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ARTICLE

Weed emergence and seedbank after three years of repetitive shallow cultivation in a muck soil field

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Abstract: Frequent cultivation is often used to control weeds in crops such as lettuce. The efficacy of this technique on weed populations has been evaluated, but the effect on weed emergence and seedbanks is less documented. Studies in mineral soil indicate that soil disturbance can increase both weed emergence and seed persistence depending on where seeds are redistributed in the soil profile. Evaluations done in muck soil are scarce. This study evaluated the effect of two and four repetitive shallow (3.4 to 7.1 cm deep) cultivations on weed emergence and the weed seedbank in muck soil. Cultivation treatments (0, 2, and 4 cultivations using a inter-row rototiller) were done in lettuce plots from 2017 to 2019. Weed density was evaluated by species before each cultivation date and after crop harvest. Viable seedbanks were evaluated by collecting soil samples before and after each growing season and placing them in greenhouse flats. Statistical analyses were based on mixed models. Results showed that shallow cultivation modified the emergence patterns of weeds but did not reduce total emergence during the subsequent years or viable seedbanks. After two seasons without seed inputs, total emergence was reduced by 46.6% and the seedbank was reduced by 31.7% regardless of the cultivation treatment. However, the seedbank of the very abundant common purslane (*Portulaca oleracea*) remained high.

Key words: inter-row rotary cultivation, head lettuce, organic soil, weed emergence.

Résumé : Le sarclage répétitif est une méthode de lutte fréquemment utilisée dans les cultures telles que la laitue. L'efficacité de la technique sur les populations de mauvaises herbe a été évaluée mais l'impact sur l'émergence et la banque de graines est moins documenté. Des études faites en sol minéral indiquent que la perturbation du sol peut augmenter à la fois l'émergence des mauvaises herbes et la persistance des semences selon leur relocalisation dans le profil de sol. Les évaluations en sol organique sont rares. Cette étude a évalué l'effet de deux et quatre sarclages peu profonds (3.4 à 7.1 cm) et répétitifs sur l'émergence des mauvaises herbes et leur banque de graines. Les traitements de sarclage (0, 2 et 4 sarclages à l'aide d'un rotoculteur dans l'entre-rang) ont été faits dans des parcelles de laitues de 2017 à 2019. La densité des mauvaises herbes a été évaluée avant chaque date de sarclage et après la récolte des laitues. La banque de graines viables a été évaluée avant et après chaque saison de croissance à l'aide d'échantillons de sol disposés dans une serre. Les analyses statistiques étaient basées sur des modèles mixtes. Les résultats démontrent que le sarclage à faible profondeur a modifié le patron d'émergence des mauvaises herbes mais n'a pas réduit l'émergence totale durant les années suivantes ou la densité de graines viables dans le sol. Après deux saisons sans apport de graines, le nombre d'émergences a été réduit de 46.6% et la banque de graines viables a été réduite de 31.7% peu importe le traitement de sarclage. Toutefois, la banque de graines du très abondant pourpier potager (*Portulaca oleracea*) est restée élevée.

Mots-clés : sarclage de l'entre-rang, laitue pommée, sol organique, émergence des mauvaises herbes.

Introduction

Field vegetable production in Canada covered 102 022 ha in 2019, principally located in Ontario (48%) and Quebec (38%), and had a farm gate value of almost 1.3 billion dollars (Agriculture and Agri-Food Canada Crops and Horticulture Division 2020). Thirty-five

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percent of all field vegetables are grown on muck soils in Québec. In Ontario, values are higher for some individual crops such as carrots, celery and lettuce (Scott 2019; OMAFRA, personal Communication, Agricultural Development Branch). Weed control in these high value crops can be challenging as herbicide applications can be limited by the availability of different selective products (Colquhoun 2006), the increasing presence of herbicide resistant weed biotypes (Simard et al. 2018; Heap 2021) and environmental concerns (Szeto and Price 1991). Consumer demand for products that are organic or grown with limited pesticide use is also on the rise (Lévesque et al. 2021). When herbicides are not applied, vegetable growers rely mainly on mechanical weeding and hand hoeing (Peigné et al. 2007). Cultivation using a rototiller is widely used to control weeds in vegetable crops such as lettuce and broccoli (Ryder 1999; Lowry and Brainard 2017). Compared with other cultivation techniques, this method can control larger weeds (Boyd et al. 2006). However, few studies have quantified the effect of repetitive shallow cultivation (less than 10 cm deep) on weed emergence and especially viable seed banks in muck soil. Previous studies done in mineral soil indicate cultivation or other soil perturbations such as secondary tillage increase weed seed germination and emergence (Roberts and Dawkins 1967; Roberts and Feast 1972; Mulugeta and Stoltenberg 1997; Boyd et al. 2006), notably by increasing seed exposure to light and oxygen (Frost et al. 2019). As for the persistence through dormancy or quiescence (non-dormant seeds that do not germinate due to unfavorable conditions) of seeds not subject to germination or seed predation, studies in mineral soil suggest it is generally increased by cultivation or tillage compared with undisturbed soil as seeds remain deeper in the soil profile. The underlying mechanism for this persistence would be generated by seed burial at depths where biological activity from bacteria and fungi that can decay them is lower, but empirical in situ evidence is scarce and the effect can be species specific (Davis et al. 2006; Wagner and Mitschunas. 2008; Ullrich et al. 2011; Frost et al. 2019). Shallow cultivation would therefore be less likely to increase persistence, but again information specific to muck soil is lacking. Left undisturbed, seeds buried in these soils can show greater, equal or lower persistence than in mineral soil depending on weed species (Lewis 1973). Our goal was to quantify weed emergence and seed banks over time in muck soil after one to three years of repetitive shallow in-row cultivation (two or four cultivations per season). We hypothesized that rototiller cultivation would increase emergence in muck soil and significantly lower seed bank persistence.

