Tillage Effects on Weed Seed Return and Seedbank Composition
Author(s): David R. Clements, Diane L. Benott, Stephen D. Murphy and Clarence J. Swanton
Source: *Weed Science*, Vol. 44, No. 2 (Apr. - Jun., 1996), pp. 314-322
Published by: Weed Science Society of America and Allen Press
Stable URL: http://www.jstor.org/stable/4045684
Accessed: 24-12-2016 23:11 UTC

REFERENCES
Linked references are available on JSTOR for this article:
http://www.jstor.org/stable/4045684?seq=1&cid=pdf-reference#references_tab_contents
You may need to log in to JSTOR to access the linked references.

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at
http://about.jstor.org/terms

Allen Press, Weed Science Society of America are collaborating with JSTOR to digitize, preserve and extend access to *Weed Science*

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms

Weed Science, 1996. Volume 44:314–322

Tillage Effects on Weed Seed Return and Seedbank Composition[1]

DAVID R. CLEMENTS, DIANE L. BENOIT, STEPHEN D. MURPHY, and CLARENCE J. SWANTON[2]

Abstract. **Weed seed return and seedbank composition, with particular reference to common lambsquarters, were studied in four tillage systems established on a site near Fingal, Ontario. The tillage treatments were moldboard plow, chisel plow, ridge-till, and no-till. The cropping system was a corn-soybean rotation. Tillage effects on weed population composition were assessed after all weed control measures had been implemented. More than 60% of the weed seedbank was concentrated in the upper 5 cm of soil in chisel plow and no-till. The seedbank of the moldboard plow system was more uniformly distributed over depth and larger than the other systems. Common lambsquarters comprised more than 50% of the seedbank in all systems except ridge-till, but only dominated the aboveground weed population in chisel plow. Seedbank populations of common lambsquarters with moldboard plowing were greater than those with ridge-till and no-till, and chisel plow seedbank populations were greater than those in ridge-till. Chisel and moldboard plow systems generally had higher aboveground plant populations of common lambsquarters than the other two systems. Seed production per plant by common lambsquarters was equivalent among the four systems, but estimated seed production per unit area was higher in moldboard plow and chisel plow systems than in the other systems. Populations of common lambsquarters and similar species may produce more seeds and persist in moldboard plow and chisel plow systems; these weeds may produce fewer seeds per unit area and be easier to manage in no-till and ridge-till systems. Nomenclature: Common lambsquarters, *Chenopodium album* L. #[3] CHEAL; corn, *Zea mays* L.; soybean, *Glycine max* (L.) Merr.**
Additional index words: **Conservation tillage, no-till, ridge-till, seedbank profile, weed spectrum, CHEAL.**

INTRODUCTION

Available evidence demonstrates that adoption of conservation tillage systems results in altered weed species composition and abundance (5, 9, 17, 21, 28, 30). Because adoption of conservation tillage represents a reduction in agroecosystem disturbance, these changes in weed communities represent a form of ecological succession (28). It has been estimated that yield, weed populations, and soil characteristics do not reach equilibrium until the management regime has been established for 4 to 10 yr (10, 18). Therefore, studies are needed to assess the effects of management on weed populations.

To understand and manage these successional changes more effectively, there is a need for data on processes such as how weed dispersal changes during long time periods, the population ecology of aboveground weeds, and how the resultant weed seedbanks will be affected (28). In conventional tillage, many weed species rely on a single regenerative strategy consisting of germination from a large, persistent soil seedbank. Part of the reason the seedbank is persistent is that most seeds are buried by moldboard plowing (1, 5, 8, 36). For many species, buried seeds remain viable and will germinate in subsequent years when returned to a suitable depth by tillage. In contrast, seeds remain on or near the soil surface in undisturbed soils, i.e., with conservation tillage (1, 5, 24, 27, 36). Adequate aboveground weed control may cause seeds present in the upper layer of soil to diminish within a few years (19). Thus, species that rely on regeneration from seedbanks and historically have been problematic in conventional tillage systems may become less of a problem in conservation tillage systems (7). Despite its potential importance in determining relative weed pressures among different tillage regimes, relatively few studies have accounted for vertical distribution of weed seeds in the soil (24).

Common lambsquarters relies on regeneration from seedbanks and often flourishes in conventional tillage systems. Seed production may range from 30 000 to 176 000 seeds per plant for common lambsquarters if shielded from herbicide applications in soybean (12). Common lambsquarters seeds buried for 20 yr still had 23% viability (22), and buried common lambsquarters seeds have survived 39 yr (31). Worldwide, common lambsquarters has been among the most important weeds in many crops, and was ranked seventh in abundance in corn (20). In soybean, 2 common lambsquarters m^{-1} of row for 5 wk of interference after crop emergence caused a 5% yield loss (12). A recent survey of corn, soybean, and winter wheat (*Triticum aestivum* L.) fields in Ontario listed common lambsquarters as the second most abundant weed (16). Derksen et al. (9) found that common lambsquarters was more common in conventional tillage systems than in minimum or no-till systems in western Canada; in Ontario, common lambsquarters mainly was associated with minimum tillage (30).

Although common lambsquarters generally can be controlled with herbicides, its persistent seedbank may cause management difficulties if it escapes treatments or develops resistance (2, 12). Weed seedbanks are an indicator, i.e., they represent the cumulative effects of many years of management but allow sampling within a single year. We were interested in observing changes in the populations of weed escapes from actual management regimes, rather than trying to extrapolate results from uncontrolled

[1]Received for publication June 9, 1994, and in revised form August 27, 1995.
[2]Asst. Prof., Dep. Biology, Trinity Western University, Langley, BC, Canada, V2Y 1Y1, Weed Sci., Agric. Canada Res. Stn., Saint-Jean-sur-Richelieu, QUE, Canada J3B 3E6; Res. Assoc., and Assoc. Prof., Dep. Crop Sci., Univ. Guelph, Guelph, ON, Canada N1G 2W1.
[3]Letters following this symbol are a WSSA approved computer code from Composite List of Weeds, Revised 1989. Available from WSSA, 1508 West University Ave., Champaign, IL, 61821-3133.

