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Cover crops and interrow tillage for weed control in short season maize (*Zea mays*)

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Abstract

Weed competition can cause substantial maize (*Zea mays* L.) yield reductions. Interseeding maize with cover crops or a combination of interrow cultivation and interseeded cover crops are possible alternative methods of weed control. This study was conducted to examine the potential of interrow cultivation plus cover crops to reduce weed density in maize without reducing the grain yield. Field experiments were conducted in 1993 and 1994 at two sites in Québec to determine the effects of planting 12 cover crops with maize on weed control. Fall rye (*Secale cereal* L.), hairy vetch (*Vicia villosa* Roth), a mixture of red clover (*Trifolium pratense* L.) and ryegrass (*Lolium multiflorum* Lam), a mixture of white clover (*Trifolium repens* L.) and ryegrass, subterranean clover (*Trifolium subterraneum* L.), yellow sweet clover (*Meliotus officinalis* Lam), black medic (*Medicago lupulina* L.), Persian clover (*Trifolium resupinatum* L.), strawberry clover (*Trifolium fragiferum* L.), crimson clover (*Trifolium incarnatum* L.), alfalfa (*Medicago sativa* L.), and berseem clover (*Trifolium alexandrinum* L.) were seeded at two planting dates, 10 and 20 days after maize emergence. Interrow cultivation was carried out weekly until forage seeding, with a final cultivation being conducted just prior to cover crop seeding. Cover crop planting date did not affect maize yields or the ability of interrow tillage plus cover crops to suppress the development of weed populations. Maize yield was less affected by the interseeded cover crops under conditions of adequate rainfall. Corn planted in fields heavily infested with weeds resulted in substantial yield reductions even when rainfall was adequate. Except for 1993 at l'Assomption interrow tillage plus cover crop treatments had consistently lower weed biomass when compared to the weedy control. Most of the weed control was due to the interrow cultivation performed prior to seeding of the cover crops. The lowest weed density occurred in the herbicide treated plots. The ability of interrow tillage plus cover crops to suppress the development of weeds was affected by the level of weed infestation, the growing conditions and location. The cover crops provide additional weed control but the interrrow tillage or some herbicide application may still be necessary. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Cover crops; Interrow tillage; Interseeded; Maize; Weed control

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1. Introduction

Weeds represent an important variable in maize production, both economically and ecologically. Weed competition can cause yield reductions of up to 70% in maize grain yields (Teasdale, 1995). During the first half of this century the most common methods of weed control were rotary hoeing and interrow cultivation. The effectiveness of interrow cultivation in suppressing weed density in maize is well documented (Wilson, 1993). However, cultivation represents an additional cost for the producer due to the consumption of fossil fuels (Lybecker et al., 1988). Frequent interrow cultivation is also associated with increased soil erosion as soil particles are more susceptible to displacement after tillage (Dabney et al., 1993; Fuller et al., 1995).

As herbicides became available, they gradually replaced cultivation as a method to control undesirable vegetation (Sprague, 1986). This was primarily due to their efficiency and convenience. However, ground and surface water pollution by pesticides are causes for concern (Hallberg, 1989), and herbicides used in maize have been among the pesticides most frequently detected in these waters (National Research Council, 1989). Improving water quality and decreasing herbicide carry over is one of the more important environmental issues for farmers and agriculture researchers (Stoller et al., 1993).

An alternative to herbicides and conventional cultivation is the use of cover crops between the crop rows. Spring seeded smother crops can reduce weed density by up to 80% with little effect on maize yield (De Haan et al., 1993). In addition to providing adequate cover to reduce soil erosion (Wall et al., 1991), legume cover crops improve soil nutrient status through addition of organic nitrogen (Holderbaum et al., 1990; Brown et al., 1993) via fixed atmospheric nitrogen which improves soil physical properties (McVay et al., 1989; Latif et al., 1992). Incorporating legume cover crops can also increase the yield of the succeeding crop (Bollero and Bullock, 1994; Decker et al., 1994). In addition, cover crops can suppress weed density by competing for light (Teasdale, 1993), water and nutrients (Mayer and Hartwig, 1986) and through the production of allelopathic compounds (White et al., 1989).

Studies in the early 1980s indicated that certain grass and legume species were well suited as cover crops for maize (Mt. Pleasant, 1982). Interseeding annual ryegrass, medium red clover, or a combination of the two provided good ground cover and dry matter production without affecting the maize grain yield if they were seeded when the maize was 15 to 30 cm high (Scott and Burt, 1985). Hairy vetch cover crops reduced weed biomass by 96% without causing any reduction in the maize yield when the vetch was planted in May or June (Hoffman et al., 1993). Hairy vetch residues inhibited the establishment of common lamb's quarter (*Chenopodium album* L.) without affecting maize establishment (Teasdale, 1993). Other legumes, such as subterranean clover, have been reported to provide equal or better weed control than herbicide treatments in no-till maize without a decrease in maize yields (Enache and Ilnicki, 1990; Ilnicki and Enache, 1992). Hairy vetch and rye cover crops provided good weed control in no-till maize production (Johnson et al., 1993). There was a 75% decrease in the number of weeds present when maize was interseeded with red clover or hairy vetch (Palada et al., 1982). Rye has good potential for suppressing weeds as it has allelopathic activity toward them. Interseeding ryegrass with maize reduced weed biomass by approximately 50% (Samson, 1991). A recent study (Mohler and Callaway, 1995) reported that the presence of fall rye decreased the seed production of *Portulaca oleraceae* L. in one year.

