Effect of tillage on weed seed bank and weed flora in maize (*Zea mays*)

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Summary The weed seed bank and above-ground weed flora were studied in a maize cropping system at the University of New England in Armidale, Australia, using no-till (NT), chisel plough (CP) and mouldboard plough (MP) tillage systems, in weed-free and weedy conditions. Tillage effects on weed seedbank size were assessed by the seedling germination method in soil samples from 0–5, 5–10, 10–15 and 15–20 cm depths in a glasshouse. Above-ground weed flora was assessed as seedling emergence in the field. Tillage systems affected both the weed seed bank and seedling emergence in the field. CP and MP triggered emergence of broadleaf weeds resulting in more weeds in the top 5 cm layer under weedy conditions. Fewer weeds emerged in NT under weedy conditions and maize yield under this system was higher than in CP and MP. Under weed-free conditions, maize yields were similar across the tillage systems. Weed seed bank size at the 0–5 cm depth was largest in the NT (559 seeds m^{-2}) and smallest in the CP treatment (232 seeds m^{-2}) under weed-free conditions.

Keywords Tillage systems, seed bank size, seedling emergence, maize.

INTRODUCTION

The size and species composition of the seed population present in arable soils reflect the extent to which past management has permitted seed production by weeds. More importantly, they also determine (at least in part) the nature and extent of weed problems in future cropping (Roberts and Chancellor 1988). Because of differences in seed production, viability, lifespan and dormancy, seed banks may not be an exact representation of the actual above-ground weed flora (Roberts 1982, Baskin and Baskin 1985). The seed bank possesses different forms of seed dormancy (Forcella *et al*. 1992), which influence the weed emergence potential (Benvenuti 2007). The density of seed banks ranges from zero in newly developed soils to 4100–137,700 m^{-2} (Schweizer and Zimdahl 1984, Warwick 1984), and up to as much as 1 million seeds m^{-2} (Fenner 1985). Roberts (1982) reported that a weedy field may contain up to 25,000 m^{-2} of viable seeds. The seed bank may also vary from field to field and between areas within a field (Altieri and Liebman 1988). Hayashi and Numato (1971) noted the majority of the seed bank to be located within 2 cm of the soil surface and nearly the entire population to be in the upper 10 cm of the soil.

The primary limiting factors for crop production in northern New South Wales and southern Queensland in Australia are low annual precipitation and high temperatures. As a rational management response to this environment, many farmers use a program of minimum or reduced tillage as a means of conserving soil moisture and improving subsequent crop yield. As the farming system is moving towards less cultivation, the weed seed bank size and composition will also change. It is therefore important to assess the effects of different tillage systems on weed seed bank levels and species composition for developing effective weed management systems.

The aim of this study was to determine the effect of tillage systems on the size and composition of the weed seed bank under weedy and weed-free conditions in maize (*Zea mays*).

MATERIALS AND METHODS

A tillage study was initiated in October 2008 at the University of New England's (UNE) Laureldale Research Station, Armidale, NSW, Australia (30°30'S, 151°40'E). The soil was a medium heavy clay chocolate basalt (pH 6.4 and 2.8% organic matter). The experimental design was a completely randomised design with four replicates. Treatments were applied in factorial combinations, i.e. three tillage treatments × two weed treatments. Tillage operations were performed in summer (7 November 2008) with a mouldboard plough (MP) inverting soil down to 25–30 cm followed by disc ploughing once to break the clods and level the soil. Chisel plough (CP) plots were chisel ploughed to 30 cm and disced once to level the soil. In no till plots (NT), the soil was disturbed only by the crop planter to a depth of 5 cm. Weed-free plots were sprayed 20 days after planting with post emergence herbicides fluroxypyr at 0.15 kg a.i. ha^{-1} + atrazine at 1 kg a.i. ha^{-1}. Herbicides were applied with a four nozzle hand boom spray at 20 kPa to deliver 106 L ha^{-1}. Weeds not controlled by herbicides were hand weeded to maintain weed-free plots. In weedy plots weeds were not controlled by either herbicides or hand-weeding.

Plots were 2.1 m wide and 6.6 m long. Maize (*Zea mays* cv. 'Hycorn 533') was sown in rows 70 cm apart at a population of 60,000 plants ha^{-1}. No starter or post emergence fertiliser was applied. Weed seedling numbers in the field were counted in 4 quadrats (0.5 × 0.7 m) placed randomly in the centre row of each plot, 30 days after planting, i.e. 10 days after spraying.

