

# Weed suppression by *Medicago sativa* in subsequent cereal crops: a comparative survey

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The ability of *Medicago sativa* to suppress weed growth may provide a viable alternative to chemical weed control and allow crop producers to reduce herbicide inputs. Quantitative information regarding the suppressive effect of *M. sativa* on weed populations in current cropping systems is lacking. A survey was conducted in Manitoba, Canada, in 1993 and 1994 to investigate weed populations in commercial cereal fields that had been preceded by either *M. sativa* hay or cereal grain crops. A total of 117 fields were surveyed; approximately half from each field type. Principle component analysis indicated that the inclusion of *M. sativa* in crop rotations resulted in weed communities different from those of continuous cereal fields. Naturally occurring populations of *Avena fatua*, *Cirsium arvense*, *Brassica kaber*, and *Galium aparine* were lower in cereal fields that had previously contained *M. sativa* than in cereal fields that had been preceded by a cereal crop. Lower field uniformity values for *C. arvense* and *Avena fatua* indicated that these weeds were also more patchy in the *M. sativa* rotations. Population differences between field types were nonsignificant for *Amaranthus retroflexus*, *Chenopodium album*, and *Polygonum convolvulus*, and although populations of *Taraxacum officinale* and *Thlaspi arvense* were greater in *M. sativa*/cereal fields than in continuous cereal crops. No consistent effect of field type on *Setaria viridis* populations was observed. These results show that *M. sativa* effectively suppressed some, but not all, of the weeds found in the study area. Including *M. sativa* hay crops in crop rotations can be part of an integrated weed management strategy for weeds such as *A. fatua*, *B. kaber*, and *C. arvense*.

**Nomenclature:** *Medicago sativa* L. MEDSA, alfalfa; *Avena fatua* L. AVEFA, wild oats; *Cirsium arvense* (L.) Scop. CIRAR, Canada thistle; *Brassica kaber* (DC.) L. C. Wheeler SINAR, wild mustard; *Galium aparine* L. GALAP, catchweed bedstraw; *Amaranthus retroflexus* L. AMARE, redroot pigweed; *Chenopodium album* L. CHEAL, common lambsquarters; *Polygonum convolvulus* L. POLCO, wild buckwheat; *Taraxacum officinale*, Weber in Wiggers TAROF, dandelion; *Thlaspi arvense* L. THLAR, field pennycress; *Setaria viridis* (L.) Beauv. SETVI, green foxtail.

**Key words:** Alternative weed control, relative abundance, weed/crop ecology, weed suppression, weed patchiness, AMARE, AVEFA, CHEAL, CIRAR, GALAP, MEDSA, POLCO, SINAR, SETVI, TAROF, THLAR.

Herbicide-resistant weeds, the need to reduce crop production costs, and public and environmental concerns regarding pesticide use are reasons that complete reliance on herbicide for weed control should be decreased (Burnside 1993; Lotz et al. 1995; Roush et al. 1990; Swanton and Weise 1991; Wyse 1994).

Perennial forages, most notably *Medicago sativa*, can compete effectively with weeds (Hunter et al. 1990; Pavlychenko 1942; Siemens 1963; Stevens 1846 in Donald 1990; Todd and Derksen 1986). Peters and Linscott (1988) stated that summer annual weeds seldom infested mature, vigorous, and densely growing *M. sativa* stands. Hodgson (1958) found that *M. sativa*, cut for hay twice a year, reduced the number of *Cirsium arvense* shoots to 1% of the original stand in 3 yr. Similarly, Derscheid et al. (1961) reported almost complete elimination of the *C. arvense* population on land heavily infested with this weed after 3 yr of *M. sativa* hay. In a study investigating competition between selected crops and *Convolvulus arvensis* L. (field bindweed), Stahler (1948) remarks upon the "inherent ability" of *M. sativa* to successfully compete for sunlight and soil moisture.

Danish researchers used multivariate analytical techniques

to analyze survey data collected from the turn of the century until 1970 and found that the average frequency of common weed species was different in *M. sativa* and perennial grass stands than in annual crops such as *Hordeum vulgare* L. (barley), *Phaseolus vulgaris* L. (field beans), and *Brassica napus* L. (canola) (Haas and Streibig 1982). They also noted that *Polygonum convolvulus* and *Chenopodium album* almost disappeared in biennial and perennial crops. Pallas (1994 in Stupnicka-Rodzynekiewicz 1996) reported that inclusion of *M. sativa* in rotation prevented subsequent crops from being infested with weeds typically found in a cereal rotation; however, Thomas et al. (1996) found that rotations including hay crops had only slightly different weed communities than rotations without hay. In a western Canadian survey, 84% of producers indicated that the inclusion of *M. sativa* in crop rotations reduced weed populations in subsequent annual crops (Entz et al. 1995). Producers noted good suppression of *Avena fatua*, *C. arvense*, *Setaria viridis*, and *Brassica kaber*.

Many conclusions in the literature regarding the effectiveness of *M. sativa* in decreasing weed populations are based on qualitative observations and anecdotal references

rather than on quantitative evidence. Information regarding the suppressive effect of *M. sativa* on weeds in current cropping systems is lacking. In addition, the majority of weed/crop studies have focused on the effect of the weed on crop yield, with less importance placed on the competitive effect of the crop on weeds. The objective of this study was to determine the ability of *M. sativa* used for hay production to suppress annual and perennial weed populations compared to cereal-based rotations that did not contain a perennial forage component.

## Materials and Methods

A survey was conducted throughout Manitoba, Canada, in early June 1993 and 1994 to determine weed populations in commercial cereal fields that had been preceded either by a cereal crop (continuous cereal fields) or by an *M. sativa* or *M. sativa*/grass crop (*M. sativa*/cereal fields). The spring-seeded cereal crops included *Triticum aestivum* L. (wheat), *H. vulgare*, or *Avena sativa* L. (oat). Differences in competitive ability between these crops were not considered important because fields were surveyed prior to crop canopy closure; that is, before the crops had an opportunity to express large differences in competitive ability against weeds.

