago, but the opposite occurred at 0.5 cm. Planting depth by seed size interactions have also been observed with several weed species (Buhler, 1995). These data indicate that seeds need to be placed well below the soil surface for maximum emergence and the optimum planting depth may vary by medic species. In the field, a planting system capable of uniformly placing seed at a specified depth will speed emergence and increase seedling density.

Smother Plant Establishment and Growth

At Crawfordsville in 1997, planting date had a greater effect on smother plant emergence than species (Table 2). The average time from planting until 10% emergence averaged over smother plant species was 14.8 days when planted on April 21 compared with 7.1 days when planted on May 6. At the April 21 planting date, it took Sava medic 1.5 to 2 days longer to emerge than the other species. When corn and smother plants were planted on May 6, there was no difference among species in the time from planting until 10% emergence.

Delaying planting resulted in more rapid emergence, but it often reduced smother plant density (Table 3). Delaying soybean planting from May 25 to June 6 at Ames in 1995 reduced yellow mustard density by more than 50%; Berseem clover and medic species had similar reductions. These reductions may have been caused by higher temperatures and less soil moisture following the late plantings that inhibited establishment of all species. Warm and dry conditions

TABLE 1. Sava and Santiago medic densities (plants m^{-2}) as affected by planting depth 28 days after planting in the greenhouse.

Medic species	Planting depth (cm)	Smother plant densities
Sava	0.5	5.7f[1]
	1.5	99.6a
	3.0	81.0b
Santiago	0.5	31.4e
	1.5	64.3c
	3.0	56.4d

[1]Means followed by the same letter are not different according to Fisher's LSD (α = 0.05).

following planting often inhibit the establishment and early growth of temperate, small-seeded species (Frame, Charlton, and Laidlaw, 1998).

Density of yellow mustard 14 DAP at Sioux Center in 1995 and 1996 was higher than the other species due to the higher seeding rate (Table 4). Berseem clover density was greater than the medics, and among the medics, Caliph had higher density than Santiago or Sava. By 28 DAP, differences in density decreased and yellow mustard had densities equal to Berseem clover and Caliph medic. No living yellow mustard plants remained by 72 DAP. By this time, Sava medic and Berseem clover had the highest plant densities. Yellow mustard remained alive longer at the other locations than it did at Sioux Center (data not shown). This was likely because yellow mustard is a long-day plant (Vaughan and Hemingway, 1959). The maximum day lengths at the more southern locations of Ames and Crawfordsville may not have been long enough to induce complete flowering and senescence, extending the vegetative growth stage of yellow mustard.

TABLE 2. Effect of planting date on initial emergence of smother plants in corn (units = days after planting) (Crawfordsville, 1997).

Smother plant species	April 21	May 6
Berseem clover	14.5b[1]	7.0a
Santiago medic	14.5b	7.0a
Sava medic	16.0a	7.5a
Yellow mustard	14.0b	7.0a

[1]Means within columns followed by the same letter are not different according to Fisher's LSD (α = 0.05). Differences between planting dates were significant for all species.

TABLE 3. Effect of planting date on smother plant densities (plants m^{-2}) 28 days after planting of soybeans (Ames, 1995).

Smother plant species	May 25	June 6
Berseem clover	140b[1]	50b
Caliph medic	160b	105a
Santiago medic	105c	53b
Sava medic	95c	42b
Yellow mustard	245a	110a

[1]Means within columns followed by the same letter are not different according to Fisher's LSD (α = 0.05). Differences between planting dates were significant for all species.

TABLE 4. Effect of time after planting on the density (plants m^{-2}) of smother plants in early planted corn (Sioux Center, 1995 and 1996).

Smother plant species	14 days after planting	28 days after planting	72 days after planting
Berseem clover	184b[1]	153a	73ab
Caliph medic	149c	126ab	66b
Santiago medic	96d	115b	39c
Sava medic	101d	108b	91a
Yellow mustard	309a	160a	0d

[1]Means within columns followed by the same letter are not different according to Fisher's LSD (α = 0.05).