Seed bank sampling Seed banks were sampled at harvest (June 2009). Six soil cores, 4.5 cm diameter and 20 cm deep were obtained from the centre of each plot at 1 m intervals (6 cores per plot) and divided into 0–5, 5-10, 10–15 and 15–20 cm depths. Cores of each depth were pooled to make one sample for each plot. The seed bank was determined according to the procedure of Forcella *et al*. (2003). The entire sample was evenly spread in a plastic tray of 7 × 12 × 17 cm with holes at the bottom for drainage and placed in a glasshouse set to 25 ± 5°C during the day and 15 ± 5°C at night. Trays were watered regularly and seedlings were identified and counted over a period of 1 month. The soil in the tray was allowed to dry for 2 weeks, then thoroughly mixed and rewatered to inspect for any further seedling emergence.

Data analysis Data were analysed using the statistical software R 2.7.0 (R Development Core Team 2008). Data were subjected to analyses of variance.

RESULTS

Tillage affected both seedling emergence (Table 1) and total weed seed density in each soil layer (Table 2).

Seedling emergence Ten weed species were observed in the field. Five of these – *Portulaca oleracea*, *Lamium amplexicaule*, *Sonchus oleraceus*, *Trifolium pratense* and *Fallopia convolvulus* – were less abundant and were grouped together as 'other weeds' (2009). Under weedy conditions more weeds emerged in the MP and CP treatments than in NT (Table 1). There were significantly more broadleaf weeds in CP (*Amaranthus hybridus*, *Stachys arvensis* and *Hibiscus trionum*) and MP (*A. hybridus*, *S. arvensis* and *H. trionum*) than in NT (*A. hybridus* and *H. trionum)*. The most abundant species in NT was *Echinochloa* spp. but this was lower than in CP and MP. Herbicide-treated plots were not sprayed until 20 days after planting and only *Polygonum aviculare* and *S. arvensis* were successfully controlled by the herbicides.

Hibiscus trionum and *A. hybridus* were present in the herbicide treated plots (Table 1) and were hand-weeded after the seedling counts, and they, like the weedy plots had more weeds in the CP and MP treatments than in NT.

Maize grain yield Tillage did not significantly affect maize grain yield under weed-free conditions (Figure 1). Under weedy conditions, NT and MP produced similar grain yield, which was significantly greater than CP. Weeds were more than double in weed-free conditions than in weedy conditions.

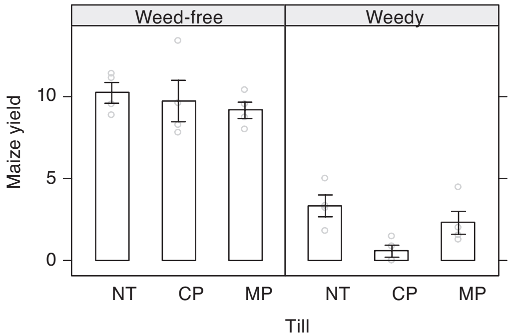

Figure 1. Maize grain yield (t ha^{-1}) in plots treated with three tillage and two weed control systems. NT – No till, CP – Chisel plough, MP – Mouldboard plough. Vertical bars represent standard errors.

Weed seed bank size The low soil disturbance NT plots had the lowest number of seeds in the 0–5 and 5–10 cm soil layer in the weedy plots, whereas in the weed-free treatment NT had more seeds in the 0–5 soil layer than CP and MP. In the weedy plots the number of seeds in NT was 1.6 and 1.8 times (Table 2) lower than CP and MP respectively, but in the weed-free plots NT contained 2.4 and 2.2 times more seeds than CP and MP seeds respectively. MP bore more seeds (32%) in the deeper soil layer than CP and NT which had 13.5 and 10.3% of the total seed bank respectively, in this soil layer.

DISCUSSION

The predominance of broadleaf weeds in the field under CP and MP was likely to be due to these tillage systems exposing seeds to germination promoters such as light (Scopel *et al*. 1994). NT suppresses annual broadleaf weed emergence by reducing the proportion of weed seeds receiving such stimulation of germination (Peachy *et al*. 2004). This resulted in more weed seeds observed in the upper soil layer in CP and MP under weedy conditions as weeds produced seeds and recharged the soil seed bank. The effect of tillage on weed emergence in this study agrees with other reports where annual broadleaf emergence was greater in tilled plots (Ogg and Dawson 1984, Mulugeta and Stoltenberg 1997), but contradicts other studies

Table 1. Seedling emergence (number m^{-2}) of different weed species in the field under three tillage and two weed control systems. ± represents the standard errors.