Surveyed fields were 15 ha or larger. Continuous cereal fields that were considered ineligible for the study were those that (1) had been sown to *M. sativa* in the past 5 yr, (2) were in a zero-tillage production system, or (3) had received a preplant spring herbicide application. *Medicago sativa*/cereal fields were selected according to the following criteria: the maximum sward grass component in *M. sativa*/grass hay stands did not exceed 50%; stand age ranged from 3 to 6 yr; and all forage crops were managed for hay production with one to two harvests per season. Ineligible fields included *M. sativa* stands that had been treated with a herbicide 2 yr prior to the survey, those that had received a preplant herbicide application after *M. sativa* stand termination, and those that had received a spring burn-off herbicide treatment prior to seeding of the cereal crop. *Medicago sativa* fields that had received an application of glyphosate for *M. sativa* control either before or after tillage during the fall, prior to the survey, were considered eligible for sampling; other fall-applied herbicides were not acceptable.

Survey fields were equally distributed throughout the cropping zone of southern Manitoba. All surveys were conducted by members of the Manitoba Weed Supervisors Association, a group of weed specialists with weed survey experience. The sampling technique was based on the "inverted W" method used by others to survey weed infestations in agricultural fields (Frick and Thomas 1992; Thomas 1985). The weed supervisor walked along the edge of the field for a predetermined, random number of paces (100 or greater), turned, and walked into the fields for another randomized number of paces. Weed sampling began at this point and followed an inverted "W" pattern, whereby five quadrats were sampled along each arm of the "W" pattern (Thomas 1985). In each sampled field, weed species were counted in 20 0.5- by 0.5-m square quadrats (0.25 m<sup>2</sup>). For perennial species such as *Eltrygia repens* (L.) Nevski (quackgrass) and *C. arvensis*, the number of shoots rather than the number of plants was counted. Twenty-four and 30 continuous cereal fields and 28 and 35 *M. sativa*/cereal fields were sampled in 1993 and 1994, respectively.

## Data Analysis

### Univariate Analysis

Data from each of the two field types were summarized by calculating mean field density, frequency, uniformity, and relative abundance values as described by Thomas (1985). Mean field density (hereafter referred to as density) of a weed species is the summed total of the average density for each field (calculated from the 20 quadrats that were sampled per field) divided by the total number of fields surveyed for a particular field type. Frequency is defined as the number of fields in which a species occurs and is expressed as a percentage of the total number of fields. Frequency estimates the extent of weed occurrence in the study area (Frick and Thomas 1992). Field uniformity is the number of quadrats in which a species occurred expressed as a percentage of the total number of quadrats measured. It is an indication of the amount of land in the study area that contained the species in question (Frick and Thomas 1992). A relative abundance value was calculated using mean field density, frequency, and uniformity values to rank the contribution of individual species to the weed community. The sum of the relative abundance value of all species equals 300 (Thomas 1985). The advantage of using a relative index is that it allows comparisons between data collected for weed communities in different years, locations, and studies (Frick and Thomas 1992). Differences in species density between the two field types were tested for significance using an unpaired *t* test. Species density values were log-transformed to ensure normal data distribution (Mead et al. 1993).

### Multivariate Analysis

Species density data were subjected to multivariate data analysis to detect differences between the weed communities of each field type. One important advantage of a multivariate analysis approach is that it allows comparisons utilizing all occurring weed species as variables in the analysis (Derksen et al. 1993). Principal component analysis (PCA) summarizes data variation in terms of derived component axes. The first component axis explains the greatest proportion of linear variation in the data, whereas the second axis explains the next greatest proportion of variation. If the data are highly structured, the first few principal component axes will explain most of the variation in the data and thereby capture the underlying data trends (Manly 1994; Podani 1993).

The ordination biplots generated by PCA are two-dimensional representations of surveyed fields and the weed densities contained within each field whereby weed density data is superimposed upon field type data in ordination space. Every surveyed field appears as a symbol on the biplot. Fields that are close together in ordination space are more similar in weed species composition than those that are further apart (Jongman et al. 1995). Weed species are represented as vectors originating from the origin of the ordination biplot. The orientation of the vector indicates the direction in which the density of the corresponding species increases most, and the length of the vector is proportional to the discriminating power of the species. Longer vectors are indicative of species that are strongly associated with a particular field type, whereas species that are common to all fields have little discriminating power and are therefore rep-

resented by short vectors (Derksen et al. 1993; Jongman et al. 1995).

The Hotelling  $T^2$  test is a multivariate statistical procedure used to test for differences between two predefined groups or classifications. It is the multivariate version of the familiar univariate  $t$  test (Morrison 1990). This test is based on the assumptions of common (homogeneous) covariance structures and multivariate normal data distribution. Another requirement is that the number of individuals (replicates) in the two groups being compared greatly exceeds the number of variables describing the groups (Green 1993). Because the number of variables (weed species) in this study was large compared to the number of fields surveyed, PCA (using a covariance matrix) was first performed on log-transformed weed density values to reduce the number of variables and to meet the assumptions of multivariate normality and homogeneity of covariance structure (Green 1993). Derived component scores from the first two PCA axes, which numerically summarize the weed density data, were then used as variables in the Hotelling  $T^2$  test (Green 1993). The Hotelling  $T^2$  statistic was then converted to a standard  $F$  statistic to determine if compositional differences between the two groups (field types) were statistically significant (Morrison 1990).

Although included in the multivariate and univariate statistical analyses, weed species with densities lower than 0.01 plants  $m^{-2}$  have been assigned a value of zero to restrict numerical values to two significant decimal places.