Although cover crops decrease weed density, they usually require suppression the following season in order to minimize competition with the following crop, as in many cases cover crops, if left untreated for the next season, will compete with and reduce the yield of the following crop (Eberlein et al., 1992). Cover crop suppression is usually provided through the use of herbicides (White and Worsham, 1990) as mowing may not provide sufficient control of their growth (Hoffman et al., 1993). Much of the recent research has concentrated on the method of suppression and the types and doses of herbicides to be used for

Table 1
Seeding rates of the interseeded cover crops in 1993 and 1994 at Macdonald and l'Assomption, Québec

Common name	Cultivar	Seeding rate (kg ha^{-1})
Fall rye	Prima	110
Hairy vetch	Canada no. 1[a]	30
Red clover + ryegrass	Khun + Marshall	10 + 8
White clover + ryegrass	Ladino + Marshall	7 + 8
Subterranean clover	Northam	12
Yellow sweet clover	Canada no. 1	7
Black medic	Canada no. 1	15
Persian clover	Canada no. 1	10
Strawberry clover	Salina	7
Crimson clover	Canada no. 1	22
Alfalfa	Nitro	12
Berseem clover	Canada no. 1	20

[a] Canada no. 1 is a category used to designate an unregistered variety.

the suppression of cover crops, but this does not contribute to decreasing herbicide use.

Interrow cultivation can provide adequate weed control in maize. It was reported that interrow cultivation controlled up to 82% of the weeds in wide row crops such as maize (Forcella et al., 1992). Greater than 85% weed control was reported (Parks et al., 1995) when cultivation was combined with lower rate application of herbicides. In an effort to reduce herbicide use, our study focuses on eliminating the use of herbicides and utilizing cover crops in combination with interrow tillage as an effective alternative means of weed control.

The objective of this experiment was to evaluate the effects of interseeded cover crops, in conjunction with interrow tillage, for weed control in maize.

2. Materials and methods

An experiment was conducted in 1993 and 1994 at two Québec (Canada) sites, the E.A. Lodds Agronomy Research Center, Macdonald Campus of McGill University, Ste Anne de Bellevue, and the Agriculture and Agri-Foods Canada Research Station at l'Assomption. The two sites are approximately 80 km apart. However, due to premature mechanical harvest of the entire l'Assomption site in 1994, corn yield data were not available for this site year.

The Macdonald site was fallowed the year before starting the experiment, and the l'Assomption site was in pasture the previous year. The soil type at the Macdonald site was a mixture of Chateauguay clay (fine loamy, mixed, non-acid, Frigid Gapludalf) in 1993 and St. Bernard clay (fine loamy, mixed, non-acid, Frigid Eutrochrept) in 1994. Soil tests prior to planting showed that the soil at the Macdonald campus site had a pH of 5.5 (0.01 M $CaCl_2$ as a extractant). 5 ton ha^{-1} of agricultural limestone was applied to raise the pH at this site. At l'Assomption the soil type was a Soulange silt loam (fine silty, mixed, non-acid, Frigid Humaquept). 210 and 95 kg ha^{-1} of 39–18–33 and 18–8–15 (N–P–K) were added to the soil through the maize seeder at the Macdonald and l'Assomption sites, respectively. Additional fertilizer was broadcast immediately prior to planting to achieve the recommended rates of 180, 37 and 100 kg ha^{-1} of N, P, and K, respectively. The soil was moldboard plowed in the fall of 1993 and harrowed 7 days before planting in the spring of 1994 after which the lime and fertilizer were broadcast and disked in, to produce a smooth seed bed.

The experiment was arranged in a split-plot randomized complete block design with four replications at each site. The main plots were cover crop planting dates (10 and 20 days after maize emergence). Scott et al. (1987) suggested that interseeded cover crops be seeded when maize is 15 to 43 cm high, corresponding approximately to 20 days after maize emergence. However, at northern locations this leaves a shorter period for cover crop development and earlier seeding could be desirable. Thus we also included a cover crop seeding treatment 10 days after maize emergence. At this stage the maize was approximately 11 cm tall. The subplots were the type of cover crops [the 12 cover crops and three control treatments including hand weeded, chemically weeded (atrazine plus dual), and unweeded] (Table 1). The interseeded cover crop cultivars and seeding rates used at all four site years are given in Table 1. Legumes were inoculated prior to planting with the appropriate commercial inoculant. In 1993 the three controls were hand weeded, chemically weeded and unweeded treatments. In 1994 a control consisting of mechanical weeding only was added for each planting date. This control was carried out on plots in which black medic had been seeded in 1993.