	Weed-free			Weedy		
Weed	No till	Chisel plough	Mouldboard plough	No till	Chisel plough	Mouldboard plough
Amaranthus hybridus	0.7 ± 0.3	13.2 ± 2.9	12.2 ± 2.7	0.5 ± 0.5	14.7 ± 2.7	16.3 ± 3.2
Echinochloa spp.	6.8 ± 1.7	3.9 ± 1.1	6.6 ± 1.4	9.3 ± 4.3	10.7 ± 2.2	15.4 ± 2.6
Hibiscus trionum	4.1 ± 1.9	27.5 ± 2.8	4.1 ± 2.0	5.0 ± 1.4	26.8 ± 4.8	34.5 ± 4.8
Polygonum aviculare	0	0	0	0	2.5 ± 2.0	3.6 ± 1.1
Stachy arvensis	0	0	0	0	7.5 ± 2.0	23.8 ± 7.0
Other weeds	0.04 ± 0.0	0.07 ± 11	0.04 ± 0.1	0.5 ± 0.4	1.79 ± 1.3	1.3 ± 1.0
Total	11.7 ± 1.0	44.8 ± 2.5	70.9 ± 4.5	15.3 ± 1.6	64 ± 3.0	94.8 ± 4.1

Table 2. Weed seed distribution (number m^{-2}) among soil layers in three tillage systems under weedy and weed-free conditions. ± represents the standard errors.

Till	Depth	Weedy	Weed free
No till	0–5	2465 ± 141	559 ± 58
	5–10	1113 ± 207	327 ± 49
	10–15	547 ± 44	314 ± 49
	15–20	264 ± 22	138 ± 33
Total	(0–20 cm)	4389	1339
Chisel plough	0–5	4055 ± 19	232 ± 21
	5–10	1729 ± 93	201 ± 32
	10–15	333 ± 38	132 ± 49
	15–20	201 ± 27	88 ± 31
Total	(0–20 cm)	6319	654
Mouldboard plough	0–5	4389 ± 135	257 ± 49
	5–10	2081 ± 68	282 ± 15
	10–15	516 ± 44	207 ± 21
	15–20	421 ± 62	352 ± 44
Total	(0–20 cm)	7407	1100

where summer annual broadleaf weed emergence was greater in no-till (Buhler 1992, Oryokot *et al*. 1997, Leon and Owen 2006). Under weed-free conditions, NT and CP had most of the seeds in the top 5 cm and these results are in accordance with previous studies (Clements *et al*. 1996, O'Donovan and MacAndrew, 2000, Auškalnienė and Auškalnis 2009). More weed seeds accumulated near the soil surface because of minimum soil disturbance in the NT limited to planted rows. Under weed-free conditions, more seeds were concentrated in the 15–20 cm layer of the MP treatment, indicating that the mouldboard plough buries some seeds at this depth when inverting the soil. Similar results were reported in other studies (Yenish *et al*. 1992, Rahman *et al*. 2000, Vasileiadis *et al*. 2007).

Maize yield was significantly affected by tillage under weedy conditions. The highest yield observed in NT under weedy conditions was mainly due to fewer weeds (in particular broadleaf weeds), and hence less weed competition compared with the other two tillage systems. The lowest yield observed in CP under weedy conditions could be due to early establishment of *Echinochloa* spp. resulting in maize plants being shaded and deprived of light. Under weed-free conditions, tillage did not affect maize yield. This is consistent with previous studies (Buhler 1992, Hussain *et al*. 1999). No till systems seem to have higher yields than mouldboard plough systems in dry years due to better soil-water storage (Eckert 1984, Lueschen *et al*. 1991). In the semiarid Great Plains maize yielded between 15 and 50% more in NT systems (Anderson 2004).

It can be concluded from this study, as has been reported in many previous studies, that different tillage systems lead to changes in both the above-ground weed flora and soil weed seed banks. NT reduced the number of broadleaf weed seedlings but grass weeds were less affected. Deep tillage caused more seedlings to emerge and resulted in a smaller seed bank.

REFERENCES

Altieri, M.A. and Liebman, M. (1988). 'Weed management in agroecosystems: ecological approaches'. (CRC Press, Boca Raton, Florida).

Anderson, R.L. (2004). Impact of subsurface tillage on weed dynamics in the central Great Plains. *Weed Technology* 18, 186-92.

Auškalnienė, O. and Auškalnis, A. (2009). The influence of tillage system on diversities of soil weed seed bank. *Agronomy Research* 7, 156-61.

Baskin, J.M. and Baskin, C.C. (1985). The annual dormancy cycle in buried weed seeds: A continuum. *Bioscience* 35, 492-8.