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms

Table 1. Herbicide use during the study period. Herbicides were applied at rates recommended for Ontario in no-till and ridge-till systems. See text for additional year- and plot-specific herbicide treatments.

Year	Crop	Herbicide applied[a]	Application method
1986	Soybean	Metolachlor/metribuzin	PRE
1987	Corn	Metolachlor/bentazon + atrazine	POST
1988	Soybean	Metolachlor/metribuzin	PRE
1989	Corn	Metolachlor + atrazine	PRE
1990	Corn	Metolachlor/2,4-D/dicamba + atrazine	PRE/PRE/POST
1991	Soybean	Glyphosate/2,4-D/imazethapyr	PRE/PRE/POST
1992	Corn	Metolachlor/2,4-D	PRE/POST
1993	Soybean	Imazethapyr	POST

[a]Metolachlor: 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide; metribuzin: 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one; bentazon: 3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide; atrazine: 6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine; 2,4-D: (2,4-dichlorophenoxy)acetic acid; dicamba, 3,6-dichloro-2-methoxybenzoic acid; glyphosate: *N*-(phosphonomethyl)glycine; imazethapyr: 2-[4,5-dihydro-4-methyl-(1-methylethyl)-5-oxo-1*H*-imidazol-2-y]-3-pyridinecarboxylic acid.

weeds (32). To accomplish this, we used on-farm studies. Advantages of on-farm research include a relatively large sampling area and the ability to monitor long-term effects of actual farmer practices; this is important in conservation tillage because of the 4–10 yr required for the system to attain equilibrium (10, 18). Effectively, long-term on-farm studies such as ours allow replication over time. The disadvantages include a lack of spatial replication within and across sites.

The objective of this study was to compare weed seed return, seedbank composition, and vertical distribution of weed seeds in the soil among four tillage systems established for eight seasons: moldboard plow, chisel plow, ridge-till, and no-till. We were able to examine common lambsquarters in more detail because it was the most prevalent weed in the seedbanks of most fields studied. To examine the effect of tillage on potential weed seed return, we analyzed the effect of tillage, in corn and soybean fields, on reproductive allocation for different size classes of common lambsquarters.

MATERIALS AND METHODS

Study sites and agronomic practices. A long-term tillage study was initiated on a private farm in 1985 near Fingal in southwestern Ontario, Canada. The field was a Beverley silt loam soil with 36% sand, 45% silt, and 19% clay. The soil organic matter content was 3.2% and pH was 7.3. The field was divided into four plots each 23 m wide and 200 m long. Each plot was managed with one of four different tillage systems: 1) conventional tillage with an autumn moldboard plow and a spring discing, 2) conservation tillage using an autumn chisel plow and a spring discing, 3) ridge tillage using a 'Buffalo ridge cultivator' in the spring and in mid-July for ridge rebuilding and 4) a no-till system where a modified 'John Deere 7000'[4] no-till drill seeder was used. The same seeder was used in all tillage systems, with adjustments made to accommodate seeding requirements of each tillage system. Mean percent residue cover (± SE) during the study period was 5.2% (±3.6%) for conventional tillage, 33.0% (±19.2%) for chisel plow, 45.9% (±17.6%) for ridge-till, and 68.6% (±15.4%) for no-till.

The cropping system was a corn-soybean rotation, except for 1989 to 1991 where corn followed corn. Corn was seeded at 68,000 seeds ha^{-1} in 75 cm wide rows in 1987, 1989, 1990, and 1992. The hybrids used were Pioneer 3737 (1987), Northrup King 3624 (1989 and 1990), and Pioneer 3751 (1992). Soybean was seeded at 375,000 seeds ha^{-1} in 1986, 1988, 1991, and 1993. The cultivars used were Elgin (1986 and 1988), Pioneer 9161 (1991), and Northrup King S20-20 (1993). Agronomic practices and herbicide treatments were consistent with those recommended for field crops in Ontario. Therefore, all assessments of weed populations were for weeds that escaped control treatments. Herbicide use across all tillage systems during the eight years of our study is presented in Table 1. In addition, the co-operators also used 2,4-D (2,4-(dichlorophenoxy)acetic acid) and glyphosate [*N*-(phosphonomethyl)glycine] in some cases. In 1986, 1987, 1992, and 1993 the no-till plot was sprayed with glyphosate as a burn-down treatment, 2 wk before planting. In 1988 and 1993, glyphosate was applied in the ridge-till plot. In 1988, 2,4-D was applied in the no-till plot. In 1990, 1991, and 1992, 2,4-D was applied postemergence on all plots except chisel plow. Average machine-harvested yields during the trial in the moldboard plow strip were 9500 and 2900 kg ha^{-1} for corn and soybean, respectively. Yields in the other systems were within 10% of the moldboard plow yields, but were higher in the case of ridge-till soybean.

Seedbank analysis. Soil samples were taken on May 10, 1992, after seedbed preparation but prior to seeding and herbicide application. One hundred fifteen cm- by 1.9-cm cores were sampled from each of the four tillage strips. The cores were collected every 4 m along each of the two middle crop rows. Half of the ridge-till samples was from the ridge; the other half was sampled within the furrow. We used a corer fitted with an acetate sleeve to divide the sample into 0–5, 5–10, and 10–15 cm segments (1, 5). Each segment was placed separately in 3-cm deep containers lined with peat. The containers were placed in a growth room (T = 25 C; photoperiod = 16:8 light:dark) on June 1 1992, and watered daily (5). Seedling emergence was monitored over a period of 6 mo and the soil was stirred once per

[4]John Deere Co., Moline IL.

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms

Table 2. Occurrence of weeds in the seedbank and aboveground among the four tillage systems in 1992 and 1993.