The main plot size was 15 by 21 m and the subplot size was 3 by 7 m. Each subplot consisted of four maize rows planted 76 cm apart with 16.4 cm between plants. The maize hybrid Pioneer 3927 was planted on 11 and 13 May 1993, 11 and 14 May 1994 at the l'Assomption and Macdonald sites, respectively. Maize was seeded at a planting density of 80 000 seed ha^{-1} with a Gaspardo planter (model SP510, Pordenone, Italy) at the Macdonald site, and with a John Deere planter (model Max Emerge2 7200) at the l'Assomption site in both years. The 1994 experiments were planted on the same sites as the 1993 ones and the plots of each treatment were planted in the same location each year. Cultivation was conducted weekly until forage seeding, with a Rabe Werk tine cultivator (Rabe Werk Machinerie Agricole, St. Cesaire, Québec, Canada). In 1994 an extra cultivation, immediately prior to cover crop seeding, was added. The tines were raised above the crop rows so that only the interrows were cultivated in 1993, but this was not done in 1994.

A mixture of atrazine (1.0 kg a.i. ha^{-1}) and metolachlor (1.9 kg a.i. ha^{-1}) was applied preemergence to the chemically treated control plot using a bicycle-wheel plot sprayer. The cover crops were hand broadcast over the plots at their respective densities (Table 1). Crop growth was dependent on precipitation; no irrigation was applied. Total monthly rainfalls and average temperatures for each site year along with 30 year averages are given in Table 2.

Maize was harvested at maturity during the second week of October in both years. Ears were harvested by hand from the two center rows of each plot leaving 1 m unsampled at each end. Corn ears were shelled on site with a small plot combine (Wintersteiger America Inc., Lincoln, NE). Corn grain was then weighed to determine wet grain

Table 2
Total monthly precipitation and average temperature recorded at Macdonald and l'Assomption during 1993 and 1994 and 30 year averages

Year	Precipitation (mm)						Temperature (°C)				
	May	June	July	August	September	Total	May	June	July	August	September
Macdonald											
1993	79.1	74.8	94.6	57.2	119.2	424.9	13.3	17.6	21.4	20.5	13.9
1994	148	194	61.3	99.9	105.5	607.8	12.1	18.9	21.3	18.0	14.3
Average[a]	70.6	88.3	89.7	92.6	97.9	439.1	13.1	18.1	21.1	19.8	14.7
l'Assomption											
1993	95.6	74.2	75.4	95.6	89.1	429.9	12.7	17.4	20.7	20.3	13.6
1994	93.8	285.9	122.8	67.8	121.6	691.9	11.8	19.3	21.0	19.2	14.7
Average[a]	72.5	87.0	84.5	94.4	84.6	423.0	12.3	17.5	20.2	18.8	13.8

[a] 30 year averages.

yield after which it was dried at 70°C to constant weight to determine the moisture content. Grain yield is reported on a 0% moisture basis.

Two quadrats (0.5 m by 0.2 m) were established parallel to maize rows in each subplot. One quadrat was placed between the maize rows, and the other on one of the two middle maize rows. During the second week of August, a destructive sample was taken in the quadrats and the weeds and cover crops were identified, grouped into broadleaves and grasses, and counted. These groups were counted separately and placed in paper bags for drying. The harvested samples were dried to a constant weight at 70°C in a forced air dryer, after which they were weighed and their biomass recorded.

The GLM procedure of the Statistical Analysis System (SAS Institute, 1985) was used to conduct the analysis of variance for all data reported. Probabilities equal to or less than 0.05 were considered significant for main effects and interactions. The Waller–Duncan test of significance was used to separate differences between treatment means if analysis of variance indicated the presence of such differences (Steel and Torrie, 1980). Since no difference was found between seeding dates for any of the measured variables, the data were pooled over cover crop planting dates for each site year.

3. Results and discussion

3.1. Climate

The weather was wetter during 1993 than 1994 (Table 2), and the l'Assomption site had more precipitation than the Macdonald site during the growing seasons of both years. The average temperature was similar for both years.

3.2. Sites

The weed density at Macdonald was less than at l'Assomption and could be controlled successfully by cultivation. The l'Assomption site was heavily infested with weeds; quack-grass (*Elytrigia repens* L.), common lambsquarter (*Chenopodium album* L.) and foxtails (*Setaria* spp.) were the predominant weeds there. These were not successfully controlled by initial cultivation and had a significant effect on the efficacy of the tillage cover crop system.