## Results and Discussion

### Weed Community Characterization

Despite expected yearly variation, similar data sets were obtained from one survey year to the next (Table 1) and typified the weed flora found in cultivated fields in Manitoba (Thomas et al. 1997). In 1993, *M. sativa*/cereal fields contained 27 different species, and continuous cereal fields contained 31 species; total field density (the sum total of weed species density values) was 48 plants  $m^{-2}$  for *M. sativa*/cereal fields and 106 plants  $m^{-2}$  for continuous cereal fields. In 1994, *M. sativa*/cereal fields contained 41 species, and continuous cereal fields contained 34 species. Total field density was 81 and 128 plants  $m^{-2}$  for *M. sativa*/cereal and continuous cereal fields, respectively. In both years, the 10 most abundant weed species accounted for more than 80% of the total relative abundance value (the summed total of all weed species relative abundance values) for both field types (Tables 2 and 3). Higher total field densities (Table 3) and greater species diversity (Table 1) in 1994 is reflective of the year to year variability often expressed by weed populations due to annual fluctuations in environmental conditions (Chepil 1946; Derksen et al. 1993; Radosevich et al. 1997).

If the 10 most abundant weed species for each field type in 1993 are considered, seven species (mainly annual dicots) were common to both field types (Table 2). The most striking differences were: (1) the absence of *S. viridis* and *A. fatua* as the first and second most abundant species in *M. sativa*/cereal fields; (2) the absence of volunteer *M. sativa*, *Taraxacum officinale*, and *Thlapsi arvense* in continuous cereal fields. Similarly, in 1994, seven of the 10 most abundant species were again common to both field types (Table 3).

*Thlapsi arvense*, volunteer *M. sativa*, and *T. officinale* were present among the 10 most abundant weed species in *M. sativa*/cereal fields and absent from this category for continuous cereal fields. As was the case in 1993, *A. fatua* was absent from the top 10 weeds in continuous cereal fields in 1994. However, *S. viridis* was the most abundant weed in both field types in 1994.

Weed species density values for *M. sativa*/cereal fields ranged from a minimum of 0.01 *Monolepis nutalliana* Greene (Nuttall povertyweed) plants  $m^{-2}$  to a maximum of 8 *B. kaber* plants  $m^{-2}$  in 1993 and from 0.01 *Geranium bicknellii* Britt (cranesbill) plants  $m^{-2}$  to 21 *S. viridis* plants  $m^{-2}$  in 1994. The greater range of densities observed in *M. sativa*/cereal fields in 1994 was due to a large increase in *S. viridis* density. When *S. viridis* was excluded from the analysis, the range of densities (0.01 to 9 plants  $m^{-2}$ ) was similar in both years. Density values recorded for continuous cereal fields were also similar for both years and ranged from 0.02 *Melilotus* spp. (sweetclover) plants  $m^{-2}$  to 27 *A. fatua* plants  $m^{-2}$  in 1993 and from 0.03 *Matricaria matricarioides* (Less) C.L. Porter (pineapple weed) plants  $m^{-2}$  to 29 *S. viridis* plants  $m^{-2}$  in 1994. Results obtained for continuous cereal fields in the present study were similar to previous surveys conducted in Manitoba (Thomas and Donaghy 1991; Thomas et al. 1997).

### Annual Grasses

Based on relative abundance values, *A. fatua* and *S. viridis* were the only annual grass species of major importance in this survey (Tables 2 and 3). The results obtained for *A. fatua* were most consistent. *Avena fatua* densities in *M. sativa*/cereal fields were 1 and 0.4 plants  $m^{-2}$  in 1993 and 1994, respectively, compared with 27 and 13 plants  $m^{-2}$ , respectively, for continuous cereal fields (differences significant at  $P \leq 0.01$  for both years). Frequency and relative abundance values were also lower for *A. fatua* in *M. sativa*/cereal fields. For example, 46 and 40% of *M. sativa*/cereal fields contained *A. fatua* in 1993 and 1994, respectively, compared with 83 and 90% of continuous cereal fields. *Avena fatua* was the first and fourth most abundant weed in continuous cereal fields in 1993 and 1994, respectively, ranking only 10th and 12th in *M. sativa*/cereal fields (Tables 2 and 3).

It is apparent from these data that *M. sativa* effectively suppresses *A. fatua* density and seed return, as has been observed by Siemens (1963). This may be due to the highly competitive root and shoot growth of *M. sativa*. Cutting regime may also influence *A. fatua* population dynamics. Because *A. fatua* seed shatters before a cereal crop is harvested (Chepil 1946; Thurston 1966), annual replenishment of the seed bank will occur each year in an annual crop rotation. However, two *M. sativa* hay cuts per growing season can reduce seed set and subsequent seed return (Schoofs 1997).

The effects of *M. sativa* in rotation were less consistent between years for *S. viridis* than for *A. fatua*. Although density, frequency and relative abundance values for *S. viridis* were lowest in *M. sativa*/cereal fields in 1993 (Table 2), little difference between field types was observed in 1994 (Table 3). The fact that density, frequency, and relative abundance trends for continuous cereal fields were consistent between years appears to rule out a year effect

TABLE 1. WSSA-approved codes, scientific names, common names, and life cycle for weed species occurring in surveyed fields in 1993 and 1994.