Yellow mustard growing with corn was taller than Berseem clover and the three medic species 40 DAP at both Ames and Sioux Center (data not shown). Sava medic was taller than the other medic species and Berseem clover. Relative height differences in soybean were similar to those in corn. However, yellow mustard and Sava medic were only about 66% as tall in soybean as in corn. The reduced light within the corn canopy caused plants to elongate compared to those growing with soybean (Salisbury and Ross, 1978).

At Crawfordsville in 1997, ground cover within the seeded band 28 DAP ranged from 15 to 40% and yellow mustard produced greater ground cover than Berseem clover and Sava and Santiago medics (Table 5). By 40 DAP yellow mustard produced more than 60% ground cover, which was greater than the 25 to 35% cover generated by the other species. All species produced 45% or more ground cover by 72 DAP with yellow mustard generating 84% cover.

Weed Suppression

When evaluated over all species, weed suppression 40 DAP with yellow mustard in corn at Ames in 1995 and 1996 was 89% (Table 6). Yellow mustard reduced weed growth more than Berseem clover and the three medic species. By 72 DAP the overall level of weed suppression declined, but the relative differences among smother plant species remained the same. Sava medic and Berseem clover reduced weed growth more than Caliph and Santiago medics.

Yellow mustard was among the most suppressive smother plants of both giant foxtail and Pennsylvania smartweed in corn at Ames in 1996 and 1997 (Table 7). Berseem clover suppressed Pennsylvania smartweed growth by 74%, but reduced giant foxtail by only 25%. Sava medic reduced giant foxtail growth by 60%, but had little effect on Pennsylvania smartweed. These differences in visual estimates of weed growth were substantiated by measurements of weed density and biomass (data not shown). Differential response of weed species to smother

TABLE 5. Smother plant ground cover (%) in early planted corn (Crawfordsville, 1997).

Smother plant species	28 days after planting	40 days after planting	72 days after planting
Berseem clover	19b[1]	33b	48b
Santiago medic	18b	31b	54b
Sava medic	15b	25b	46b
Yellow mustard	40a	62a	84a

[1]Means within columns followed by the same letter are not different according to Fisher's LSD (α = 0.05).

TABLE 6. Effect of smother plants on weed suppression (visual estimation of percent biomass reduction) of all species in corn (Ames, 1995 and 1996).

Smother plant species	40 days after planting	72 days after planting
Berseem clover	56b[1]	55b
Caliph medic	38c	37c
Santiago medic	24c	19d
Sava medic	61b	58b
Yellow mustard	89a	75a

[1]Means within columns followed by the same letter are not different according to Fisher's LSD (α = 0.05).

plants and cover crops has been reported previously (Buhler, Kohler and Foster, 1998; Teasdale, 1998). These differences in weed suppression have been attributed to differences in emergence times of weed species, ability of weeds to emergence through plant residue, and differential responses to light competition.

Crop Yields

At Ames in 1997 (Table 8), the yellow mustard treatment resulted in lower corn yields than Sava medic, Santiago medic, and the weedy check. No smother plant treatment resulted in a corn yield as great as the weed-free control. At Sioux Center in 1996, no smother plant treatment yielded as much corn as the weed-free control and corn growing with yellow mustard or Berseem clover yielded less than other smother plant treatments. There were no differences in yield between the weedy check and yellow mustard or the medic species in soybean at Ames in 1995. Berseem clover resulted in a lower soybean yield than any other treatment.

In related research (Buhler, Kohler, and Foster, 1998), the yield of corn growing with Berseem clover was similar to the weed-free control and yellow mustard reduced corn yield compared with Berseem clover.