3.3. Weed density and biomass

Weed density and biomass were lower in 1994 than 1993. This was probably due to the extra cultivation the plots received immediately prior to the seeding of cover crops in 1994, which is in agreement with results from previous research (Pava and Ulanday, 1993). Weed biomass and density were higher on the maize rows than between the rows (Tables 3 and 4) at the Macdonald site in both years. The same trend was observed at l'Assomption only in 1993. This may have been due to the better growing conditions in 1993 than 1994 (Table 2). The generally higher weed biomass on the rows than between the rows was probably due to interrow cultivation. A similar study, investigating the use of intercropped large seeded legumes for weed control, also found that interrow tillage of the intercrop, prior to seeding, provided the bulk of the weed control (Carruthers et al., 1997). In 1993 the cultivator tines were raised over the maize rows so as to minimize the maize damage. As a result, the rows themselves and the space near the rows were not cultivated, allowing weeds to establish and grow more readily there. In 1994 the tines were lowered in order to cultivate the maize rows more vigorously. This led to a lower overall weed biomass on the rows in 1994 than in 1993 (Tables 3 and 4). Previous research has shown that row crop cultivators controlled between row weeds more effectively than on row weeds (Mulder and Doll, 1994).

In both years at the Macdonald site, weed control in plots receiving the herbicide treatment was greater than any of the other treatments (Tables 3 and 4). 95 and 91% of the weeds were controlled by the herbicides in 1993 and 1994, respectively. At the same site, the combination of cover crops and cultivation controlled 77 and 80% of the weeds, respectively. The combination of interseeded red clover plus ryegrass, subterranean clover, yellow sweet clover, crimson clover, alfalfa

Table 3
Weed density and biomass, and grain yield as affected by interseeded cover crops at Macdonald, Québec, in 1993

Treatments	On the row		Between rows		Total		
	Number[a] (m^{-2})	Weight ($g\ m^{-2}$)	Number (m^{-2})	Weight ($g\ m^{-2}$)	Number (m^{-2})	Weight ($g\ m^{-2}$)	Grain yield[b] ($Mg\ ha^{-1}$)
Hairy vetch	5.3 b	1.0 b	4.3 b	5.3 b	10.5 b	23.7 bc	8.7 ab
Red clover + ryegrass	5.3 b	15.5 b	2.1 bc	1.2 bc	9.2 b	21.3 bc	8.3 ab
White clover + ryegrass	7.9 ab	25.5 ab	3.9 b	3.1 bc	13.3 b	32.4 b	8.4 ab
Subterranean clover	5.3 b	19.8 b	2.4 bc	1.5 bc	8.3 b	22.0 bc	8.9 a
Yellow sweet clover	3.1 bc	7.7 bcd	2.1 bc	0.8 bc	5.7 b	9.6 cde	7.7 bc
Black medic	7.3 ab	24.2 ab	1.8 bc	3.5 bc	10.0 b	29.6 bc	8.5 ab
Persian clover	4.0 b	12.0 bc	2.4 bc	1.1 bc	6.9 b	13.2 bcd	8.1 abc
Strawberry clover	3.9 bc	13.6 b	3.9 b	2.0 bc	8.6 b	17.2 bc	8.6 ab
Crimson clover	2.7 bc	10.3 bc	2.4 bc	1.5 bc	5.7 b	12.0 bcd	7.0 c
Alfalfa	3.3 bc	13.0 bc	3.1 bc	1.4 bc	6.9 b	15.7 bc	7.9 abc
Berseem clover	6.8 ab	23.5 ab	1.8 bc	0.3 c	9.3 b	23.8 bc	7.8 abc
Control, hand weeded	3.5 bc	1.5 cd	2.1 bc	0.4 c	6.0 b	1.8 de	8.6 ab
Control, chemically weeded	0.5 bc	0.5 b	0.5 c	0.1 c	1.2 c	1.8 e	8.7 ab
Control, weedy	13.2 a	45.7 a	12.5 a	41.5 a	26.5 a	89.8 a	5.4 d

[a] Values within the same column, followed by the same letter, are not significantly different by an ANOVA protected Waller–Duncan multiple range test ($P<0.05$).
[b] Maize grain yield data were adapted from Abdin et al. (1998).

Table 4
Weed density and biomass, and grain yield as affected by interseeded cover crops at Macdonald, Québec, in 1994