Material and Methods

Site and experimental design description

The experiment was located at Agriculture and Agri-Food Canada's research farm in Sainte-Clotilde (45° 10′12″ N, 73° 40′48″ W), QC on a muck soil classified as a Histosoil (Soil Survey Staff. 1999) containing 84% organic matter with a pH of 5.25. Head lettuce (*Lactuca sativa* L. var. Estival) was grown during three years in the same field from 2017 to 2019. Lettuce plants grown in a commercial greenhouse were transplanted by hand at the two leaf stage in 35 cm wide rows following tillage using a vibrashank (Kongskilde Agriculture, Albertslund, Denmark) (15–20 cm deep) and seedbed preparation using a rototiller (Khun, Saverne, France) (15 cm deep), every year. Sprinkler irrigation was provided when needed and fertilisation was applied each year based on standard practices. Table 1 presents a detailed account of the different operations and dates. The experimental design was a randomised complete block with three cultivation treatments, four replications and repeated measures. These treatments included no cultivation (0×), cultivating twice (2×) and cultivating four times (4×). Inter-rows were cultivated at an average depth of 3.44 to 7.13 cm (Table 1) using a four-unit rototiller (COMEB Inter Row Rotavator, COMEB S.R.L., Budrio, Italy) when weeds were at the 1–2 leaf stage. Rows were hand weeded when necessary in all plots. To ensure weeding efficiency, the uncultivated treatment was weeded using sequential banded herbicide applications of post-emergence herbicides or careful hand weeding on the same date as the cultivation treatments. Carfentrazone-ethyl (AIM EC 240 g/L) was applied at a dose of 28 g a.i.$\cdot$ha^{-1} and sethoxydim was applied (Poast ultra 450 g/L) at a dose of 495 g a.i.$\cdot$ha^{-1} with a hooded sprayer in June (except in 2019, hand weeding only). Hand weeding was done by clipping the base of the weeds without disturbing the soil. Weeds were also clipped in all quadrats after each emergence count. No weeds were left to set seeds in any treatment. After harvest, glyphosate was applied at a dose of 1080 g a.e.$\cdot$ha^{-1} (IPCO® Factor 540) on the entire field at regular intervals three to four times after each emergence count until no more emergence was observed (Table 1). Soil moisture was measured on the same day before each cultivation treatment with a soil moisture probe (SM200 Soil Moisture Sensor and HH2 moisture meter, Delta-T Devices Ltd., 130 Low Road, Burnwell, Cambridge, CB25 0EJ, UK) (% by volume) at five random positions in center rows. Cultivation depth was evaluated at two locations (one per center row) per plot.

Weed emergence counts

Weed emergence counts were done before each cultivation and until no further emergence was observed, for a total of five to eight counts per season. Weeds were counted in two rectangular 20 × 25 cm quadrats each randomly located in a different row. When the width of the cultivation was reduced not to injure the larger lettuce plants (after the third cultivation), counts were done in 10 × 50 cm quadrats to ensure only emergences occurring in the cultivated area were recorded.

Table 1. Sequence of operations performed in the lettuce plots. Average soil moisture levels before each cultivation and cultivation depths are also indicated.