Code	Scientific name	Common name	Tillage systems[a] MP	CP	RT	NT
CHEAL	*Chenopodium album* L.	Common lambsquarters	S–A[b]	S–A	S–A	S–A
ABUTH	*Abuthilon theophrasti* Medic.	Velvetleaf	S–A	S–A	—	A
PLAMA	*Plantago major* L.	Broadleaf plantain	S–A	S–A	S	S–A
AMBEL	*Ambrosia artemisiifolia* L.	Common ragweed	S–A	S–A	S–A	A
SETVI	*Setaria viridis* (L.) Beauv.	Green foxtail	S	A	S	S–A
SENVU	*Senecio vulgaris* L.	Common groundsel	—	S	S	—
PHYHE	*Physalis heterophylla* Nees	Clammy ground cherry	—	S	S	A
TAROF	*Taraxaxum officinale* Weber in Wiggers	Dandelion	A	S–A	A	A
CERVU	*Cerastium vulgatum* L.	Mouseear chickweed	—	—	S–A	—
SOOCA	*Solidago canadensis* L.	Canada goldenrod	—	—	S	—
FRAVI	*Fragaria virginiana* Mill./Duch.	Wild strawberry	—	—	—	S
ECHCG	*Echinochloa crus-galli* (L.) Beauv.	Barnyardgrass	A	—	—	S
AGRRE	*Elytrigia repens* (L.) Nevski	Quackgrass	A	A	A	A
ASCSY	*Asclepias syriaca* L.	Common milkweed	A	—	A	A
CYPES	*Cyperus esculentus* L.	Yellow nutsedge	A	A	A	—
POLPE	*Polygonum persicaria* L.	Ladysthumb	A	—	A	A
SINAR	*Sinapsis arvensis* L.	Wild mustard	A	—	A	—
AMARE	*Amaranthus retroflexus* L.	Redroot pigweed	—	A	—	—
PANDI	*Panicum dichotomiflorum* Michx.	Fall panicum	—	A	—	—
PTLRC	*Potentilla recta* L.	Sulfur cinquefoil	—	A	—	—
CIRAR	*Cirsium arvense* (L.) Scop.	Canada thistle	—	A	—	A
ERIAN	*Erigeron annuus* (L.) Pers.	Annual fleabane	—	—	A	—
OXAST	*Oxalis stricta* L.	Yellow woodsorrel	—	—	A	—
RUBID	*Rubus idaeus* L.	European red raspberry	—	—	A	A
MEDLU	*Medicago lupulina* L.	Black medic	—	—	A	A
DAUCA	*Daucus carota* L.	Wild carrot	—	—	A	A
DIGIS	*Digitaria ischaenum* (Schreib. ex. Schweig.) Shreb. ex Muhl.	Smooth crabgrass	—	—	—	A
SETLU	*Setaria glauca* (L.) Beauv.	Yellow foxtail	—	—	—	A
DACGL	*Dactylis glomerata* L.	Orchardgrass	—	—	—	A
PRTQU	*Parthenocissus quinquefolia* (L.) Planch.	Virginia creeper	—	—	—	A
SONOL	*Sonchus oleraceus* L.	Annual sowthistle	—	—	—	A

[a]MP = moldboard plow, CP = chisel plow, RT = ridge-till, NT = no-till.

[b]Presence/absence where S = seedbank, A = aboveground, S–A = present in both the seedbank and aboveground.

month (3). This was followed by a period of 3 mo at –4 C in darkness (beginning 1 October), and 3 additional mo of monitoring germination in the growth room (3). Seedlings were identified by species.

Weed counts and sampling. Weed density was evaluated on September 9, 1992, and September 10, 1993, using 0.75 by 0.3 m quadrats placed every 4 m. Weeds were counted in 100 quadrats in each tillage system. On October 7, 1992, and September 30, 1993, common lambsquarters was harvested to determine seed production. At this date, common lambsquarters development was at a stage where few seeds had shattered. The harvested plants were divided into two size classes: less than and greater than 30 cm tall. For each tillage treatment, 10 plants from each size class were randomly selected. Because of the relatively low density of common lambsquarters in some tillage systems, it would have been impossible to locate many more than 10 plants within a given size class, and thus it was felt that the sample was representative of the population. Plant height was measured at harvest. All harvested plants were air dried at 80 C for 3 d.

Following drying, common lambsquarters was separated into inflorescence and vegetative components and weighed. Reproductive allocation was calculated as the dry weight of the inflorescence divided by the sum of inflorescence and vegetative dry weight. For plants over 30 cm tall, the number of seeds produced was estimated by dividing the total seed weight by the weight of a 100 seed subsample weighed for each plant.

Analysis. Analyses of variance (ANOVAs) were used to test the effect of tillage practice used on the above-ground weed populations, seedbanks, vertical distribution of seeds in the soil and the reproductive effort and seed production in lambsquarters. Means were separated by $LSD_{(0.05)}$. Weed density data were log-transformed to adjust for heterogeneity of variance. Vertical distribution of seeds was expressed as a proportion of the total seed bank.

RESULTS AND DISCUSSION

Weed spectrum. Over the four tillage systems, three weed species appeared only in soil samples, 19 were observed exclusively in the aboveground sampling and 12 appeared in both samples (Table 2). All of the species observed only in aboveground samples were relatively uncommon at our site; hence, it

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms

is not surprising that these species did not appear in the soil samples.

In 1992, the moldboard plow system had the lowest number of weed species, with 8 aboveground and 5 in the seedbank; however, in 1993 there were 11 species identified aboveground in moldboard plowed fields. In no-till, 16 were recorded aboveground in 1992 and 10 in 1993. In a separate study set up on part of the same site (different herbicide treatments), Benoit et al. (3) recorded the lowest number of species in the moldboard plow system (five species aboveground and in the soil), and recorded that the highest number of species [19] occurred aboveground in the no-till system. The trend toward greater species diversity with conservation tillage is supported by ecological theory that predicts greater species diversity at intermediate levels of disturbance (7, 28).