Treatments	On the row		Between rows		Total		
	Number[a] (m^{-2})	Weight ($g\ m^{-2}$)	Number (m^{-2})	Weight ($g\ m^{-2}$)	Number (m^{-2})	Weight ($g\ m^{-2}$)	Grain yield[b] ($Mg\ ha^{-1}$)
Fall rye	5.1 bc	3.5 bc	8.2 abc	4.8 b	13.5 bc	8.7 b	8.8 a
Hairy vetch	2.5 bc	1.3 bc	11.8 ab	4.1 b	14.4 bc	5.4 b	9.0 a
Red clover + ryegrass	6.6 b	2.2 bc	2.8 c	1.7 bc	9.8 bcd	3.9 bc	9.3 a
White clover + ryegrass	6.2 b	5.0 b	9.0 abc	2.9 bc	15.8 b	8.2 b	8.8 a
Subterranean clover	3.5 bc	1.2 c	6.7 bc	2.4 bc	10.7 bcd	3.8 bc	8.7 a
Yellow sweet clover	5.6 bc	4.8 b	6.6 bc	2.6 bc	12.7 b	7.7 b	8.7 a
Persian clover	2.7 bc	1.2 bc	6.9 bc	3.9 b	10.1 bcd	5.4 bc	8.6 a.
Strawberry clover	5.4 bc	2.2 bc	7.3 bc	5.4 ab	13.0 b	8.2 b	8.9 a
Crimson clover	3.5 bc	1.0 bc	3.0 c	2.2 bc	7.0 bcd	3.3 bc	9.7 a
Alfalfa	3.9 bc	0.8 bc	4.1 bc	2.5 bc	8.0 bcd	3.6 bc	8.8 a
Berseem clover	3.7 bc	1.8 bc	4.7 bc	1.8 bc	8.6 bcd	3.8 bc	9.4 a
Control, cultivated	6.5 b	3.3 bc	8.7 abc	4.4 b	15.5 bcd	8.4 b	9.4 a
Control, hand weeded	2.6 bc	0.4 c	2.3 c	0.2 c	5.3 bcd	0.6 c	8.9 a
Control, chemically weeded	1.8 c	0.8 bc	2.4 c	1.2 bc	4.1 cd	1.8 bc	8.7 a
Control, weedy	19.9 a	16.1 a	16.9 a	10.7 a	37.5 a	27.5 a	7.0 b

[a] Values within the same column, followed by the same letter, are not significantly different by an ANOVA protected Waller–Duncan multiple range test ($P<0.05$).
[b] Maize grain yield data were adapted from Abdin et al. (1998).

and berseem clover with interrow cultivation was as effective as the chemical and hand weeded treatments for controlling the weed population and biomass between the rows in both years.

At the l'Assomption site the cover crops plus tillage reduced weed density and biomass by 54 and 38% in 1993 and by 11 and 84% in 1994, respectively, when compared to the unweeded control. Due to the relatively high weed infestation in 1993 at l'Assomption, the combination of interrow tillage and cover crops was less effective for controlling the weeds in that year. A previous study reported that subterranean clover was able to control approximately 80% of the fall Panicum (*Panicum dichotomilflorum* Michx.) and hedge bindweed (*Convolvulus sepium* L.) in minimum tilled maize (Enache and Ilnicki, 1990).

Inclusion of the interrow tillage control treatment in 1994 allowed us to separate the tillage and cover crop effects. In 1994, when compared to the weedy control, the combination of cover crops and interrow tillage reduced the weed biomass by 81 and 78%, while cultivation alone controlled 70 and 80% of the weeds present at the Macdonald and l'Assomption sites (Tables 4 and 6), respectively. Thus the cover crops alone were responsible for approximately 10% of the weed control at Macdonald site. However, this was not true for the highly infested l'Assomption site, as the interrow cultivation alone was able to control more weeds than interrow cultivation in combination with cover crops, indicating some effectiveness for using cover crops in fields with low weed densities but not for weedy fields.

Dicotolyledonous weed biomasses were generally higher than monocotolyledonous weed biomass, except at l'Assomption in 1994 (Tables 3, 4, 5 and 6). In 1993, at both locations, weed density followed the same pattern as weed biomass, being higher on the maize rows than between the rows. In 1994 at l'Assomption weed density on the maize rows was less than between the rows (Table 6), although the weed biomass was higher on the row. This indicated that the on row population was composed of fewer but larger plants than the between row population.

In both years at the Macdonald site, and in 1994 at the l'Assomption site, all cover crops plus cultivation treatments suppressed weed densities and biomasses to levels that were lower than the weedy control. In 1993 at l'Assomption, most of the interseeded cover crops did not compete effectively with the weeds due to the severe weed infestation at that site (Table 5); the exception was for fall rye, crimson clover and alfalfa. Chemical and manual treatments were the only effective weed control methods at the l'Assomption site (Tables 5 and 6).

At Macdonald in both years, the combination of interrow tillage and interseeded cover crops suppressed weed densities and biomass compared to the unweeded control. In 1993, interseeded yellow sweet clover, Persian clover, and crimson clover with interrow cultivation were as effective in weed control as the chemical and hand weeded controls. In 1994, these cover crops were consistently effective in weed control, except for yellow sweet clover. At l'Assomption in 1993, although all interseeded cover crops reduced the weed density, the weed biomass was decreased only by interseeded fall rye, alfalfa and crimson clover. In 1994, all interseeded cover crops suppressed weed biomass except for fall rye and subterranean clover. Collectively, these results suggest that the ability of interrow tillage plus cover crops to suppress the development of weeds was affected by the level of weed infestation, the growing conditions and location.