	Year		
Operation	2017	2018	2019
Emergence count before tillage	—	11 May	16 May
Vibrashank tillage	12 May	11 May	16 May
Fertiliser and rototiller	16 May	11 May	16 May
Irrigation – 20 mm	16 May	14 May	—
Lettuce transplantation	17 May	14 May	16 May
Irrigation – 20 mm	19 May	—	—
Inter-row cultivation	1 June	31 May	6 June
Depth (cm)	5.06 ± 0.75	5.34 ± 0.80	3.44 ± 0.68
Moisture (% volume)	37.4 ± 3.9	29.2 ± 2.2	27.4 ± 4.8
Inter-row cultivation	12 June	12 June	17 June
Depth (cm)	5.31 ± 0.75	6.76 ± 1.03	3.60 ± 0.43
Moisture (% volume)	25.3 ± 3.9	31.9 ± 4.2	25.9 ± 4.4
Herbicide in weed free plots	13 June	12 June	—
Irrigation – 20 mm	14 June	—	7 June
Irrigation – 20 mm	—	—	19 June
Inter-row cultivation	22 June	22 June	28 June
Depth (cm)	4.81 ± 0.56	6.83 ± 0.56	4.14 ± 0.42
Moisture (% volume)	30.4 ± 4.7	18.7 ± 4.3	32.8 ± 4.8
Manual Harvest	4 July	3 July	8 July
Inter-row cultivation	5 July	3 July	8 July
Depth (cm)	5.25 ± 0.71	7.13 ± 0.57	4.31 ± 0.50
Moisture (% volume)	32.0 ± 5.5	17.6 ± 3.9	15.8 ± 3.9
Herbicide in all plots	20 July	20 July	25 July
Herbicide in all plots	22 Aug.	9 Aug.	28 Aug.
Herbicide in all plots	25 Sept.	7 Sept.	3 Sept.
Herbicide in all plots	—	12 Oct.	—

Note: Mean cultivation depth ($n = 16$ or 8 when only the 4× plots were cultivated) and moisture level ($n = 60$) ± standard error.

Quadrats were positioned at the same location every year using both GPS and *x–y* coordinates (from pegs located in the field borders) and repositioned after each cultivation using flags located on the row.

Seedbank evaluation

Five soil samples were collected per plot twice a year using a large push probe (3.5 cm diam × 15 cm depth). Samples were collected in the spring before seedbed preparation and in the fall before the first frost. All samples were kept at 4 °C before being laid in flats in a greenhouse. Each sample was emptied into one of six individual inserts of a flat and spread to obtain a soil thickness of about 1.5 cm. All flats were equipped with an irrigation mat and the samples were watered solely by capillarity. Seedlings were allowed to emerge for a period of six weeks (day/night 16/8h, 25/15 °C). Once a week, seedlings were identified, counted and gently pulled out. The samples were then placed at −4 °C in the dark for three months. After the freezing period all samples were thawed at 4 °C for 24 h. Each sample was then hand stirred and put back in greenhouse flats for another six weeks as above. After this second growth period the soil samples were dried at 30 °C until constant weight and weighed.

Lettuce yield and quality

Lettuce plants were harvested by hand between 3 July and 8 July (Table 1). Yield was evaluated by harvesting six randomly selected lettuce plants per plot located along a center row. Each head was evaluated for height, diameter, fresh weight, stem length, head firmness (1–5 scale) (Kader et al. 1973), presence of downy mildew (*Bremia lactucae*) and marketability. The height over diameter ratio was also calculated. Lettuce plants with downy mildew or any other diseases or physiological disorders (bolting, tip burn, malformed heads) were classified as non-marketable.

Statistics

Data analyses were conducted using the MIXED procedure in SAS OnDemand for Academics 9.04.01 M6P11072018 (SAS Institute Inc. 2021). Block and sampling year were set as random effects while other effects were set as fixed for the analysis of the following variables: weed emergence, lettuce yield and additional yield parameters. Weed emergence (from field counts) and seedbank (from soil cores laid in the greenhouse) data as well as lettuce height, weight, and stem length were analyzed using either the VC (variance component) or the CSH (heterogeneous compound symmetry) covariance. When emergence and seedbank density were analyzed, the model included block as a random effect and sampling date × year interaction as a repeated fixed effect. Either the un@ar(1) (Direct Product AR[1]) or un@un (Direct Product UN) covariance were used for analyzing the data. All covariance structures were selected according to the best model fit based on the Akaike information criterion. For all analyses, homogeneity of variance was verified by plotting residuals using the SGPLOT procedure. The normal distribution of residuals was assessed graphically and by performing a Shapiro-Wilk test using the UNIVARIATE procedure. The standard error of means was also calculated using the TABULATE procedure. Logarithmic (emergence) or square root transformations (emergence and weed seed bank density) were applied to data that did not meet these criteria and were back-transformed for the presentation of results. Statistical significance between multiple comparisons were determined using Tukey's honestly significant difference test based on a 95% confidence interval. Yield parameters were also correlated.