While yellow mustard often resulted in fewer weeds than the other smother plant treatments, it usually did not produce the greatest corn or soybean yields among the smother plant treatments. This is likely due to the allelopathic nature of *Brassica* species (Al-Khatib, Libbey, and Boydston, 1997). Corn yield reductions with rye cover crops have also been attributed to the allelopathic nature of the rye residues (Kessavalou and Walters, 1997; Tollenaar, Mihajlovic, and Vyn, 1993). Reductions in crop yields may also have been caused by allowing the smother plants to survive to maturity. DeHaan et al. (1994) suggested that the

TABLE 7. Weed suppression by smother plants (visual estimation of percent biomass reduction) by weed species in corn 60 days after planting (Ames, 1996 and 1997).

Smother plant species	Giant foxtail	Pennsylvania smartweed
Berseem clover	25b[1]	74a
Caliph medic	24b	18b
Santiago medic	18b	12b
Sava medic	60a	12b
Yellow mustard	70a	60a

[1]Means within columns followed by the same letter are not different according to Fisher's LSD ($\alpha = 0.05$).

TABLE 8. Corn and soybean yield (Mg ha^{-1}) as affected by smother plant treatments.

Smother plant species	Corn, Ames (1997)	Corn, Sioux Center (1996)	Soybean, Ames (1996)
Weed-free	10.2a[1]	8.0a	2.9a
Weedy	6.2b	7.0b	2.3bc
Berseem clover	5.8bc	6.4c	1.7d
Santiago medic	6.9b	7.0b	2.3bc
Sava medic	7.0b	6.8b	2.4b
Yellow mustard	4.3c	6.1c	2.1c

[1]Means within columns followed by the same letter are not different according to Fisher's LSD ($\alpha = 0.05$).

smother plants be removed after 4 weeks of competition to prevent yield loss from yellow mustard. In our research, yellow mustard densities were declining by 4 weeks after planting, but some plants survived longer, especially at the central and southern Iowa locations.

Spatial and Temporal Arrangements

Because of the inconsistent weed suppression and crop yield reductions, the effects of altering the spatial and temporal arrangements of smother plants were examined. Sava medic was used in these experiments because of its effectiveness in preliminary experiments (Buhler, Kohler, and Foster, 1996) and other research (DeHaan, Sheaffer, and Barnes, 1997) and a lower frequency of corn yield reduction than yellow mustard in the research reported herein (Table 8).

The spatial arrangement of Sava medic did not affect giant foxtail suppression when the medic was allowed to grow until it matured (Table 9). Removing medic 30 DAP, as suggested by DeHaan et al. (1994), reduced giant foxtail suppression compared with allowing it to reach maturity regardless of spatial arrangement. When the medic was removed 30 DAP, giant foxtail suppression was greater when the medic was broadcast or banded over the rows than when banded between the rows. Corn yields did not vary greatly among treatments and none equaled the yield of the weed-free control (Table 9).

Seeding Sava medic in conjunction with rotary hoeing increased suppression of giant foxtail and redroot pigweed in comparison with similar rotary hoeing alone (Table 10). For example, seeding Sava medic prior to the second rotary hoeing in a 7 and 14 DAP treatment increased giant foxtail suppression from 53 to 86% and redroot pigweed suppression from 43 to 66%. Similar increases in weed suppression occurred when rotary hoeing was done only at 7 DAP. Corn yield was similar among all treatments that included 7 DAP rotary hoeing only, however, the addition of the Sava medic to the 7 and 14 DAP rotary hoeing increased yield compared with rotary hoeing alone (data not shown). The results of this experiment were encouraging and present a different approach to smother plant management. Delaying the seeding of the smother plant until 7 to 14 DAP gave the crop a competitive advantage over the smother plant and the rotary hoeing controlled emerged weeds and incorporated the smother plant seed into the soil.

CONCLUSIONS

Spring-seeded smother plants showed potential for weed control in this research. However, inconsistencies among locations, years, and crops suggest that we have much to learn about this system. Timely establishment of a competitive smother plant population presents the fundamental challenge in this system.