Code	Scientific name	Common name	Year appearing	Life cycle
AGRRE	<i>Elytrigia repens</i> (L.) Nevski	Quackgrass	both	Perennial graminoid
AMABL	<i>Amaranthus blitoides</i> S. Wats.	Prostrate pigweed	1994 only	Annual dicot
AMARE	<i>Amaranthus retroflexus</i> L.	Redroot pigweed	both	Annual dicot
ARTAB	<i>Artemisia absinthium</i> L.	Absinth	1994 only	Perennial dicot
ARTBI	<i>Artemisia biennis</i> Willd.	Biennial wormwood	1994 only	Annual dicot
ASCSY	<i>Asclepias syriaca</i> L.	Common milkweed	1993 only	Annual dicot
	<i>Astragalus cicer</i> L.	Cicer milkvetch	1994 only	Perennial dicot
AVEFA	<i>Avena fatua</i> L.	Wild oat	both	Annual graminoid
	<i>Brassica napus</i> L.	Canola	both	Annual volunteer crop
CAPBP	<i>Capsella bursa-pastoris</i> (L.) Medikus	Shepherdspurse	both	Annual dicot
CHEAL	<i>Chenopodium album</i> L.	Common lambsquarters	both	Annual dicot
CHEGL	<i>Chenopodium glaucum</i> L.	Oakleaf goosefoot	1994 only	Annual dicot
	<i>Chenopodium hybridum</i> L.	Mapleleaf goosefoot	1994 only	Annual dicot
CIRAR	<i>Cirsium arvense</i> (L.) Scop.	Canada thistle	both	Perennial dicot
CVPTE	<i>Crepis tectorum</i> L.	Narrowleaf hawksbeard	1994 only	Annual dicot
DESSO	<i>Descurainia sophia</i> (L.) Webb. ex Prantl	Flixweed	1994 only	Annual dicot
DRAPA	<i>Dracocephalum parviflorum</i> Nutt.	American dragonhead	1994 only	Annual dicot
ECHCG	<i>Echinochoa crusgalli</i> (L.) Beauv.	Barnyard grass	both	Annual graminoid
	<i>Euphorbia serpyllifolia</i> Pers.	Thyme-leaved spurge	both	Annual dicot
EQUAR	<i>Equisetum arvense</i> L.	Field horsetail	both	Perennial cryptogam
ERWGA	<i>Erucastrum gallicum</i> (Willd.) O. E. Schulz	Dog mustard	1994 only	Annual dicot
	<i>Geranium bicknellii</i> Britt.	Cranesbill	1994 only	Annual dicot
GAETE	<i>Galeopsis tetrahit</i> L.	Common hempnettle	both	Annual dicot
GALAP	<i>Galium aparine</i> L.	Catchweed bedstraw (cleavers)	both	Annual dicot
HORJU	<i>Hordeum vulgare</i> L.	Barley	1993 only	Annual volunteer crop
KCHSC	<i>Kochia scoparia</i> (L.) Schrad	Kochia	1994 only	Annual dicot
	<i>Linum usitatissimum</i> L.	Flax	both	Annual volunteer crop
LOLPS	<i>Lolium persicum</i> Boiss. et Hohen. ex Boiss.	Persian darnel	1993 only	Annual graminoid
LPLSQ	<i>Lappula echinata</i> Gilib.	European sticktight (bluebur)	both	Annual dicot
	<i>Silene alba</i> (Mioll.) E.H.L. Krause	White cockle	1993 only	Annual dicot
	<i>Malva pusilla</i> Sm.	Round-leaved mallow	1994 only	Annual dicot
MATMT	<i>Matricaria matricarioides</i> (Less.) C. L. Porter	Pineappleweed	1994 only	Annual dicot
MEDLU	<i>Medicago lupulina</i> L.	Black medic	1994 only	Annual dicot
MEDSA	<i>Medicago sativa</i> L.	Alfalfa	both	Perennial dicot
MELNO	<i>Silene noctiflora</i> L.	Nightflowering catchfly	both	Annual dicot
	<i>Melilotus</i> species	Sweetclover species	1993 only	Annual dicot
MOPNU	<i>Monolepis nuttalliana</i> Greene	Povertyweed	1993 only	Annual dicot
	<i>Poa</i> species	Grass species	1993 only	Annual graminoid
POLAM	<i>Polygonum amphibium</i> L.	Perennial smartweed	1994 only	Perennial dicot
POLAV	<i>Polygonum aviculare</i> L.	Prostrate knotweed	1994 only	Annual dicot
POLCO	<i>Polygonum convolvulus</i> L.	Wild buckwheat	both	Annual dicot
PTLNO	<i>Potentilla norvegica</i> L.	Rough cinquefoil	1994 only	Perennial dicot
	<i>Polygonum</i> species	Annual smartweed species	both	Annual dicot
SASKR	<i>Salsola iberica</i> Sennen et Pau	Russian thistle	both	Annual dicot
SETVI	<i>Setaria viridis</i> (L.) Beauv.	Green foxtail	both	Annual graminoid
SINAR	<i>Brassica kaber</i> (DC.) L. C. Wheeler	Wild mustard	both	Annual dicot
SOLTR	<i>Solanum triflorum</i> Nutt.	Cutleaf nightshade (wild tomato)	1994 only	Annual dicot
SONAR	<i>Sonchus arvensis</i> L.	Perennial sowthistle	both	Perennial dicot
STEME	<i>Stellaria media</i> (L.) Vill.	Common chickweed	both	Annual dicot
TAROF	<i>Taraxacum officinale</i> Weber in Wiggers	Dandelion	both	Perennial dicot
THLAR	<i>Thlaspi arvense</i> L.	Field pennycress (stinkweed)	both	Annual dicot

for *S. viridis*, even though higher air temperature in 1994 (Table 4) was more conducive to emergence of this  $C_4$  plant (Douglas et al. 1985). Schoner et al. (1978) described a distinct biotype of *Setaria glauca* (L.) Beauv. (yellow foxtail) that was morphologically similar to *S. viridis* but had developed a shorter, more prostrate growth habit as a result of repeated mowing. However, it is unlikely that the higher densities obtained in 1994 are indicative of a second *S. viridis* biotype because the survey

was conducted throughout a wide geographic area. Therefore, observations of higher *S. viridis* populations following *M. sativa* in 1994 vs. 1993 remain unexplained. However, less *S. viridis* after perennial *M. sativa* than after an annual crop rotation were observed by prairie producers (Entz et al. 1995). *Setaria viridis* relative abundance values for continuous cereal fields in this study (47 in both 1993 and 1994) were similar to those reported by Thomas et al. (1997) (average of 41).