Results

Based on yearly averages (from 2017 to 2019), the emerging weed flora was dominated by common purslane (*Portulaca oleracea* L.) (74.8%), hairy galinsoga (*Galinsoga ciliata* (Raf.) Blake) (15.7%) and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] (9.1%). All other species represented 0.4% of emerged seedlings. Based on yearly averages, the weed seedbank in the collected soil samples was also dominated by common purslane (77.1%), hairy galinsoga (11.3%) and barnyard grass (5.2%). All other species represented 6.4% of the seedbank.

Weed emergence

There was a significant effect of weed species on emergence ($p < 0.001$, details not shown) when we initially included this variable in the model and this variable interacted with others. Therefore, we analysed and present total emergence (all species) as well as common purslane, hairy galinsoga and barnyard grass separately. The other species could not be analysed separately because numbers were too low to generate reliable models.

There was a significant effect of cultivation treatment ($p < 0.001$), monthly date ($p < 0.001$) and year ($p < 0.001$) on total emergence and most interactions were significant, including triple interactions, except cultivation × year ($p > 0.05$). Therefore, the effect of the cultivation treatment on weed emergence varied by week. In plots with no inter-row cultivation, total numbers were higher during the first weeks and lowered more or less constantly during the growing season (Fig. 1). In cultivated treatments, emergence values were on average 31.0% higher in plots cultivated twice and 77.9% higher in plots cultivated four times and more stochastic compared with uncultivated plots. Weekly values show increases, decreases, and equal values after cultivation with no clear in-season pattern except for more late-season emergence (Fig. 1).

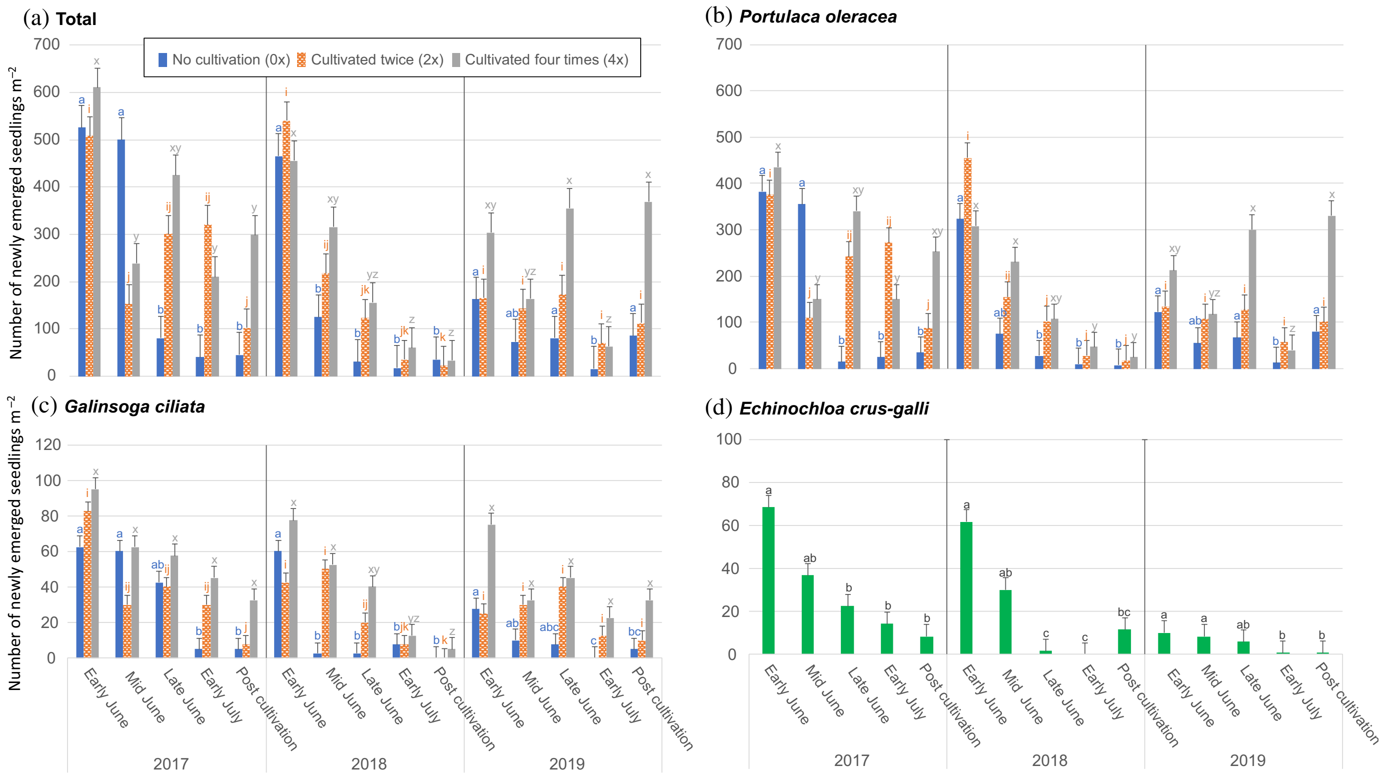
Similar results and conclusions can be drawn when we analyse common purslane and hairy galinsoga separately. For common purslane emergence values were modulated by cultivation ($p < 0.001$) and were on average 49.1% higher in plots cultivated twice and 91.2% higher in plots cultivated four times. For hairy galinsoga emergence values were modulated by cultivation ($p < 0.001$) and were on average 43.7% higher in plots cultivated twice and 131.1% higher in plots cultivated four times (Fig. 1). For barnyard grass, the cultivation treatment effect was not significant ($p = 0.7995$). There was a significant week ($p < 0.001$) and year ($p < 0.001$) effect and these factors interacted ($p = 0.0015$) but other interactions were not significant (Fig. 1). Emergence counts generally decreased as the season progressed and every year (Fig. 1).

