Manipulating the seed bank to manage herbicide-resistant weeds

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Summary Weed control and farming system practices are being assessed for their ability to reduce the seed banks of weed species that have developed herbicide resistance. In six long-term field experiments in southern Queensland, we are testing a wide variety of management practices to deplete soil seed banks of key annual weed species, such as wild oat, common sowthistle, liverseed grass, barnyard grass and awnless barnyard grass. Irrigation increased the emergence of all species with timing of irrigation being important. Higher stubble levels increased the emergence of larger seeded species including wild oat and awnless barnyard grass, but decreased the emergence of sowthistle. Cultivation reduced emergence of sowthistle and summer grasses, but had little effect on wild oat emergence. The wild oat seed bank was reduced by up to 70% in the top 5 cm of soil either with or without cultivation. However, cultivation increased the number of wild oat seeds persisting below 5 cm. Data suggest that wetter environments will encourage a more rapid depletion of summer grasses and sowthistle through increased emergence. Similarly, maintaining crop residue may increase seed bank depletion of larger seeded species through increased emergence. Cultivation increases the persistence of all the target species and is not a favoured practice for rapid depletion of the seed bank.

Keywords Herbicide resistance, seed bank, wild oat, barnyard grass, sowthistle.

INTRODUCTION

The incidence of herbicide-resistant weeds is increasing in Australian farming systems. In the northern cropping region of Australia several cases of glyphosate resistance in awnless barnyard grass (*Echinochloa colona* L. (Link)) and liverseed grass (*Urochloa panicoides* P.Beauv.) have developed since the first cases in 2007 and 2008 respectively (Storrie *et al.* 2008). Populations of wild oat (*Avena fatua*) have resistance to Group A, B and Z herbicides and are at high risk of Group M resistance. Populations of common sowthistle (*Sonchus oleraceus*) are resistant to Group B herbicides and are also at risk of Group M resistance. Effective strategies for prevention and management of resistant weeds and those at high risk are required.

The weed seed bank is the predominant source of new weed infestations. Thus, the ability to quickly reduce existing seed banks through increased emergence, seed decay or predation, or by placing seeds where they are unable to emerge, will minimise future weed pressures, which is important for difficult-to-control weed species.

This paper reports on the emergence and seed persistence of wild oat, common sowthistle, liverseed grass, barnyard grass (*E. crus-galli*) and awnless barnyard grass in response to a range of weed control and farming systems practices in the sub-tropical environment of the northern grain region. Preliminary results are discussed in relation to their implications for better management of these problem weeds and provide information to better understand their seed bank ecology.

MATERIALS AND METHODS

To help plan the experiments, the literature was reviewed to identify possible treatments that encourage rapid depletion of seed banks of the target weed species. Following this, six long-term experiments were established in June 2008 at Wellcamp (27°40'S, 151°50'E), west of Toowoomba, Queensland. The soil at the site is a black earth with swelling and cracking characteristics. The experiments are planned to continue for 3 and possibly 5 years.

Establishment of the seed bank To increase the initial seed bank, the target weed species were sown over each experimental area in June (wild oat) or December 2008 (liverseed, barnyard grasses, sowthistle) and allowed to set seed. Experiment 1 had liverseed, barnyard grass, awnless barnyard grass and wild oat planted in separate plots, whereas the remaining experiments had awnless barnyard grass, wild oat and sowthistle in every plot.

The average starting seed bank was, as assessed through soil sampling, 240, 1720, 4475 and 21,200 seeds m^{-2} for liverseed grass, wild oat, barnyard grass and awnless barnyard grass respectively. Due to the small seed size of common sowthistle, the starting seed bank was not assessed.

Treatments This paper considers only Experiments 1, 2 and 3. The experiments are exploring the influence of differences between species (Experiment 1), environmental factors (Experiment 2), and tillage and stubble (Experiment 3). Each experiment has eight treatments with three (Experiment 1) or four replicates. Treatments started after all seed set was complete (April 2009).

Assessments Changes in the soil seed bank over time are being assessed by emergence counts, taken after each rain event, and by soil cores (except for sowthistle) taken every 6 months in selected plots. After emergence counts are made, each plot is sprayed or cultivated depending on treatment. Soil cores are collected in April and September each year from the standard treatment (zero-tillage long fallow) and the treatment expected to have the greatest seed bank depletion in each experiment. Soil cores are taken using a 10 cm diameter soil corer to a depth of 10 cm, except for Experiment 3 where cores are taken at three depths, 0–5 cm, 5–10 cm and 10–20 cm to account for seed burial. Cores are processed via washing through sieves before sorting and counting weed seeds. Initial soil cores were collected in April 2009.

Statistical analyses have not been included in this paper as experiments are in their early stages with further data to be collected.