Species identified in the moldboard plow system were found in all systems [e.g., common lambsquarters, common ragweed (*Ambrosia aretemisiifolia* L.), and quackgrass (*Elytrigia repens* (L.) Nevski)], whereas other species were restricted to one or two of the conservation tillage systems (Table 2). Dandelion (*Taraxacum officinale* Weber in Wiggers) was found in all systems and was most abundant in the least disturbed systems, ridge-till and no-till. Six species were unique to no-till, three were unique to ridge-till, and three were found only in chisel plow (Table 2). The aboveground densities of these unique species never exceeded 0.5 plants m^{-2}.

Vertical distribution of seeds. The vertical distribution of seeds in the soil varied among tillage systems (Figure 1). The top 5 cm of soil contained 37 and 33% of the seedbank in moldboard and ridge-till systems, respectively; in no-till and chisel plow systems, the top 5 cm contained most of the seeds (74 and 61%, respectively). In ridge-till systems, the highest concentration of seeds (45%) was in the 5- to 10-cm layer. The 5 to 10 cm layer contained the highest concentration of seeds on both the ridge and in the furrow. The top 5 cm contained 33% of the seedbank on the ridge; 27% of the seedbank was in the furrow.

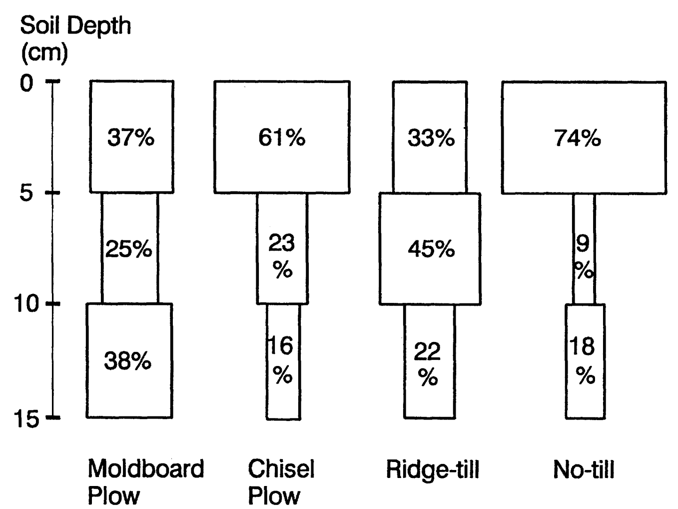

Figure 1. Effect of tillage methods on the vertical distribution of total weed seed after six growing seasons in a corn-soybean rotation. LSD (0.05) for chisel plow = 20%, no-till = 25%, moldboard plow and ridge-till were non-significant.

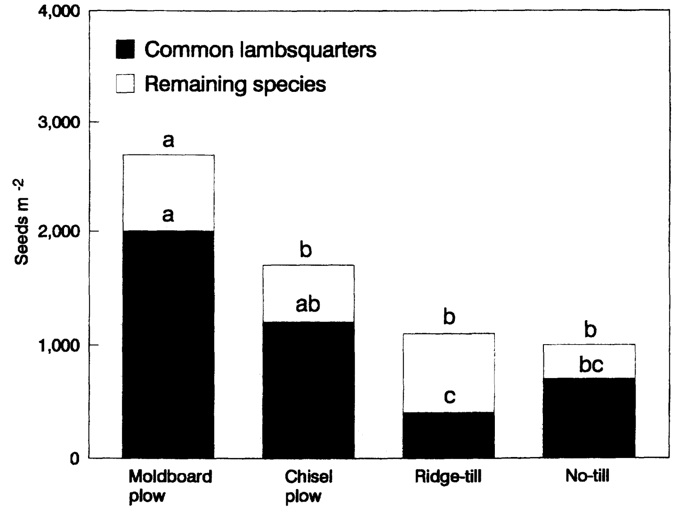

Figure 2. Seedbank populations in the four tillage systems in 1992, for total weeds and common lambsquarters. Bars with the same letter are not different according to the LSD test; letters refer to the bar immediately below them (i.e., upper letter refers to total weeds, lower letter refers to common lambsquarters).

Differences in the vertical distribution of seeds between moldboard plow tillage and chisel or no-till systems is consistent with other reports (1, 5, 36). Published information on the vertical distribution of seeds in ridge-till is limited (15), and further studies are needed to explain the patterns observed. The patterns may relate to "scalping" of the top layer of soil on the ridges by the ridge-till cultivator.

Weed seedbanks. Moldboard plowed fields had the largest seedbank, 2667 seeds m^{-2} in the top 15 cm; this was greater ($P > 0.05$) than the seedbanks of the other three tillage systems (Figure 2). The seedbank population in the top 10 cm in the moldboard plow seedbank population was approximately 1500 m^{-2}. In comparison, Forcella and Lindstrom (15) detected 200 to 700 seeds m^{-2} in the top 10 cm of soil in ridge-tilled or moldboard plowed fields. Their study is comparable to ours in that a corn-soybean rotation was used and the fields were sampled 7 to 8 years after establishment of different tillage practices. We detected more seeds in moldboard plowed fields and this may reflect a greater infestation of weeds with long-lived seeds.

For ridge-till fields, we detected 800 weed seeds m^{-2}; this is above the range (200 to 700 seeds m^{-2}) detected by Forcella and Lindstrom (15) in their ridge-till fields. They suggested that layby cultivation, used to build-up ridges in mid-season, can stimulate germination of weeds; if not controlled, more weeds may set seed in ridge-till than conventional tillage systems in continuous corn. In our study, the significant difference in seedbank populations between moldboard plowed and ridge-tilled fields may suggest that the weeds were controlled and this reduced weed seed return. Additionally, it may indicate that the layby cultivation in our study occurred after the peak weed

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms

germination period. As a consequence, weed seeds or seedlings may become desiccated.

Timing of cultivation also affected weed germination and seedling survivorship in other conservation tillage systems (4, 11). Desiccation of weed seeds or other factors such as increased seed predation on the numerous seeds that are close to the surface in chisel plow and no-till fields may explain reduced weed seed return and smaller seedbanks.