Regardless of the cultivation treatment, the average density of emerged seedlings per sampling date was significantly lower after the first year while reductions were not significant after the second year, except for barnyard grass (Fig. 2). The average density of all emerged seedlings per sampling date lowered by 39.7% after the first year but values were only 6.9% lower after the second year, for a total decrease of 46.6%. The density of common purslane seedlings decreased by 40.6% after the first year and values were only 1.5% lower after the second year, for a total decrease of 42.1%. The density of hairy galinsoga seedlings decreased by 42.2% after the first year and values were only 0.8% lower after the second year, for a total decrease of 43.0%. Density values for barnyard grass were 30.0% lower after the first year and significantly decreased by 52.8% after the second for a total decrease of 82.8% (Fig. 2).

Weed seedbank

There was a significant effect of weed species ($p < 0.001$, details not shown) on seedbanks when we initially included this variable in the model and this variable interacted with others. We analysed total seedbank (all species) as well as common purslane, hairy galinsoga and barnyard grass separately. Other species (pooled as

Fig. 1. Average density of newly emerged weeds. All species (*a*), common purslane (*Portulaca oleracea* L.) (*b*), hairy galinsoga (*Galinsoga ciliata* [Raf.] Blake) (*c*) and barnyard grass (*Echinochloa crus-galli* [L.] Beauv.) (*d*) observed when the soil was left uncultivated (0×, blue), cultivated twice (2×, orange) or cultivated four times (4×, grey) or irrespective of cultivation treatment (barnyard grass, green) during the growing season from 2017 to 2019. Different letters indicate means are significantly different within cultivation treatment within year based on Tukey–Kramer honest significant difference (HSD) at $p \leq 0.05$. Error bars indicate + standard error. [Colour online.]



one) could not be analysed separately because numbers were too low to generate reliable models. There was no significant effect of our cultivation treatment on total counts or any species analysed separately ($p > 0.05$). Collection date (before or after the growing season) was never significant ($p > 0.05$) and no interactions were significant. Only year had a significant effect on total numbers and on the density of all individual species ($p < 0.05$) except common purslane ($p = 0.1419$).

The total seedbank decreased by 17.6% after the first year and by 14.1% after the second year for a total decrease of 31.7% in 2019 compared with 2017. The common purslane seedbank did not significantly decrease, as mentioned above, but values were 8.9% lower after the first year, 15.6% lower after the second year and 24.5% lower in 2019 compared with 2017. The hairy galinsoga seedbank decreased by 41.8% after the first year and values were lower by 18.0% after the second year for a total decrease of 59.8% in 2019 compared with 2017. The barnyard grass seedbank decreased by 60.3% after the first year and did not decrease after the second year for a total decrease of 48.3% in 2019 compared with 2017 (Fig. 2).