3.4. Maize yield and weed control

The time of interseeding the cover crop did not affect maize yields (Abdin et al., 1998) during this study. Maize yields were only reduced if the planting date for the forage legumes was early (Exner and Cruse, 1993). Our data suggests that cover crops can be seeded quite close to corn planting in this area. In 1993 at Macdonald the interseeded cover crops did not affect maize yields, except for crimson clover which was competitive enough to reduce the grain yields by 19% relative to the weeded controls (Table 3). In 1993 at l'Assomption all the cover crop treatments reduced maize yields compared to the weeded controls, but the yields of these treatments were higher than the weedy treatment, except for Persian clover and

Table 5
Weed density and biomass, and grain yield as affected by interseeded cover crops at l'Assomption, Québec, in 1993

Treatments	On the row		Between rows		Total		
	Number[a] (m^{-2})	Weight ($g\ m^{-2}$)	Number (m^{-2})	Weight ($g\ m^{-2}$)	Number (m^{-2})	Weight ($g\ m^{-2}$)	Grain yield[b] ($Mg\ ha^{-1}$)
Fall rye	14.1 b	26.9 bc	12.2 bc	6.4 bcd	27.2 b	35.3 bc	7.5 b
Hairy vetch	26.6 ab	55.2 ab	10.9 bcd	7.4 bcd	38.1 b	63.8 abc	7.0 bc
Red clover + rye grass	28.9 ab	56.8 ab	9.0 bcd	3.3 cd	39.4 b	62.1 abc	7.2 bc
White clover + rye grass	27.5 ab	46.6 abc	14.7 bc	12.0 bc	44.5 b	58.8 abc	7.5 b
Subterranean clover	24.6 ab	48.4 abc	10.7 bcd	7.2 bcd	36.2 b	56.2 abc	6.3 cd
Yellow sweet clover	27.5 ab	64.1 a	14.9 bc	7.3 bcd	43.3 b	74.7 ab	7.5 b
Black medic	14.5 b	45.9 abc	9.4 bcd	6.7 bcd	24.4 b	54.4 abc	7.1 bc
Persian clover	15.9 b	32.0 abc	15.3 bc	15.2 b	33.4 b	55.3 abc	6.7 bcd
Strawberry clover	28.9 ab	45.6 abc	11.9 bc	9.1 bcd	41.4 b	55.5 abc	6.8 bcd
Crimson clover	21.0 b	27.6 cd	18.8 ab	7.6 bcd	42.0 b	27.8 c	6.4 cd
Alfalfa	25.7 ab	35.9 abc	12.3 bc	4.9 bcd	37.9 b	41.8 bc	6.9bc
Berseem clover	24.6 ab	57.1 ab	7.4 cd	2.2 d	33.1 b	60.2 abc	7.6 b
Control, hand weeded	15.0 b	4.0 d	9.4 bcd	3.5 cd	25.3 b	7.7 d	9.0 a
Control, chemically weeded	3.5 c	4.1 d	3.1 d	2.0 d	6.6 c	6.1 d	8.7 a
Control, weeded	39.6 a	40.7 abc	33.5 a	43.7 a	79.4 a	86.4 a	5.8 d

[a] Values within the same column, followed by the same letter, are not significantly different by an ANOVA protected Waller–Duncan multiple range test ($P<0.05$).
[b] Maize grain yield data were adapted from Abdin et al. (1998).

Table 6
Weed density and biomass as affected by interseeded cover crops at l'Assomption, Québec, in 1994

Treatments	On the row		Between rows		Total	
	Number[a] (m^{-2})	Weight ($g\ m^{-2}$)	Number (m^{-2})	Weight ($g\ m^{-2}$)	Number (m^{-2})	Weight ($g\ m^{-2}$)
Fall rye	33.9 ab	11.2 b	28.2 b	4.0 bc	63.7 ab	16.4 bc
Hairy vetch	27.8 ab	8.1 b	58.0 ab	5.3 bc	86.3 ab	14.6 bcd
Red clover + rye grass	23.7 ab	10.3 b	26.1 b	3.1 bc	50.9 ab	14.5 bcd
White clover + rye grass	81.4 a	6.0 b	40.6 ab	5.3 bc	124.9 a	12.1 bcd
Subterranean clover	26.7 ab	12.6 b	41.9 ab	5.0 bc	66.7 ab	21.9 b
Yellow sweet clover	22.8 ab	7.8 b	57.9 ab	5.5 bc	82.3 ab	14.5 bcd
Persian clover	24.4 ab	4.2 b	30.1 ab	6.7 b	56.5 ab	11.8 bcd
Strawberry clover	38.9 ab	8.7 b	65.3 ab	4.7 bc	105.9 a	14.4 bcd
Crimson clover	21.0 ab	7.0 b	28.9 ab	4.1 bc	50.6 ab	11.6 bcd
Alfalfa	73.2 a	7.4 b	50.8 ab	4.3 bc	139.2 a	12.0 bcd
Berseem clover	15.2 ab	10.3 b	56.4 ab	5.2 bc	76.9 ab	17.4 bcd
Control, cultivated	25.4 ab	6.1 b	78.5 a	5.4 bc	106.6 a	12.2 bcd
Control, hand weeded	32.4 ab	3.6 b	30.4 ab	1.8 c	64.0 ab	5.7 d
Control, chemically weeded	4.6 c	2.8 b	4.0 c	4.0 c	8.8 b	6.9 d
Control, weeded	35.3 ab	32.4 a	52.8 ab	27.0 a	92.4 a	60.7 a