Above-ground weed populations. Above-ground weed populations were ranked differently than the seedbank populations. In 1992, no-till and chisel plow systems had higher weed densities than the other two systems (Figure 3). In 1993, this ranking changed, in order of decreasing weed density, to no-till, moldboard plow and ridge-till, and chisel plow (Figure 4). The difference in ranking by tillage practice between the above-ground populations and seedbanks can be attributed to the increased density of perennial weeds, (e.g., quackgrass) in no-till systems. These weeds may be better adapted to less-disturbed environments and tend to reproduce asexually rather than producing seeds that will be returned and detected in the seed bank. Additionally, there were relatively large dandelion populations (0.9 to 12.3 m^{-2}) present in no-till and ridge-till systems that inflated total weed density, particularly in 1993. The agamospermous dandelion tends to produce seeds that withstand desiccation in no-till and ridge-till fields but the seeds do not persist long in seedbanks (35).

There was a shift in weed density in 1993. Weed density in moldboard plowed and ridge-tilled fields increased dramatically (Figures 3 and 4). Some of this was related to increased infestations of lambsquarters (moldboard plow) and dandelion (ridge till) but density of all other species also increased (Figures 3 and 4). It is possible that this increase was related to weather conditions that were more conducive to weed germination and growth in 1993, i.e., it was much warmer in 1993. This is supported by the increased weed densities that occurred in no-till; however, weed density decreased in chisel plowed systems. It is also possible that there were herbicide failures in all but the chisel plow systems in 1993 but it seems unlikely that this would occur consistently across all fields. The most likely factor was the change from corn in 1992 to soybeans in 1993. Soybeans have a smaller canopy and are less effective competitors for light. As a consequence, more weed seedlings reached maturity and weed density increased.

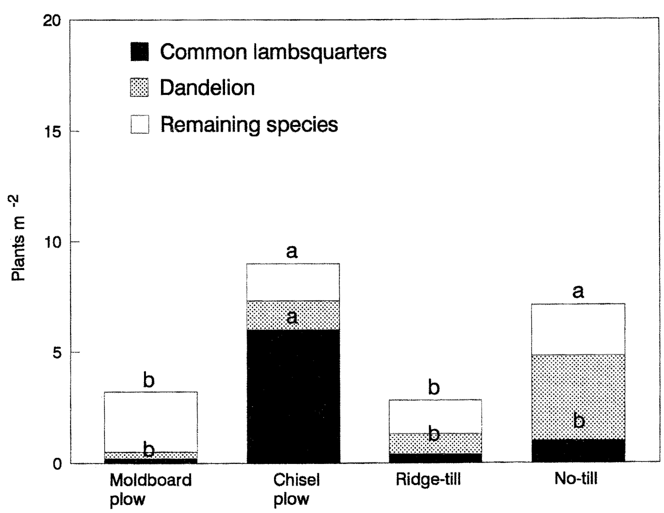

Figure 3. Aboveground populations in the four tillage systems in 1992, for total weeds, dandelion, and common lambsquarters. Bars with the same letter are not different according to the LSD test; letters refer to the bar immediately below them (i.e., upper letter refers to total weeds, lower letter refers to common lambsquarters).

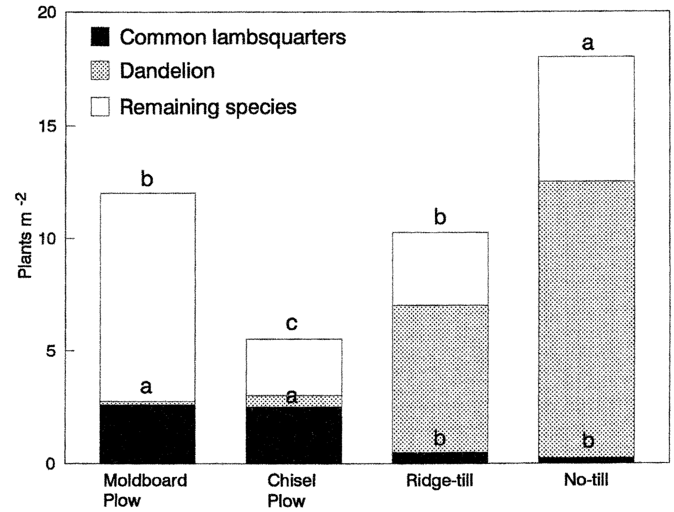

Figure 4. Aboveground populations in the four tillage systems in 1993, for total weeds, dandelion, and common lambsquarters. Bars with the same letter are not different according to the LSD test; letters refer to the bar immediately below them (i.e., upper letter refers to total weeds, lower letter refers to common lambsquarters).

Common lambsquarters populations. Common lambsquarters was the dominant weed in the seedbank for chisel plow (69% of total seeds), no-till (74%), and moldboard plow (76%) systems; in ridge-till, lambsquarters comprised 35% of the seedbank (Figure 2). In 1992, the number of common lambsquarters seeds in the seedbank did not differ between moldboard and chisel plow systems, chisel plow and no-till systems or ridge-till and no-till systems (Figure 2). There were more lambsquarters' seeds in moldboard plow than in ridge-till and no-till systems and chisel plow vs. ridge-till systems (Figure 2).

Common lambsquarters densities did not exceed 1.1 m^{-2} in no-till and ridge-till, whereas densities ranged as high as 5.6 m^{-2} in the chisel plow system (Figures 3 and 4). In the chisel plow system, common lambsquarters formed 67 and 46% of the aboveground weed density in 1992 and 1993, respectively. By contrast, common lambsquarters was less than 50% of weed density in the other three systems. Over 1992-1993, common lambsquarters comprised less than 22, 15, and 16% of the aboveground weed populations observed in moldboard plow, no-till, and ridge-till systems, respectively. Common lambsquarters plants were most abundant in the chisel plow system in 1992

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms

Table 3. Reproductive allocation and seed production per plant by height classes of common lambsquarters collected in corn on 7 October 1992[a].