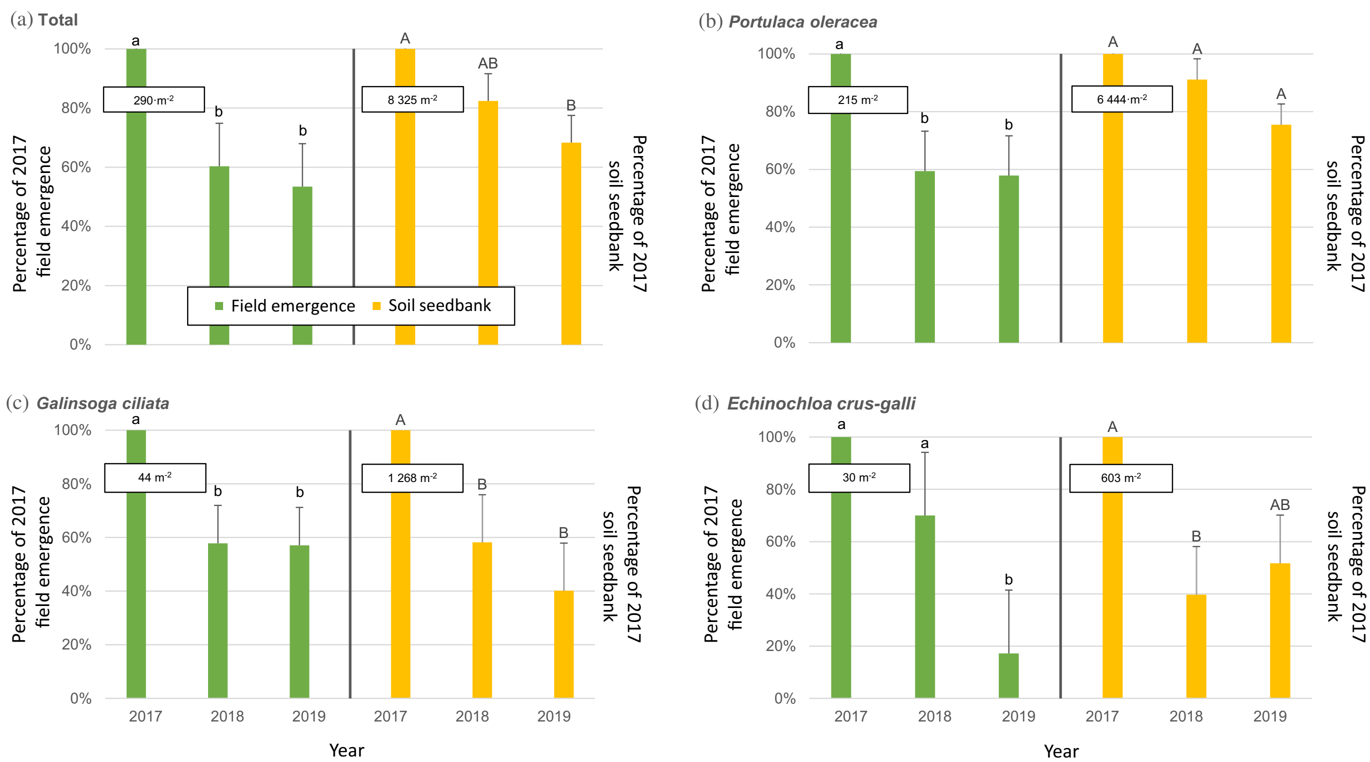
Lettuce yields

There was an effect of year on lettuce height, diameter, height-diameter ratio and head firmness ($p < 0.001$, all variables) as well as stem length ($0 = 0.0199$) but not on total and marketable fresh yields ($p = 0.7974$), both being equivalent as all the harvested heads were classed as marketable (Table 2). No interactions between year and treatment were significant. All values except height: diameter ratios and firmness were higher in 2017 and lowest in 2018 or 2019 depending on the variable (Table 2). There was no effect of cultivation treatment on yields or yield parameters ($p > 0.05$), except stem length ($p = 0.0362$). Stem lengths were 9.3% shorter in the plots cultivated four times (4×) (32.06 ± 1.36 mm) than the equivalent 0× and 2× (35.33 ± 0.68 mm) cultivation treatments (Table 2). All yield parameters were positively correlated ($p < 0.05$) except firmness and height ($p = 0.41$).

Discussion

All three species investigated had extended emergence periods, as expected (Bagavathiannan et al. 2011; Egley and Williams 1991; Feng et al. 2015; Maun and

Fig. 2. Percentage of 2017 emergence counts in the field (left, green) and percentage of 2017 soil seedbank (right, yellow) observed in 2018 and 2019. Average density of newly emerged seedlings observed after ~10 d (see Fig. 1) and average density of viable seeds from soil cores retrieved twice (to a depth of 15 cm) are indicated on the 2017 bar (rounded to the nearest whole number). All weeds (*a*), common purslane (Portulaca oleracea L.) (*b*), hairy galinsoga (Galinsoga ciliata [Raf.] Blake) (*c*) and barnyard grass (Echinochloa crus-galli [L.] Beauv.) (*d*). Different letters indicate emergence (lowercase) or seedbank (uppercase) values are significantly different based on Tukey–Kramer honest significant difference (HSD) at $p \leq 0.05$. Error bars indicate + standard error. [Colour online.]