TABLE 2. Density, frequency, uniformity, and relative abundance values for *Medicago sativa*/cereal fields (A.C. Fields) and continuous cereal fields (C.C. Fields) in 1993.<sup>a</sup>

Species common name	Relative abundance		Density		Level of significance Log scale	Frequency		Uniformity	
	C.C. Fields	A.C. Fields	C.C. Fields	A.C. Fields		C.C. Fields	A.C. Fields	C.C. Fields	A.C. Fields
	— plants m <sup>-2</sup> —					%			
Wild oat	53.03	13.14	27.15	1.26	≤ 0.05	83.33	46.43	54.79	11.43
Green foxtail	44.63	23.86	22.32	2.66	≤ 0.01	75.00	64.29	45.83	26.25
Wild mustard	31.68	32.43	10.63	7.90	≤ 0.10	79.17	57.14	38.13	22.68
Wild buckwheat	31.38	39.71	9.15	6.10	NS	83.33	85.71	40.00	42.14
Annual smartweed spp.	20.85	16.59	6.78	1.80	NS	66.67	57.14	20.21	13.75
Quackgrass	19.79	19.09	7.58	3.70	NS	50.00	42.86	20.83	15.54
Common lambsquarters	15.47	28.99	3.16	5.70	NS	54.17	57.14	18.75	25.71
Canada thistle	13.69	2.52	2.33	0.27	≤ 0.01	54.17	7.14	15.63	2.68
Catchweed bedstraw	12.71	6.76	6.40	1.50	NS	20.83	10.71	13.13	6.07
Field pennycress	7.28	17.86	0.49	3.00	NS	41.67	46.43	5.63	14.46
Dandelion	1.98	28.34	0.08	4.35	≤ 0.01	12.50	64.29	1.25	28.93
Volunteer alfalfa	0.59	39.56	0.03	6.38	≤ 0.01	4.17	85.71	0.21	40.18
Redroot pigweed	3.55	5.32	0.26	0.51	NS	20.83	17.86	2.50	5.00
Perennial sowthistle	5.95	1.48	0.76	0.11	< 0.10	29.17	7.14	5.42	0.71
Persian darnel	4.54	0.00	2.88	0.00	NS	4.17	0.00	4.17	0.00

<sup>a</sup> Weed and crop species with (1) nonsignificant differences between field types or (2) population densities less than 1 m<sup>-2</sup> are not included in this table.

### Annual Dicots

Annual dicots of major significance in this survey included *P. convolvulus*, *B. kaber*, *Polygonum* spp. (smartweed), *Amaranthus retroflexus*, and *C. album*. These species were consistently among the top 10 most abundant species for both field types and survey years. Two of these weeds, *B. kaber* and *Polygonum* spp., plus a less abundant weed, *Galium aparine*, were strongly influenced by inclusion of *M. sativa* in rotation. *Brassica kaber* density in *M. sativa*/cereal fields was 8 and 7 plants m<sup>-2</sup> in 1993 and 1994, respectively, compared with 11 and 23 plants m<sup>-2</sup>, respectively, in continuous cereal fields ( $P \leq 0.10$  in 1993 and  $P \leq 0.05$  in 1994). Frequency of *B. kaber* was lower in *M. sativa*/cereal fields in 1993 (Table 2), although no differences between field type were observed in 1994 (Table 3). Based on fre-

quency observations, *B. kaber* populations were reduced but not eliminated by *M. sativa*. In 1994, similar trends were exhibited for *Polygonum* spp. with significantly fewer plants ( $P \leq 0.10$ ) present in *M. sativa*/cereal fields. *Galium aparine* was the third annual dicot whose density was significantly reduced by the inclusion of *M. sativa* in rotation. This plant is gaining prominence throughout the Canadian prairies as an important weed in *B. napus* fields (Anonymous 1997). *Galium aparine* was ranked as the ninth most abundant species in continuous cereal fields in 1993 and 1994, compared with relative abundance rankings of 11th and 17th for *M. sativa*/cereal fields. Frequency of *G. aparine* was lower in *M. sativa*/cereal fields in both years (Tables 2 and 3), whereas in 1994, *G. aparine* density was significantly lower ( $P \leq 0.05$ ) in *M. sativa*/cereal fields than in continuous cereal fields.

TABLE 3. Density, frequency, uniformity, and relative abundance values for *Medicago sativa*/cereal fields (A.C. Fields) and continuous cereal fields (C.C. Fields) in 1994.<sup>a</sup>

Species common name	Relative abundance		Density		Level of significance Log scale	Frequency		Uniformity	
	C.C. Fields	A.C. Fields	C.C. Fields	A.C. Fields		C.C. Fields	A.C. Fields	C.C. Fields	A.C. Fields
	— plants m <sup>-2</sup> —					%			
Green foxtail	46.66	47.99	29.33	20.79	NS	90.00	80.00	58.50	53.47
Wild mustard	39.30	25.57	23.25	6.97	≤ 0.05	83.33	82.86	50.67	31.94
Wild buckwheat	35.84	33.11	15.47	8.91	NS	100.00	91.43	54.17	48.06
Wild oat	33.48	6.37	13.03	0.43	≤ 0.01	90.00	40.00	56.50	6.53
Common lambsquarters	23.32	29.53	8.10	8.75	NS	80.00	82.86	35.17	38.61
Annual smartweed spp.	20.75	13.68	8.83	2.58	≤ 0.10	63.33	54.29	29.50	18.06
Canada thistle	14.41	12.20	3.79	1.91	NS	63.33	62.86	19.67	12.78
Redroot pigweed	13.13	14.89	2.63	2.77	NS	63.33	54.29	18.17	22.22
Catchweed bedstraw	12.22	1.78	8.84	0.14	≤ 0.05	20.00	11.43	13.17	1.67
Perennial sowthistle	10.80	5.53	3.53	0.26	≤ 0.05	43.33	40.00	14.33	4.17
Field pennycress	10.15	25.32	3.51	9.91	≤ 0.05	46.67	60.00	10.33	26.25
Quackgrass	8.11	11.27	2.73	3.37	NS	33.33	37.14	10.17	12.50
Volunteer alfalfa	0.68	24.71	0.11	6.90	≤ 0.01	3.33	74.29	1.00	32.36
Dandelion	3.43	17.94	0.30	4.09	≤ 0.01	20.00	65.71	4.50	23.19
Shepherdspurse	2.07	5.69	0.71	1.34	NS	13.33	17.14	0.50	8.61

<sup>a</sup> Weed and crop species with (1) nonsignificant differences between field types or (2) population densities less than 1 m<sup>-2</sup> are not included in this table.