Tillage system	Vegetative biomass	Inflorescence weight	Reproductive allocation[b]	Total seed weight	Weight per seed	Seed number
	mg			mg		
Below 30 cm size class						
Moldboard plow	234 a	72 a	0.35 ab	12 a	0.8 a	17 a
Chisel plow	96 a	43 a	0.26 b	9 a	0.4 c	18 a
Ridge-till	114 a	85 a	0.40 a	32 a	0.5 bc	52 a
No-till	106 a	62 a	0.38 a	18 a	0.7 ab	28 a
Above 30 cm size class						
Moldboard plow	472 b	272 b	0.35 ab	130 b	0.7 ab	205 b
Chisel plow	487 b	289 b	0.35 ab	147 b	0.7 a	234 b
Ridge-till	1090 ab	383 b	0.36 a	148 b	0.6 ab	234 b
No-till	1510 a	921 a	0.26 b	386 a	0.5 b	828 a

[a]Means within a column in a size class followed by the same letter are not significantly at the 0.05 level as determined by LSD (0.05).

[b]Reproductive allocation = inflorescence weight/(inflorescence weight + vegetative biomass).

(Figure 3) and in both the chisel plow and moldboard plow systems in 1993 (Figure 4).

In their study on the same site from 1986 to 1989, Benoit et al. (3) observed that common lambsquarters comprised 47 to 81% of the seedbank, where the highest percentages were in the no-till and chisel plow systems. If herbicide inputs were reduced, or if control by preemergence herbicides was ineffective, common lambsquarters was among the most commonly observed weeds (3). Regardless of the method, control of common lambsquarters was most difficult in the chisel plow system (3). Among the fields surveyed by Frick and Thomas (16) (about 200 for each system), common lambsquarters density averaged 1.4, 3.7, and 3.3 m^{-2} for conventional, chisel plow, and no-till fields, respectively.

Reproductive allocation of common lambsquarters. In general, tillage system did not affect reproductive allocation of common lambsquarters (Tables 3 and 4). Similarly there was little effect of tillage on seed production per plant. One exception was higher seed production in no-till relative to other systems for common lambsquarters taller than 30 cm in 1992 (Table 3). Common lambsquarters taller than 30 cm had greater vegetative biomass than common lambsquarters in moldboard plow and chisel plow in 1992, and had greater inflorescence weight, total seed weight, and seed number per plant than common lambsquarters in the other three systems (Table 3). Reproductive allocation of the > 30 cm plants in 1992 was relatively low in the no-till system, and was less than that for the ridge-till system. Weight per seed was not correlated with plant size although in 1992 plants 30 cm in the no-till plot had relatively low-weight seeds. In 1993, the only parameter that varied with tillage system was weight per seed, but there were no consistent trends in seed weight across years (Tables 3 and 4).

Because a single weed may produce large numbers of seeds (26), we examined the contribution to seed production by the few, larger plants in 1992 (0.007 m^{-2} in ridge-till and moldboard plow systems, 0.022 m^{-2} in the chisel plow system and 0.033 m^{-2} in no-till). Estimated seed production by common lambsquarters in no-till was 58 m^{-2}, with nearly half of this coming from plants in the larger size class (Table 5). In other systems, particularly chisel plow, the smaller plants contributed most of the seed

Table 4. Reproductive allocation and seed production by height classes of common lambsquarters collected in soybeans on 30 September 1993[a].

Tillage system	Vegetative biomass	Inflorescence weight	Reproductive allocation[b]	Total seed weight	Weight per seed	Seed number
	mg			mg		
Below 30 cm size class						
Moldboard plow	324 a	188 a	0.32 a	60 a	0.6 a	104 a
Chisel plow	311 a	104 a	0.26 a	10 a	0.4 b	33 a
Ridge-till	401 a	273 a	0.34 a	110 a	0.5 a	212 a
No-till	286 a	125 a	0.33 a	28 a	0.6 a	46 a
Above 30 cm size class						
Moldboard plow	4856 ab	5126 a	0.47 a	3014 a	0.6 ab	5403 a
Chisel plow	3731 b	3721 a	0.40 a	1928 a	0.6 a	3598 a
Ridge-till	4542 ab	3587 a	0.45 a	1672 a	0.6 ab	2932 a
No-till	8170 a	4330 a	0.37 a	1975 a	0.5 b	3986 a

[a]Means within a column in a size class followed by the same letter are not different at the 0.05 level has determined by LSD (0.05).

[b]Reproductive allocation = inflorescence weight/(inflorescence weight + vegetative biomass).

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms

Table 5. Common lambsquarters seed production estimates for four tillage systems[a].

		Seed production			
Tillage system	Year	Below 30 cm size class	Above 30 cm size class	Total seeds	% of seedbank population
		——— no. m^{-2} ———			
Moldboard plow	1992	2	2	4	<1
	1993	54	11,238	11,292	557
Chisel plow	1992	101	5	106	9
	1993	41	4,498	4,539	383
Ridge-till	1992	31	2	33	9
	1993	42	880	922	242
No-till	1992	31	27	58	8
	1993	2	638	640	91

[a]Seed production computed from information on seed production per plant in Tables 3 and 4, and weed density from Figure 3 and Figure 4. In 1992 the density of plants above 30 cm was extremely low, and density estimates taken from the October harvest were used in the calculation of seed production by above 30 cm plants, whereas in 1993, approximate ratios of below to above 30 cm plants in October were used to estimate the relative contributions to seed production using density information from Figure 4.

production in 1992. In 1993, when large plants exhibited higher density and higher seed production, the majority of seeds (95 to 100%) were produced by the above 30 cm size class. Harrison (12) also determined that seed production increased with plant size and that growth of common lambsquarters varied greatly with environmental conditions (12).

In 1992, the estimated seed production by common lambsquarters in all systems comprised less than 10% of the common lambsquarters seeds accumulated from previous years in the seedbank (Table 5). In 1993, a warmer, drier year, seed production per area was much higher in all systems, especially in moldboard plow and chisel plow plots (Table 5). Moldboard and chisel plow plots had greater populations of common lambsquarters than no-till and ridge-till plots (Figure 4). The estimated seed production per unit area was nearly 6 and 4 times the 1992 seedbank populations for moldboard plow and chisel plow systems, respectively. Estimated seed production per area in the no-till plot was only 91% of the 1992 seedbank; thus, during 1992 and 1993, the common lambsquarters seedbank may have been declining. The no-till seedbank was much smaller (one third the size) than the moldboard plow seedbank (Figure 2). In the ridge-till plot, estimated seed production was approximately 2.5 times the seedbank in 1992. However, the ridge-till plot also had the smallest common lambsquarters seedbank (Figure 2); at 386 m^{-2}, this was about one fifth the size of the moldboard plow seedbank.