[a] Values within the same column, followed by the same letter, are not significantly different by an ANOVA protected Waller–Duncan multiple range test ($P<0.05$).

strawberry clover which were not different from the weedy control (Table 5). The reduction in maize yield in the interseeded plots at l'Assomption was probably the result of competition from both the interseeded cover crops plus the existing weeds. There were no differences among treatments (except for the weedy control treatment) for grain yield at the Macdonald site in 1994 (Table 4), presumably due to the decrease in competition for moisture (Table 2) and the beneficial effects of the legumes from the previous year (Abdin et al., 1998). In some cases of this study, we found that cover crop provided little or no weed control when weed development interfered with cover crop establishment. This was particularly true in l'Assomption. Therefore, when the weed infestation was moderate the cover crop offers some potential advantages; the matter of effective weed control remains to be resolved. The cover crop itself can provide some weed control (Doran and Smith, 1991), but the interrrow tillage or some herbicide application may still be necessary.

4. Conclusions

Cover crop planting date did not affect maize yields or the ability of interrow tillage plus cover crops to suppress the development of weed densities. Except for 1993 at l'Assomption interrow tillage plus cover crop treatments had consistently lower weed biomass than the weedy control when the weed pressure was not excessive. Most of the weed control was due to the interrow cultivation performed prior to seeding of the cover crops. The cover crops provide additional weed control but the interrrow tillage or some herbicide application may still be necessary. The lowest weed density occurred in the herbicide treated plots. The ability of interrow tillage plus cover crops to suppress the development of weeds was affected by the level of weed infestation, the growing conditions and location.

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References

Abdin, O.M., Coulman, B.E., Cloutier, D., Faris, M.A., Zhou, X.M., Smith, D.L., 1998. Yield and yield components of corn interseeded with cover crops. Agron. J. 90, 63–68.

Bollero, G.A., Bullock, D.G., 1994. Cover cropping systems for the central corn belt. J. Product. Agric. 7, 55–58.

Brown, R.W., Varvel, G.E., Shapiro, C.A., 1993. Residual effects of interseeded hairy vetch on soil nitrate–nitrogen levels. Soil Sci. Soc. Am. J. 57, 121–124.

Carruthers, K., Fe, Q., Cloutier, D., Smith, D.L., 1997. Intercropping corn with soybean, lupin and forages: weed control by intercrops combined with interrow cultivation. Eur. J. Agron. 8, 225–238.

Dabney, S.M., Murphree, C.E., Meyer, L.D., 1993. Tillage, row spacing, and cultivation affect erosion from soybean cropland. Trans. Am. Soc. Agric. Eng. 36, 87–94.

De Haan, R.L., Wyse, D.L., Ehlke, N.J., Maxwell, B.D., Putnam, D.H., 1993. Simulation of spring-seeded smother plants for weed control in corn (*Zea mays*). Weed Sci. 42, 35–43.

Decker, A.M., Clark, A.J., Meisinger, J.J., Mulford, F.R., McIntosh, M.S., 1994. Legume cover crop contribution to no till corn. Agron. J. 86, 126–135.

Doran, J.W., Smith, M.S., 1991. Role of cover crops in the nitrogen cycle. In: Hargrove, W.L. (Ed.), Cover Crop for Clean Water. Soil and Water Conservation Society, Ankeny, IA, pp. 85–90.

Eberlein, C.V., Sheafer, C.C., Oliveira, V.F., 1992. Corn growth and yield in an alfalfa living mulch system. J. Product. Agric. 5, 332–339.

Enache, A.J., Ilnicki, R.D., 1990. Weed control by subterranean clover (*Trifolium subterraneum*) used as a living mulch. Weed Technol. 4, 534–538.

Exner, D.N., Cruse, R.M., 1993. Interseeded forage legume potential as a winter ground cover, nitrogen source, and competitor. J. Product. Agric. 6, 226–231.

Forcella, F., Westgate, M.E., Warnes, D.D., 1992. Effect of row width on herbicide and cultivation requirements in row crops. Am. J. Altern. Agric. 7, 161–167.

Fuller, L.G., Gon, T.B., Oscarson, D.W., 1995. Cultivation effects on dispersible clay of soil aggregates. Can. J. Soil Sci. 75, 101–107.

Hallberg, G.R., 1989. Pesticide pollution of ground water in the humid United States. Agric. Ecosyst. Environ. 26, 299–367.