Barrett 1986; Warwick and Sweet 1983). Shallow inter-row rotary cultivation generated both decreases and increases in the emergence of the most abundant species during the season but, except for barnyard grass, emergence was generally higher in cultivated plots, especially later during the season. Tillage is known to increase emergence in mineral soil by exposing buried seeds to light and oxygen (Frost et al. 2019). Although some weeds do not require light for germination, hairy galinsoga and barnyard grass are photoblastic (Maun and Barrett 1986; Warwick and Sweet 1983), as are Canadian populations of common purslane (El-Keblawy and Al-Ansari 2000). Exposure to higher temperature fluctuations, prevalent at the soil surface, can also increase germination in barnyard grass (Maun and Barrett 1986). Shallow rotary cultivation will also kill germinating plants that have not yet emerged. Therefore germinating seedlings were potentially killed after some cultivation passes but more seeds eventually germinated to increase emergence counts later during the season. Melander and Rasmussen (2000) also wanted to lower seedbanks using repetitive cultivation (using goosefoot cultivators in a sandy loam) but observed no clear effect on the subsequent weed emergence of common lambsquarters (*Chenopodium album* L.), bird's eye speedwell (*Veronica persica* Poir), common chickweed [*stellaria media* (L.) Vill.], scentless chamomile [*Tripleurospermum inodorum* (L.) Shultx-Bipontinus] and annual bluegrass (*Poa annua*). Mulugeta and Stoltenberg (1997) observed that secondary soil disturbance increased the emergence of the abundant common lambsquarters in silt loam only when soil moisture was limiting while other species [Redroot pigweed (*Amaranthus retroflexus* L.) and velvetleaf (*Abutilon theophrasti* Medik.)] were unaffected. Thus depletion by seedling emergence was generally low. Egley and Williams (1990) also found that annual tillage type, including cultivation, or depth did not modify the decline in weed emergence in the absence of seed return of common purslane, prickly sida (*Sida spinosa* L.), velvetleaf, spurred anoda [*Anoda cristata* (L.) Schlecht.] and morningglory species (*Ipomoea* sp.).

As observed during this experiment, the prevention of seed shedding was more important than cultivation to promote seedbank decline (Melander and Rasmussen 2000; Egley and Williams 1990). Without extra seed inputs average emergence values and seedbank counts were 46.6% and 31.7% lower, respectively, after two seasons without seed inputs. During a three year time

Table 2. Lettuce yield and yield parameters by year and treatment.

		Year			
		2017	2018	2019	All years
Variable	Treatment				
Fresh biomass (g/plant)	0×	465.46 ± 41.37	509.29 ± 59.02	523.08 ± 56.32	499.28 ± 28.56A
	2×	466.46 ± 20.15	494.04 ± 32.63	459.67 ± 48.61	473.39 ± 19.20A
	4×	471.92 ± 42.23	434.92 ± 73.90	393.42 ± 37.09	433.42 ± 29.62A
All treatments		467.94 ± 18.85a	479.42 ± 31.68a	458.72 ± 29.72a	—
Diameter (cm)	0×	12.17 ± 0.18	11.71 ± 1.07	10.38 ± 0.43	11.42 ± 0.42A
	2×	12.45 ± 0.07	12.18 ± 0.50	10.08 ± 0.35	11.57 ± 0.37A
	4×	12.69 ± 0.42	11.30 ± 0.98	10.10 ± 0.36	11.37 ± 0.47A
All treatments		12.44 ± 0.15a	11.14 ± 0.47a	10.19 ± 0.20b	—
Height (cm)	0×	13.53 ± 0.49	11.25 ± 0.56	12.43 ± 0.60	12.40 ± 0.40A
	2×	13.10 ± 0.26	11.28 ± 0.22	12.32 ± 0.17	12.23 ± 0.25A
	4×	13.70 ± 0.35	10.88 ± 0.45	11.57 ± 0.20	12.05 ± 0.41A
All treatments		13.44 ± 0.21a	11.14 ± 0.23c	12.11 ± 0.23b	—
Stem length (mm)	0×	37.17 ± 1.02	36.13 ± 2.90	32.58 ± 1.47	35.29 ± 1.19A
	2×	35.17 ± 0.93	36.42 ± 1.11	34.54 ± 1.73	35.38 ± 0.72A
	4×	36.71 ± 1.53	30.04 ± 2.40	29.42 ± 1.17	32.06 ± 1.36B
All treatments		36.35 ± 0.67a	34.19 ± 1.48ab	32.18 ± 1.00b	—
Height: diameter ratio	0×	1.11 ± 0.03	0.98 ± 0.01	1.20 ± 0.04	1.10 ± 0.04A
	2×	1.05 ± 0.02	0.93 ± 0.03	1.23 ± 0.04	1.07 ± 0.04A
	4×	1.08 ± 0.01	0.98 ± 0.06	1.15 ± 0.04	1.07 ± 0.03A
All treatments		1.08 ± 0.01b	0.96 ± 0.04c	1.20 ± 0.02a	—
Firmness (1 to 5)	0×	2.9 ± 0.1	3.3 ± 0.1	3.3 ± 0.1	3.2 ± 0.07A
	2×	2.9 ± 0.1	3.3 ± 0.1	3.1 ± 0.2	3.1 ± 0.08A
	4×	2.9 ± 0.1	3.1 ± 0.1	2.9 ± 0.1	3.0 ± 0.07A
All treatments		2.9 ± 0.03b	3.2 ± 0.06a	3.1 ± 0.08a	—