TABLE 4. Actual and long-term average monthly precipitation and temperature at Carman and Winnipeg in 1993.

Month		1993				1994			
		Carman		Winnipeg		Carman		Winnipeg	
		Precipitation	Temperature	Precipitation	Temperature	Precipitation	Temperature	Precipitation	Temperature
		mm	C	mm	C	mm	C	mm	C
May	Actual	70.0	11.5	43.9	12.5	39.1	12.9	150.7	12.6
	Normal	52.7	11.6	56.8	11.9	52.7	11.6	56.8	11.9
June	Actual	120.0	15.0	111.8	15.9	53.5	17.7	94.7	17.9
	Normal	72.8	17.1	94.9	16.6	72.8	17.1	94.9	16.6
July	Actual	152.8	17.1	307.6	18.6	48.0	18.0	96.7	18.1
	Normal	69.1	19.8	70.6	19.4	69.1	19.8	70.6	19.4
Aug	Actual	114.0	17.5	265.9	18.8	102.6	16.8	100.8	16.5
	Normal	65.5	18.4	60.5	18.1	65.5	18.4	60.5	18.1
Sept	Actual	28.8	10.6	39.9	10.9	54.8	14.8	73.2	14.5
	Normal	49.0	12.5	52.9	12.3	49.0	12.5	52.9	12.3

No significant differences in *C. album* density or frequency were observed between field types in either year, although this weed was more abundant in *M. sativa*/cereal fields in both 1993 and 1994 (Tables 2 and 3). *Chenopodium album* seed may remain viable in the soil for a prolonged period of time. Roberts and Feast (1973) found that it was one of the species with the highest number of viable seeds remaining in undisturbed soil after 6 yr. Therefore, it is not expected that the effects of *M. sativa* would greatly influence the numbers of viable *C. album* seed in the seed bank because of seed longevity.

Although *P. convolvulus* densities were consistently lower in *M. sativa*/cereal fields, density values were not significantly different from continuous cereal fields (Tables 2 and 3). *Polygonum convolvulus* was more abundant in *M. sativa*/cereal fields in 1993 but little difference was observed between field types in 1994. Eighty-three and 100% of continuous cereal fields contained *P. convolvulus* in 1993 and 1994, respectively, compared with 86 and 91% for *M. sativa*/cereal fields. Roberts and Feast (1973) found that the number of *P. convolvulus* seeds remaining in undisturbed soil after 6 yr was much lower than that of *C. album* (26 vs. 53%), suggesting that factors other than seed longevity were of greater importance in determining the effect of *M. sativa* on *P. convolvulus* populations.

*Amaranthus retroflexus* was not of major importance in 1993: density values were less than 1 plant m<sup>-2</sup>, and relative abundance and frequency values were extremely low for both field types (Table 2). Interestingly, all three population parameters for both continuous cereal and *M. sativa*/cereal fields increased for *A. retroflexus* in 1994, placing this weed into the 10 most abundant species category that year. This may be attributed to higher than normal temperatures in the spring and summer of 1994 (Table 4). As a C<sub>4</sub> plant, the germination and growth of *A. retroflexus* would be positively stimulated by elevated temperatures (Black 1973; Pearcy et al. 1981).

### Perennial Grasses and Dicots

The present study supports previous observations of the ability of *M. sativa* to suppress *C. arvensis* (Derscheid et al. 1961; Hodgson 1958; Stahler 1948). In 1993, *C. arvensis*

shoot density was significantly lower in *M. sativa*/cereal fields compared with continuous cereal fields ( $P \leq 0.01$ ), and a similar but nonsignificant trend was observed in 1994 (Tables 2 and 3). *Medicago sativa* in rotation was also found to reduce the relative abundance of *C. arvensis* relative to continuous cereal rotations. Frequency of occurrence for *C. arvensis* was lower for *M. sativa*/cereal fields in 1993 (54 vs. 7%), but no differences were observed in 1994 (Table 3). Higher frequency of *C. arvensis* in 1994 may be attributed to wet conditions the previous summer (Table 4), which may have stimulated *C. arvensis* seed germination and enhanced vegetative plant growth in the late summer (Moore 1975). *Medicago sativa* also suppressed *Sonchus arvensis* L. (perennial sowthistle) because density values were significantly lower in *M. sativa*/cereal fields than in continuous cereal fields in both years ( $P \leq 0.10$ ). The relative abundance and frequency of *S. arvensis* was higher in 1994 than 1993 for both field types, with the greatest increase observed in *M. sativa*/cereal fields (Tables 2 and 3). These observations may once again be related to greater than average amounts of precipitation in 1993 (Table 4).

*Medicago sativa* in rotation resulted in significant ( $P \leq 0.01$ ) increases in *T. officinale* density (4 vs. 1 plant m<sup>-2</sup>) and frequency relative to cereal following cereal rotations (Tables 2 and 3). Furthermore, *T. officinale* was the fifth and seventh most abundant weed in 1993 and 1994 in *M. sativa*/cereal fields, compared with 21st and 13th most abundant weed in 1994 in cereal following cereal rotations, respectively. *Taraxacum officinale* population demographics remained relatively stable over years. Therefore, although the *Cirsium* species considered in this study had higher densities and levels of occurrence after the wet season of 1993, *T. officinale* appears to have been unaffected.