Seed production per plant in both years was orders of magnitude below the range of 30,000 to 176,000 Harrison (12) recorded for unsprayed common lambsquarters. This may indicate that common lambsquarters escaping herbicide treatments pose a reduced threat to future control, even at the densities observed in the chisel and moldboard plow systems. While it is possible that our method of assessment underestimated seed production, the reduced seed production likely reflected the combined effect of crop competition and reduced plant size due to herbicide applications under managed conditions (32). Longer-term studies dedicated to weed seed return to seedbanks are needed to clarify this issue.

Common lambsquarters populations among tillage practices. Through three phases of the life-cycle: seedbank, aboveground plant, and reproduction per area, no-till, and ridge-till systems exhibited lower populations of common lambsquarters than moldboard plow and chisel plow systems. Differences in seed production per area were not a function of differences in seed production per plant, but rather were related to higher aboveground densities. Similarly, differences in aboveground densities likely were related to differences in seedbank populations.

The problems associated with large weed seedbanks are best illustrated by the moldboard plow plot. In 1992, the moldboard plow plant populations were relatively low; however, in 1993, there were large numbers of common lambsquarters in the same plot and seed production was relatively high. Tillage practices that disturb the soil increase the amount of environmental variation; in years where environmental conditions are favorable, seed germination and production may be high. More importantly, this means that year-to-year variation in weed density and weed seed return will increase and lead to less predictable weed problems. The reduction in seedbanks in no-till and ridge-till may be caused by shallower burial of seeds under conservation tillage systems, differences in herbicide use and management among systems, and differences in weed growth and mortality resulting from differences in tillage practices.

In our study and in others (1, 5, 8, 36), seeds were concentrated in the upper 5 cm of soil in conservation tillage systems. Theoretically, this factor alone would increase, rather than decrease, weed populations because of increased emergence from shallower depths. Weaver et al. (33) recorded higher emergence of common lambsquarters for seeds sown on the surface than seeds buried 1.5 cm deep. In our study, the herbicides apparently controlled weeds emerging in the conservation tillage systems such that over time seedbanks were reduced in comparison to the moldboard plow seedbank. This may indicate that management was effective enough to prevent excessive seed production (24). Population patterns of common lambsquarters in the chisel plow system were similar to those observed in the moldboard plow system, despite the shallow burial of seeds in chisel plow. One difference between the chisel plow system and the other conservation tillage systems was the lack of glyphosate or 2,4-D treatments in the chisel plow plot. This could affect common lambsquarters populations over time because a relatively large proportion of individuals may emerge prior to planting (13).

Timing and degree of soil disturbance may determine whether more or less weed seed emergence is stimulated or whether tillage effects interact with herbicide effects. Common lambsquarters germinates at cooler temperatures than most weed species (6, 33, 34), and thus control measures that act earlier may

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms

be more effective in reducing populations. Alternatively, the potential delay in emergence with lower soil temperatures under conservation tillage conditions may be a factor (14). Further studies are needed to examine the interaction of tillage systems with timing of emergence. Even though the chisel plow does not bury seeds as deeply as the moldboard plow, there still is a higher amount of disturbance relative to no-till or ridge-till; this may result in higher levels of emergence or seedling survival. The additional disturbance to construct ridges also may stimulate weed seed germination (15). Although seed production also may increase in ridge-till fields (15), this did not occur in our study. The lack of soil disturbance in no-till may result in mortality of weed seeds for species such as common lambsquarters, if they are vulnerable to desiccation, seed predation or other factors that seeds are exposed to on the soil surface (24, 28).

The amounts of residue left overwinter on the soil in this study ranked, from lowest to highest, was moldboard plow, chisel plow, ridge-till, and no-till. Residue remaining on the soil surface may affect weed population dynamics, e.g. interactions with herbicide applications, allelopathy, and shading effects and may result in reduced weed seedling emergence (23, 25, 29).

Populations of common lambsquarters and similar species that persist in conventional tillage systems may be managed more readily in reduced tillage systems, as indicated by this on-farm research where actual management practices were employed over 8 yr. However, given that these results were obtained from a single site, further information on the long-term effect of tillage on common lambsquarters populations would be useful. This would expedite the development of management strategies to reduce populations of weeds with seedbank regeneration strategies and to manage the successional dynamics of weeds in conservation tillage (28).

ACKNOWLEDGMENTS

We thank Hugh Martin of the Ontario Ministry of Agriculture and Food and the farm operators Al and Paul Jones and Dennis Zettler for cooperating in the Tillage 2000 project. Kevin Chandler provided technical assistance. Douglas Buhler and two anonymous reviewers provided helpful comments on earlier versions of this manuscript.