Hoffman, M.L., Regnier, E.E., Cardina, J., 1993. Weed and corn (*Zea mays*) response to a hairy vetch (*Vicia villosa*) cover crop. Weed Technol. 7, 594–599.

Holderbaum, J.F., Decker, A.M., Meisinger, J.J., Mulford, F.R., Vough, L.R., 1990. Fall-seeded legume cover crops for no-tillage corn in the humid east. Agron. J. 82, 117–124.

Ilnicki, R.D., Enache, A.J., 1992. Subterranean clover living mulch: an alternative method of weed control. Agric. Ecosyst. Environ. 40, 249–264.

Johnson, G.A., Defelice, M.S., Helsel, Z.R., 1993. Cover crop management and weed control in corn. Weed Technol. 7, 425–430.

Latif, M.A., Mehuys, G.R., Mackenzie, A.F., Alli, I., Faris, M.A., 1992. Effect of legumes on soil physical quality in a maize crop. Plant and Soil 140, 15–23.

Lybecker, D.W., Schweizer, E.E., King, R.P., 1988. Economic analysis of four weed management systems. Weed Sci. 36, 846–849.

Mayer, J.B., Hartwig, N.L., 1986. Corn yield in crown vetch relative to dead mulch, Proceedings of the Annual Meeting of the Northeastern Weed Science Society Vol. 40, 34–35.

McVay, K.A., Radcliffe, D.E., Hargrove, W.L., 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Sci. Soc. Am. J. 53, 1856–1862.

Mohler, C.L., Callaway, M.B., 1995. Effects of tillage and mulch on weed seed production and seed banks in sweet corn. J. Appl. Ecol. 32, 627–639.

Mt. Pleasant, J., 1982. Corn polyculture systems in New York. M.Sc. Thesis, Cornell University, Ithaca, NY.

Mulder, T.A., Doll, J.D., 1994. Reduced input corn weed control: the effects of planting date:, early season weed control, and row-crop cultivator selection. J. Product. Agric. 7, 256–260.

National Research Council, 1989. Alternative Agriculture. National Academy Press, Washington, DC, pp. 98–108.

Palada, M.C., Ganser, S., Hofstetter, R., Volak, B., Culik, M., 1982. Association of interseeded cover crops and annual row crops in year-round cropping systems. In: Lockeretz, W. (Ed.), The Fourth IFOAM Conference, Cambridge, MA, USA, 193–213.

Parks, R.J., Curran, W.S., Roth, G.W., Hartwig, N.L., Calvin, D.D., 1995. Common lambsquarters (*Chenopodium album*) control in corn (*Zea mays*) with post emergence herbicides and cultivation. Weed Technol. 9, 728–735.

Pava, H.M., Ulanday, M.A., 1993. Frequency of cultivation and pendimethalin application as weed control on soybean monoculture and intercropped with corn. Weedwatcher 23, 4–5.

Samson, R.A., 1991. The weed suppressing effects of cover crops, Proc. Fifth Annual REAP Conference, Macdonald College, Ste Anne de Bellevue, Québec.

SAS Institute, 1985. SAS User's Guide. Statistics, Vers. 5. SAS Institute, Cary, NC.

Scott, T.W., Burt, R.F., 1985. Cover crops and intercrops for New York. Cornell Cooperative Extension Fact Sheet, 452 pp.

Scott, T.W., Pleasant, J.M., Burt, R.F., Otis, D.J., 1987. Contribution of ground cover, dry matter, and nitrogen from intercrops and cover crops in a corn polyculture system. Agron. J. 79, 792–798.

Sprague, M.A., 1986. Overview. In: Sprague, M.A., Triplett, G.B. (Eds.), No Tillage and Surface Tillage Agriculture. Wiley, New York, pp. 1–18.

Steel, R.G.D., Torrie, J.H., 1980. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill, New York.

Stoller, E.W., Wax, L.M., Alm, D.M., 1993. Survey results on environmental issues and weed science research priorities within the corn belt. Weed Technol. 7, 763–770.

Teasdale, J.R., 1993. Reduced-herbicide weed management systems for no-tillage corn (*Zea mays*) in a hairy vetch (*Vicia villosa*) cover crop. Weed Technol. 7, 879–883.

Teasdale, J.R., 1995. Influence of narrow row/high population corn (*Zea mays*) on weed control and light transmittance. Weed Technol. 9, 113–118.

Wall, G.J., Pringle, E.A., Sheard, R.W., 1991. Intercropping red clover with silage corn for soil erosion control. Can. J. Soil Sci. 71, 137–145.

White, R.H., Worsham, A.D., Blum, U., 1989. Allelopathic potential of legume debris and aqeous extracts. Weed Sci. 37, 674–679.

White, R.H., Worsham, A.D., 1990. Control of legume cover crops in no till corn and cotton. Weed Technol. 4, 57–62.

Wilson, R.G., 1993. Effect of preplant tillage, post-plant cultivation and herbicides on weed density in corn. Weed Technol. 7, 728–734.