Greater abundance of *T. officinale* after *M. sativa* may be due to its prostrate growth habit that may make it possible for the species to avoid defoliation during mechanical hay harvesting. The germination pattern of *T. officinale* may also be a factor. Because it does not exhibit a regular or marked periodicity of germination over a growing season (Chepil 1946), the potential for successful germination is constant throughout the year. Therefore, the opportunity exists for it to establish itself during the period after a hay cut when much of the soil surface is exposed or in the fall when *M.*

*sativa* is dormant. Champness (1949) concluded that *T. officinale* populations could not withstand the competition from *M. sativa* that was neither grazed nor cut for hay during the growing season. Legere (1993) observed greater *T. officinale* populations in a rotation containing *Trifolium repens* L. (red clover) and attributed the increase to a more stable environment created by the absence of tillage.

In addition, high *T. officinale* populations after *M. sativa* may be attributed to increased weed invasion due to declining *M. sativa* stand health. In the 1994 survey, 75% of producers indicated that deteriorating *M. sativa* vigor was the motivating factor for terminating the stand. Entz et al. (1995) reported that the strategy of most forage producers was to maximize forage stand life and rotate forages only when necessary because of weed invasion and declining hay yields. Therefore, the higher presence of *T. officinale* in *M. sativa*/cereal fields may be an artifact of poor stand health, suggesting that an intensive stand management regime, designed to optimize plant vigor and based on timely *M. sativa* stand termination, may result in lower *T. officinale* populations.

The population demographics of *E. repens* varied substantially from year to year. *Medicago sativa*/cereal fields contained fewer plants  $m^{-2}$  than continuous cereal fields in 1993 (Table 2). However, in 1994, density for both field types was similar (Table 3). In 1993, *E. repens* was ranked as the seventh and sixth most abundant weed in *M. sativa*/cereal fields and continuous cereal fields, respectively. Relative abundance decreased across both field types in 1994 to occupy the 11th and 12th position, indicating the presence of a year effect due to factors other than crop/weed interaction.

### Winter Annuals

Winter annual weed species germinate in the fall when *M. sativa* is dormant and resume growth early in the spring prior to the resumption of *M. sativa* growth. Hence, these weeds can become established in healthy *M. sativa* stands (Peters and Linscott 1988). Data on *T. arvense* populations support this conclusion (Tables 2 and 3). *Thlapsi arvense* densities in *M. sativa*/cereal fields in 1993 and 1994 were 3 and 10 plants  $m^{-2}$ , respectively, compared to 0.5 and 3.5 plants  $m^{-2}$  in continuous cereal fields; differences were significant in 1994 only. *Thlapsi arvense* abundance values were higher in *M. sativa*/cereal fields than in continuous cereal fields. In 1993, 46 and 42% of *M. sativa*/cereal fields and continuous cereal fields, respectively, contained *T. arvense*. In 1994, the difference between frequency values for the two field types was greater. Roberts and Feast (1973) observed a strong tillage response for *T. arvense*, and Chepil (1946) and Roberts and Feast (1973) reported that, in addition to early seasonal emergence in the spring that continued to the end of the growing season, its seeds remained viable for an extended period of time, allowing germination to take place in substantial numbers over a period of 4 to 6 yr. These characteristics would favor its survival in *M. sativa* rather than in an annual crop where spring and fall tillage or herbicides would reduce populations that had germinated the previous summer and fall. Data trends similar to those obtained for *T. arvense* were evident for *Capsella bursa-pastoris* (L.) Medikus (shepherdspurse) in 1994, although population values were smaller (Table 3).

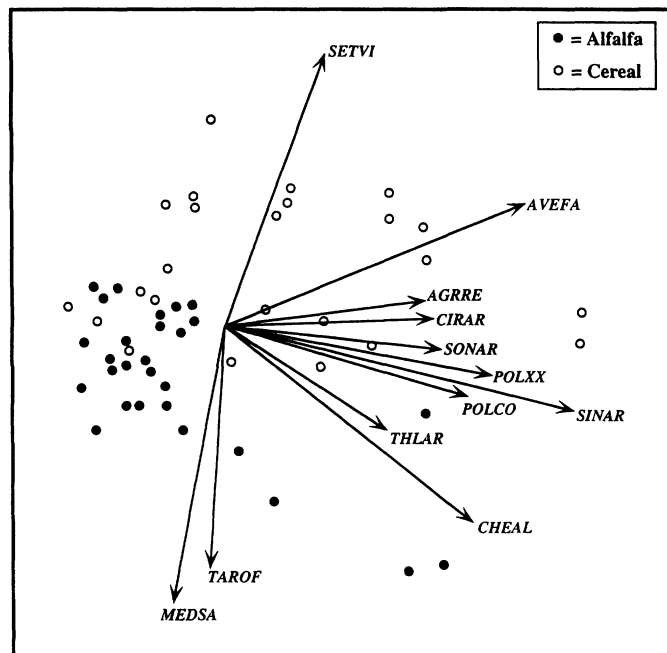


FIGURE 1. Principal component analysis ordination diagram of *M. sativa*/cereal and continuous cereal field clusters and biplot scaling of associated weed species vectors for 1993. Vector label codes are given in Table 1.

### Field Uniformity—A Measure of Weed Patchiness

Uniformity measurements provide an indication of weed patchiness. Results of the present study indicate that *A. fatua*, *C. arvense*, *S. arvensis*, and *G. aparine* were much less uniform (i.e., more patchy) in fields following *M. sativa* compared with annual rotations, and uniformity of *T. officinale*, *T. arvense*, and volunteer *M. sativa* was greater in *M. sativa*/cereal fields (Tables 2 and 3). Therefore, *M. sativa* in a cropping system may facilitate patch-based control measures (such as spot-spraying) for certain weeds (e.g., *A. fatua*), while reducing this option for other weeds (e.g., *T. officinale*). Greater patchiness for some weeds after *M. sativa* may provide clues to the mechanisms of weed suppression with *M. sativa*. For example, greater patchiness of *A. fatua* after *M. sativa* suggests that the crop may have reduced movement out of an original patch or resulted in a decreased *A. fatua* seed bank in areas outside the dense “mother” patches.