TABLE 9. Effect of spatial arrangement and period of growth of Sava medic on giant foxtail suppression (visual estimation of percent biomass reduction) in corn 70 days after planting and corn yield (Mg ha^{-1}) (Ames, 1996 and 1997).

Spatial arrangement[1]	Growth period	Giant foxtail	Corn yield
Broadcast	To maturity	72 a[2]	6.7 b
	30 days[3]	43 b	6.6 b
Band between rows	To maturity	75 a	6.8 b
	30 days	32 c	6.4 b
Band over rows	To Maturity	80 a	7.0 b
	30 days	45 b	6.5 b
Weed-free			9.4 a

[1]All treatments included interrow cultivation 45 days after planting.
[2]Means within columns followed by the same letter are not different according to Fisher's LSD (α = 0.05).
[3]Treated with dicamba plus 2,4-D.

TABLE 10. Effect of rotary hoeing and delayed seeding of Sava medic on weed suppression (% biomass reduction) 70 days after planting in corn (Ames, 1996 and 1997).

Rotary hoe (days after planting)[1]	Medic seeding	Giant foxtail	Redroot pigweed
7	None	33d[2]	20c
7 and 14	None	53c	43b
7	Before rotary hoe	67b	50b
7 and 7	Between rotary hoe passes	54c	48b
7 and 14	Before 14 day rotary hoe	86a	66a

[1]All treatments included interrow cultivation 45 days after planting.
[2]Means within columns followed by the same letter are not different according to Fisher' s LSD (α = 0.05).

Rapid establishment is essential so that smother plants gain a competitive advantage over weeds. In many cases the smother plants did not establish rapidly and densely enough to effectively compete with early emerging weeds. However, seeding the smother plant 7 to 14 days after crop planting in conjunction with rotary hoeing may be a potential solution to this problem.

Smother plants were more successful in corn than soybean because establishment was more rapid, uniform, and consistent during the cooler, moister conditions that followed corn planting. Yellow mustard was more effective in suppressing weeds than the other species tested as previously reported (DeHaan et al., 1994), but also reduced corn yields. While the greater allelopathic properties of yellow mustard compared to the other species tested made it effective in suppressing weeds (Al-Khatib, Libbey, and Boydston, 1997), this property also increased the risk of crop yield reduction (Kessavalou and Walters, 1997; Tollenaar, Mihajlovic, and Vyn, 1993). Smother plants that are allelopathic may require different management practices than species that suppress weeds through resource competition.

We still feel that the concept of using smother plants as a component of weed management in corn and soybean has merit. However, the approach of co-seeding the smother plant with corn or soybean may need to be reconsidered. While some of the initial results were encouraging (DeHaan et al., 1994), we have been unable to consistently repeat these results in this and other research (Buhler, Kohler, and Foster, 1998). Our lack of success appears to be due to: (a) inconsistency of smother plant establishment, especially when seeding is not immediately followed by several days of moist soil; (b) failure to generate ground cover rapidly enough to suppress early emerging weed species; (c) interference with the crop; and (d) smother plant life cycles that are too long. We began to address some of these issues in this research and feel that altering cultural practices to provide a competitive advantage for the crop over the smother plant is worthy of continued investigation. Another potential approach may be to plant smother plants earlier in the growing season to make them more competitive with early emerging weeds (Figure 1). It may be unrealistic to expect that a smother plant seeded at a time coinciding with rapid weed emergence (Buhler et al., 1997) can be sufficiently competitive to prevent weed establishment. Other methods such as seed priming or coating may also be useful to facilitate rapid emergence of smother plants. In addition, breeding plants with shorter life cycles and altered plant architecture would be a great advance for smother plant and other cover crop systems.

Finally, looking at smother plants as a direct replacement for herbicides will not advance integrated weed management (Buhler, 1999). Even if they are as effective as herbicides, weeds will shift in response to smother plants just as they do to herbicides, tillage, or other production practices. If smother plants are to be a significant advance in weed management, they must be considered in a broad management and ecological context.

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