Note: Average ($n = 24$) ± standard error. Different letters indicate means are significantly different between years (lowercase letters) or treatments (uppercase letters) based on Tukey–Kramer honestly significant difference (HSD) test at $p \leq 0.05$.

frame, Burnside et al. (1986) observed reductions of at least 50% in the germinable seedbank collected to a depth of 20 cm in soils that had 16% to 38% of clay when no seed return was allowed. Our observations in muck soil are line with these results but are largely due to reductions in the seedbank of species other than common purslane.

Common purslane seeds are persistent as 82.4% of seeds collected to a depth of 20 cm were germinable after one year (Feng et al. 2015) and viable seeds were recovered after 40 years of burial (Darlington and Steinbauer 1961). Although cultivation increased the number of emerged seedlings, its impact of the seedbank was negligible and after three years of intensive cultivation, or not, 75.5% of the initial seedbank was still viable based on germination counts. Hairy galinsoga emergence was also modified by shallow cultivation. False seedbed strategies have been shown to reduce subsequent emergence in this species but tillage intensity (single versus double passes) did not modify results (De Cauwer et al. 2019). De Cauwer et al. (2020) also recommend not inverting the soil which we did every spring and this could have promoted seedbank persistence. Although hairy galinsoga is thought to show relatively low seed persistence enabling the control of infestations after 3–4 yr without seed return (see De Cauwer et al. 2020) we still observed seedling counts close to 100 seedlings·m^{-2} per season after two seasons without seed inputs and relatively high seedbanks. Barnyard grass emergence was not modified by shallow cultivation and showed the greatest reduction in emergence counts after three years compared with common purslane and hairy galinsoga although its seedbank longevity was equivalent to the latter, suggesting that the remaining viable seeds were more quiescent (potentially deeper in the soil profile) or more dormant than remaining hairy galinsoga seeds. The seedbank longevity of barnyard grass was also higher than observed in sandy loam by Dawson and Bruns (1975) but lower than observed by Rahn et al. (1968) in clay at comparable depths. It is difficult to determine if soil type is an explanatory factor here since seedbank longevity is modulated by multiple factors including tillage and its evaluation is difficult and biased by sampling effort, seedbank density and evaluation technique (Mulugeta and Stoltenberg 1997; Reinhardt and Leon 2018).

Soil disturbance generally reduces soil health and in organic soils it can accelerate the ongoing aerobic degradation of the organic matter (Gesch et al. 2007; Elder and Lal 2008). Solutions known to reduce the loss of organic matter include water table management, reducing tillage, amendments that inhibit microbial activity and the application of organic mulches (Morris et al. 2004; Gesch et al. 2007, Wright and Snyder 2009; Kätterer et al. 2012). However, if tillage results in very dry conditions that are unfavourable for microbial decomposition it can actually reduce carbon loss (see Kätterer et al. 2012). As cultivation did not significantly reduce the viable seedbank after three years, it should be used with parsimony to maintain soil health.

Lettuce yields were not significantly different from year to year during the trial although morphometric parameters were different. The smaller heads measured during the second and third seasons had higher firmness. Lettuce stem lengths were slightly reduced by four consecutive cultivations. Although this measure is correlated with lettuce yields, yield reductions generated by four cultivations were not significant. Slight reductions in vigor could have been generated because cultivation can damage lettuce roots and weaken plants (Fennimore et al. 2014) as lettuce roots are shallow. Frequent cultivation can also increase the incidence of disease when leaves are injured (Dillard and Cobb 1995) but we did not observe this in our plots. Likewise, Trembley (1997) did not observe any increase in disease incidence in lettuce plots when weeds were managed using four different cultivators during a 2-yr trial.

Conclusions

Seedbanks were not lowered by stimulating weed emergence using shallow cultivation in muck soil in a single field. We acknowledge that trials in multiple fields would be needed to evaluate the effect of different weed floras and densities. Limiting seed inputs did reduce emergence counts and viable seedbanks. This strategy alone would not allow a reduction in herbicide use or mechanical weeding but could significantly reduce manual weeding costs.

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