### Weed Species and Field Type Associations

Results from PCA clearly revealed that each field type contained a unique weed community, thereby confirming the effect of crop rotation on weed community dynamics. Differences in weed community composition between field types are illustrated in the ordination biplots generated by PCA (Figures 1 and 2). Continuous cereal fields form a cluster in the upper right portion of the biplots, while *M. sativa*/cereal fields tend to cluster in the bottom left portion of the biplots. The region of overlap, which occurs approximately at the midpoint of an arbitrary diagonal, indicates that these fields possess similar weed species. The significant differences ( $P \leq 0.01$ ) obtained between field type density values for both study years in the results from the Hotelling  $T^2$  test ( $F_{2,49} = 30.81$  in 1993 and  $F_{2,62} = 44.85$  in 1994)

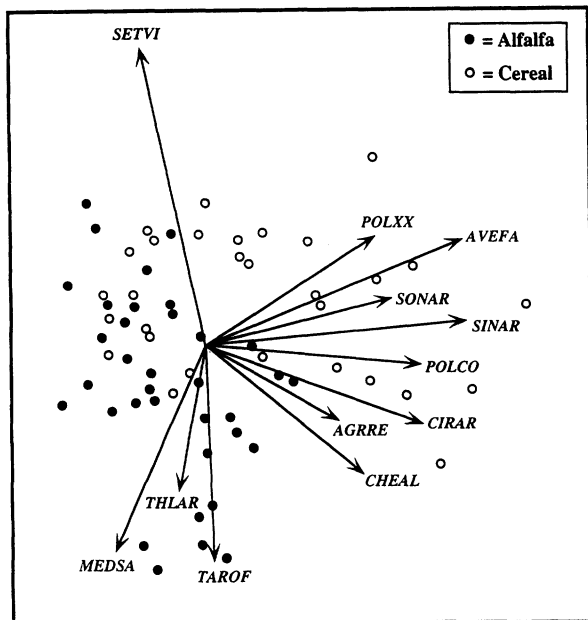


FIGURE 2. Principal component analysis ordination diagram of *M. sativa* cereal and continuous cereal field clusters and biplot scaling of associated weed species vectors for 1994. Vector label codes are given in Table 1.

support the conclusions drawn from the ordination biplots. The total variation accounted for by the first two component axes was 42 and 37% in 1993 and 1994, respectively.

The majority of weed species vectors move in a direction from the origin to the continuous cereal cluster, signifying the greater presence or abundance of these weeds in this field type. In both 1993 and 1994, *Polygonum* spp., *A. fatua*, *S. arvensis*, and *B. kabera* were strongly associated with continuous cereal fields. *Setaria viridis*, for which results were inconclusive in the univariate analysis, strongly influenced community composition, as can be seen from the length of its vector. In 1993, *S. viridis* was distinctly associated with continuous cereal fields. In 1994 however, it was not strongly associated with either field type, as its vector was moving in the direction of the overlapping fields. A similar trend was exhibited for *C. album*. *Cirsium arvense* and *E. repens* were more strongly associated with continuous cereal fields in 1993 than in 1994, as the vectors in the 1994 biplot shifted to occupy positions midway between the two field type clusters. As was indicated in the univariate analysis, *T. officinale*, *T. arvense*, and volunteer *M. sativa* were clearly associated with *M. sativa*/cereal fields, particularly in 1994.

Although the spectrum of weed species found in the two field types was similar, it is clear that *M. sativa* had a strong effect on weed species composition and abundance. From data obtained in this study, it is possible to categorize weed species into four groups: (1) *A. fatua*, *B. kabera*, *C. arvense*, *S. arvensis*, and *G. aparine*, whose populations were lower in *M. sativa*/cereal fields, indicating greater suppression by *M. sativa* than by annual crop production practices; (2) *P. convolvulus*, *A. retroflexus*, and *C. album*, whose populations were similar for both field types; (3) *T. officinale* and *T. arvense*, whose populations increased in *M. sativa* because of conditions more conducive to growth than in a cereal rotation; (4) *S. viridis*, for which the data are inconclusive due to large year to year variations.

These results have several implications for weed manage-

ment. First, inclusion of *M. sativa* in a rotation is an effective alternative to chemical weed control for certain weeds. In particular, *M. sativa* hay production can be used as a tool to manage herbicide-resistant weeds such as *A. fatua*. Second, for those weed species where no differences between field types were observed, inclusion of *M. sativa* in rotation can deliver the same degree of suppression as herbicides in an annual production system. Third, the rise in *T. officinale* and *T. arvense* populations in *M. sativa*/cereal fields is a concern that needs to be addressed. Finally, the effects of *M. sativa* on weed patchiness in following crops may in some cases facilitate patch-based management strategies.

From a weed ecology perspective, the results obtained in this study and by others (Derksen et al. 1993) emphasize the need to study weed population dynamics on an individual species basis. It is clear that classification of weed species into commonly accepted categories of annual, biennial, and perennial life histories is not always sufficient to predict the effect of crop rotation on weed populations. Information addressing how *M. sativa* affects seedling recruitment, growth, and subsequent seed set for individual weed species is needed.

From an agronomic perspective, the study illustrates the need to better understand how alfalfa stand management influences weed populations. Factors such as stand age and fertility and cutting regime are important in determining stand health, which in turn directly affects the ability of *M. sativa* to compete with weeds. *Medicago sativa* stand termination method (i.e., disturbed vs. nondisturbed) is another factor that will affect weed populations in succeeding crops.

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