RESULTS

Experiment 1 The greatest emergence of all species was in the zero-till long fallow treatment (Table 1). The largest portion of the seed bank emerging was for wild oat, while barnyard grass emerged more than either awnless barnyard or liverseed grass. The emergence of the summer grasses was reduced by both cultivation and winter cropping. In contrast, the emergence of wild oat was affected to a lesser extent by both treatments.

Experiment 2 Irrigation of two applications of 25 mm each increased the emergence of awnless barnyard grass (Table 2) and sowthistle (Figure 1). Irrigation applied in summer increased the emergence of awnless barnyard grass considerably, whereas winter irrigation had no impact. The cumulative emergence of sowthistle was increased by irrigation at any time of the year, but the greatest emergence occurred when there were two applications over summer.

Irrigation at any time of the year had little or no impact on the emergence of wild oat (Table 2). This was reflected in a similar depletion of the seed bank in no irrigation (78%) compared with the winter/summer (×2) irrigation treatment (77%).

Table 1. Cumulative emergence (as % of initial seed bank) of four weed species in Experiment 1. ABG = awnless barnyard grass, BG = barnyard grass, LSG = liverseed grass, WO = wild oat.

Weed	Treatment	Emergence (%)
ABG	Zero-till long fallow	2.5
	Cultivation	0
	Winter cropping	0
BG	Zero-till long fallow	3.7
	Cultivation	1.5
	Winter cropping	0.76
LSG	Zero-till long fallow	2.3
	Cultivation	0.65
	Winter cropping	0
WO	Zero-till long fallow	4.9
	Cultivation	3.7
	Winter cropping	3.5

Table 2. Cumulative emergence (% of initial seed bank) of two weed species in Experiment 2, where ABG = awnless barnyard grass, WO = wild oat.

Weed	Irrigation treatment	Emergence (%)
ABG	Nil	2.4
	Summer (×2)	3.6
	Winter (×2)	2.6
	Winter and summer (×2)	5.7
WO	Nil	9.6
	Summer (×2)	9.3
	Winter (×2)	9.0
	Winter and summer (×2)	9.1

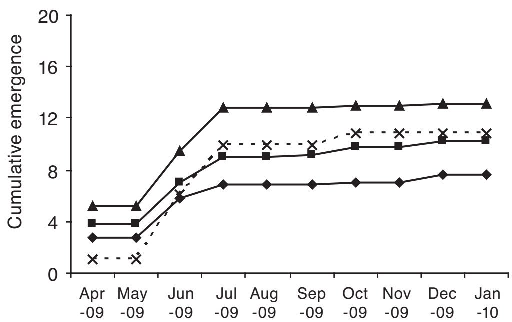

Figure 1. Cumulative emergence (no. m^{-2}) of common sowthistle in response to irrigation with 50 mm applied in summer (triangle) or winter (square), and 25 mm in winter and summer irrigation (cross) compared with no irrigation (diamond).

Experiment 3 Cultivation with various frequencies and intensities altered the emergence of wild oat, awnless barnyard grass (Table 3) and sowthistle (Figure 2). A light harrow increased the emergence of wild oat, but not awnless barnyard grass, whereas a regular cultivation after each flush of emergence decreased overall emergence of awnless barnyard grass, but not wild oat. All forms of cultivation reduced the emergence of sowthistle (Figure 2). As the intensity increased, the emergence decreased with the lowest emergence under a treatment of tillage after every flush of emergence.

The persistence of wild oat seed and position in the soil profile changed between April and September 2009 in all sampled treatments (Table 4). The seed bank in the top 5 cm was reduced by 64–70%. In contrast, the seed bank increased substantially for the depths of 5–10 and 10–20 cm. These changes were for both cultivation and zero till treatment, although the increase in wild oat seed number was greater with cultivation with an approximate 3- to 7-fold increase (Table 4).

The addition of either wheat or barley stubble increased the emergence of both wild oat and awnless barnyard grass (Table 3) and decreased the emergence of sowthistle (Figure 2).

DISCUSSION

Summer grasses Cultivation reduced the emergence of summer grasses in both Experiments 1 and 3. The reduction in emergence is likely due to burial of seed beyond the depth of emergence for these species. Awnless barnyard grass emergence is favoured at a depth of 0–2 cm and liverseed grass emergence is favoured at a depth of 5 cm (Walker *et al.* 2010).

However, burial of seed below the depth of emergence can result in increased seed persistence. Walker *et al.* (2010) found that burial of these summer grasses to a depth of 10 cm increased persistence up to 24 months and stated the importance of keeping seeds of summer grass species on or close to the soil surface for rapid depletion of the seed bank. Therefore, while cultivation may decrease emergence, it increases the seed bank's persistence.