Benvenuti, S. (2007). Weed seed movement and dispersal strategies in the agricultural environment. *Weed Biology and Management* 7, 141-57.

Buhler, D. (1992). Population dynamics and control of annual weeds in corn (*Zea mays*) as influenced by tillage systems. *Weed Science* 40, 241-8.

Clements, D.R., Benoit, D.L., Murphy, S.D. and Swanton, C.J. (1996). Tillage effects on weed seed return and seedbank composition. *Weed Science* 44, 314-22.

Eckert, D.J. (1984). Tillage system planting date interactions in corn production. *Agronomy Journal* 76, 580-2.

Fenner, M. (ed.) (1985). 'Seed ecology', p. 151. (Chapman Hall, New York).

Forcella, F., Webster, T. and Cardina, J. (2003). Protocols for weed seed bank determination in agroecosystems. *In* 'Weed management for developing countries', eds I. Addendum and R. Labrada, pp. 3-18. FAO-Rome Plant Production and Protection Paper. (FAO, Rome).

Forcella, F., Wilson, R.G., Renner, K.A., Dekker, J., Harvey, R.G., Alm, D.A., Buhler, D.D. and Cardina, J. (1992). Weed seedbanks of the US corn belt: magnitude, variation, emergence, and application. *Weed Science* 40, 636-44.

Hayashi, I. and Numato, M. (1971). Viable buried-seed population in the *Miscanthus* and *Zoysia* type grasslands in Japan: ecological studies on the buried seed population in the soil related to plant succession. *VI. Japanese Journal of Ecology* 20, 243-5.

Hussain, I., Olson, K.R. and Ebelhar, S.A. (1999). Impacts of tillage and no-till on production of maize and soybean on an eroded Illinois silt loam soil. *Soil and Tillage Research* 52, 37-49.

Leon, R.G. and Owen, M.D.K. (2006). Tillage systems and seed dormancy effects on common waterhemp (*Amaranthus tubersulatus*) seedling emergence. *Weed Science* 54, 1037-44.

Lueschen, W.E., Radford, J.H., Hoverstad, T.R., Kanne, B.K., Orf, J.H., Stienstra, W.C., Warnes, D.D. and Hicks, D.R. (1991). Soybean production as affected by tillage in a corn and soybean management system: I. Cultivar response. *Journal of Production Agriculture* 4, 571-9.

Mulugeta, D. and Stoltenberg, D.E. (1997). Increased weed emergence and seed bank depletion by soil disturbance in no-tillage systems. *Weed Science* 45, 234-41

O'Donovan, J.T. and McAndrew, D.W. (2000). Effect of tillage on weed populations in continuous barley (*Hordeum vulgare*). *Weed Technology* 14, 726-33.

Ogg, A.G. and Dawson, J.H. (1984). Time of emergence of eight weed species. *Weed Science* 32, 327-35.

Oryokot, J.O.E., Murphy, S.D. and Swanton, C.J. (1997). Effect of tillage and corn on pigweed (*Amaranthus* spp.) seedling emergence and density. *Weed Science* 45, 120-6.

Peachy, R.E., William, R.D. and Mallony-Smith, C. (2004). Effect of no-till or conventional planting and cover crops residues on weed emergence in vegetable row crops. *Weed Technology* 18, 1023-30.

Rahman, A., James, T.K., Mellsop, J. and Grbavac, N. (2000). Effect of cultivation methods on weed seed distribution and seedling emergence. *New Zealand Plant Protection* 53, 28-33.

Roberts, H.A. (ed.) (1982). 'Weed control handbook: principles' (Blackwell Scientific Publication, Oxford, London).

Roberts, H.A. and Chancellor, R.J. (1988). Seed bank of some arable soils in the English Midlands. *Weed Research* 26, 251-7.

Schweizer, E.E. and Zimdahl, R.L. (1984). Weed seed decline in irrigated soil after rotation of crops and herbicides. *Weed Science* 32, 84-9.

Scopel, A.L., Ballare, C.L. and Sanchez, R.Z. (1994). Photostimulation of seed germination during soil tillage. *New Phytologist* 126, 145-52.

Vasileiadis, V.P., Froud-Williams, R.J. and Eleftherohorinos, I.G. (2007). Vertical distribution, size and composition of the weed seed bank under various tillage and herbicide treatments in a sequence of industrial crops. *Weed Research* 47, 222-30.

Warwick, M.A. (1984). Buried seeds in arable soils in Scotland. *Weed Research* 24, 261-8.

Yenish, J.P., Doll, D. and Buhler, D.D. (1992). Effect of tillage on vertical distribution and viability of weed seed in soil. *Weed Science* 40, 429-33.