LITERATURE CITED

1. Ball, D.A. 1992. Weed seedbank response to tillage, herbicides, and crop rotation sequence. Weed Sci. 40:654–659.
2. Bandeen, J. D., G. R. Stephenson, and E. R. Cowett. 1982. Discovery and distribution of herbicide-tolerant weeds in North America. Pages 9–30 *in* H. M. LeBaron and J. Gressel, eds. Herbicide Resistance in Plants. John Wiley & Sons, Toronto, ON.
3. Benoit, D. L., C. J. Swanton, K. Chandler, and D. A. Derksen. 1991. Changes in weed populations and seed bank through two cycles of a maize-soyabean rotation in Ontario, Canada. Proc. Brit. Crop Prot. Conf.—Weeds-1991. 1:403–410.
4. Buhler, D. D., J. L. Gunsolus, and D. F. Ralston. 1992. Integrated weed management techniques to reduce herbicide inputs in soybean. Agron. J. 84:973–978.
5. Cardina, J., E. Regnier, and K. Harrison. 1991. Long-term tillage effects on seed banks in three Ohio soils. Weed Sci. 39:186–194.
6. Chu, C. C., P. M. Ludford, J. L. Ozbun, and R. D. Sweet. 1978. Effects of temperature and competition on the establishment and growth of redroot pigweed and common lambsquarters. Crop. Sci. 18:308–310.
7. Clements, D. R., S. F. Weise, and C. J. Swanton. 1994. Integrated weed management and weed species diversity. Phytoprotection 75:1–18.
8. Cousens, R. and S. R. Moss. 1990. A model of the effects of cultivation on the vertical distribution of weed seeds within the soil. Weed Res. 30:61–70.
9. Derksen, D. A., G. P. Lafond, A. G. Thomas, H. A. Loeppky, and C. J. Swanton. 1993. Impact of agronomic practices on weed communities: tillage systems. Weed Sci. 41:409–417.
10. Dick, W. A. and T. C. Daniel. 1987. Soil chemical and biological properties as affected by conservation tillage: Environmental implications. Pages 125–147 *in* T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash, eds. Effects of Conservation Tillage on Groundwater Quality. Lewis Publishers, Inc., Chelsea, MI.
11. Eadie, A. G., C. J. Swanton, J. E. Shaw, and G. W. Anderson. 1992. Banded herbicide applications and cultivation in a modified no-till corn (*Zea mays*) system. Weed Technol. 6:535–542.
12. Harrison, S. K. 1990. Interference and seed production by common lambsquarters (*Chenopodium album*) in soybeans (*Glycine max*). Weed Sci. 38:113–118.
13. Harvey, S. J. and F. Forcella. 1993. Vernal seedling emergence model for common lambsquarters (*Chenopodium album*). Weed Sci. 41:309–316.
14. Hayhoe, H. N., L. M. Dwyer, D. Balchin, and J.L.B. Culley. 1993. Tillage effects on corn emergence rates. Soil Till. Res. 26:45–53.
15. Forcella, F. and M. J. Lindstrom. 1988. Weed seed populations in ridge and conventional tillage. Weed Sci. 36:500–503.
16. Frick, B. and A. G. Thomas. 1992. Weed surveys in different tillage systems in southeastern Ontario field crops. Can. J. Plant Sci. 72:1337–1347.
17. Froud-Williams, R. J. 1988. Changes in weed flora with different tillage and agronomic management systems. Pages 213–236 *in* M. A. Elder and M. Liebman, eds. Weed Management in Agroecosystems: Ecological Approaches. CRC Press, Boca Raton, Florida.
18. Gebhardt, M. R., T. C. Daniel, E. E. Schweizer, and R. R. Allmaras. 1985. Conservation tillage. Science 230:625–630.
19. Jan, P. and R. Faivre-Dupaigre. 1977. Incidence des facon culturales sur la flore aventice. Proc. EWRS Symposium on Different Methods of Weed Control and Their Integrations, Uppsala 1:57–64.
20. Holm, L. G., D. L. Plucknett, J. V. Pancho, and J. P. Herberger. 1977. The world's worst weeds. East-West Center Book, Univ. Press of Hawaii, Honolulu, Hawaii. 609 p.
21. Kapusta, G. and R. F. Krausz. 1993. Weed control and yield are equal in conventional, reduced-, and no-tillage soybean (*Glycine max*) after 11 years. Weed Technol. 7:443–451.
22. Lewis, J. 1973. Longevity of crop and weed seeds: survival after 20 years in soil. Weed Res. 13:179–191.
23. Mohler, C. L. 1991. Effects of tillage and mulch on weed biomass and sweet corn yields. Weed Technol. 5:545–552.
24. Mohler, C. L. 1993. A model of the effects of tillage on emergence of weed seedlings. Ecol. Appl. 3:53–73.
25. Mohler, C. L. and M. B. Callaway. 1992. Effects of tillage and mulch on the emergence and survival of weeds in sweet corn. J. Appl. Ecol. 29:21–34.
26. Norris, R. F. 1992. Case history for weed competition/population ecology: Barnyardgrass (*Echinochloa crus-galli*) in sugarbeets (*Beta vulgaris*). Weed Technol. 6:220–227.
27. Roberts, H. A. and F. G. Stokes. 1965. Studies on the weeds of vegetable crops. V. Final observations on an experiment with different primary cultivations. J. Appl. Ecol. 2:307–315.
28. Swanton, C. J., D. R. Clements, and D. A. Derksen. 1993. Weed succession under conservation tillage: a hierarchical framework for research and management. Weed Technol. 7:286–297.
29. Teasdale, J. R., C. E. Beste, and W. E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Sci. 39:195–199.
30. Thomas, A. G. and B. L. Frick. 1993. Influence of tillage systems on weed abundance in Southwestern Ontario. Weed Technol. 7:699–705.
31. Toole, E. H. and E. Brown. 1946. Final results of the Durvel buried seed experiment. J. Agric. Res. 72:201–210.
32. Weaver, S. E. 1991. Size-dependent economic thresholds for three broadleaf weed species in soybeans. 5:674–679.

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms

33. Weaver, S. E., C. S. Tan, and P. Brain. 1988. Effect of temperature and soil moisture on time of emergence of tomatoes and four weed species. Can. J. Plant Sci. 68:877–886.
34. Wiese, A. M. and L. K. Binning. 1987. Calculating the threshold temperature of development for weeds. Weed Sci. 35:177–179.
35. Wilson, R. G. 1988. Biology of weed seeds in the soil. Pages 28–39 *in* M. A. Altieri, and M. Liebman eds. Weed Management in Agroecosystems: Ecological Approaches. CRC Press, Boca Raton, Florida.
36. Yenish, J. P., J. P. Doll, and D. D. Buhler. 1992. Effects of tillage on vertical distribution and viability of weed seed in soil. Weed Sci. 40:429–433.

This content downloaded from 160.36.178.25 on Sat, 24 Dec 2016 23:11:57 UTC
All use subject to http://about.jstor.org/terms