In a zero tilled system, the addition of summer irrigation greatly increased the emergence of awnless barnyard grass. Such an increase in emergence should result in an equal or greater reduction of the seed bank (although not yet measured). In environments where more summer rain is received, the seed bank of these summer grasses is likely to decline more rapidly. Diligence in controlling emergences will be required to limit seed bank replenishment.

The addition of stubble increased the emergence of awnless barnyard grass. Designed to mimic crop residue after harvest, the results show that leaving high levels of crop residue behind may speed up depletion of the seed bank. The amount and type of residue may also have an impact.

Table 3. Emergence (as % of initial seed bank) of target weed species in Experiment 3. ABG = awnless barnyard grass, WO = wild oat.

Weed	Cultivation treatment	Emergence (%)
ABG	Nil no stubble	3.8
	After every flush	1.3
	Light harrow	3.2
	Nil with stubble	4.5
WO	Nil no stubble	8.0
	After every flush	8.0
	Light harrow	10.3
	Nil with stubble	14.8

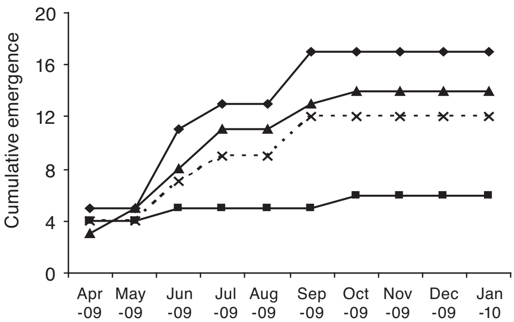

Figure 2. Cumulative emergence (no. m^{-2}) of common sowthistle in response to cultivation with annual light harrow (triangle), tillage after every flush (square) compared with no tillage + no stubble (diamond) and no tillage + high stubble levels (cross).

Table 4. A comparison between the impact of cultivation after every flush and zero-till long fallow on the persistence of wild oat seeds in Experiment 3 (% change of initial seed bank).

Treatment	Depth (cm)	Initial seed bank	Change (%)
Zero till	0–5	1930	↓ 70
Cultivation		1970	↓ 64
Zero till	5–10	33	↑ 103
Cultivation		33	↑ 276
Zero till	10–20	134	↑ 293
Cultivation		152	↑ 697

Common sowthistle Cultivation reduced the emergence of sowthistle, with an increasing intensity being more effective. Widderick *et al.* (2010) also found that emergence was favoured under zero tillage systems where most seeds remain in the top 1 cm of soil, from where emergence was greatest. They also found that sowthistle seed numbers in the top 2 cm of soil were reduced by up to 90% when cultivated two or three times.

As well, Widderick *et al*. (2010) found that sowthistle seed buried below 2 cm can persist for up to 30 months, whereas seeds on or near the soil surface rarely persist beyond 8 months. Therefore, the perceived benefit of cultivating to reduce sowthistle emergence is outweighed by the persistence of seeds buried at depth.

Irrigation at any time of the year increased the emergence of sowthistle, but most by two summer irrigations. Sowthistle can emerge all year round in the sub-tropical environment of the northern grain region and its emergence is determined more by water availability than temperature (Widderick *et al.* 2010). Data show that wetter environments will favour all year round sowthistle emergence. Emergence of sowthistle in summer will be greater in environments with greater summer rain. Widderick *et al.* (2010) found that greater rainfall was required in hotter months for emergence of sowthistle.

Adding stubble was effective in reducing sowthistle emergence. This is in contrast to the effect on both awnless barnyard grass and wild oat. The difference may be the smaller size of sowthistle seed and its inability to penetrate the layer of stubble. The effect of added stubble on the seed bank is yet to be determined in this study.

Wild oat Emergence of wild oat was increased by a light harrow but not affected by regular cultivation. Wild oat can emerge over a wide range of depths with very few emerging from the soil surface (Medd 1996). The light harrow may have incorporated some of the seeds that were still on the soil surface resulting in their emergence.

As for awnless barnyard grass, the addition of stubble increased the emergence of wild oat seedlings. Similarly, the stubble provided a favourable environment for wild oat emergence, possibly via either increased water or reduced soil temperature. Maintaining crop residues after harvest may increase the emergence of wild oat resulting in a more rapid reduction of the seed bank.

The general trend of persistence in wild oat was for a reduction in the top 5 cm of soil and an increase in the 5–20 cm layer. The soil that these experiments are on is a black earth, which has a propensity to shrink and swell resulting in large cracks and crevices and movement of seeds up and down the soil profile depending upon the stage of the wetting and drying cycle. In addition, wild oat has the ability to bury itself during repeated hydration/dehydration cycles.

Results from this paper have shown that both environmental factors and the weed control tactics used will impact on the rate of seed bank depletion. Weed seed bank depletion should be a part of every integrated weed management system. Applying useful tactics in combination could have large positive effects toward depleting seed banks.

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