Impacts of Strategic Tillage in a No-Tillage Conservation Cropping System on Wild Oats Population

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Summary Wild oats (*Avena sterilis* ssp. *ludoviciana*) is a major winter weed in no-tillage conservation agriculture (NTCA) systems of Australia's Northern Grains Region. Many wild oat seeds shed before crop harvest and build a persistent seed bank in the 0-2 cm soil layer in a NTCA paddock. Reintroduction of tillage in a strategic way can be useful to manage this weed effectively. To understand the impact of strategic tillage (ST) on the soil seedbank dynamics and emergence pattern of wild oats, four tillage treatments were evaluated in a long-term NTCA paddock. The treatments were NT: no-tillage, ST_1: ST applied in the first year of study only, ST_2: ST applied in the second year of study only, and CT: conventional tillage. Soil samples were collected from 0-5, 5-10, and 10-15 cm depths to study the seedbank dynamics, and two 1 m^2 permanent quadrats were established per plot to study the emergence pattern of wild oats. In NT, 95% of wild oat seeds were found at 0-5 cm depth, whereas 88% of seeds were distributed to a depth of 10 cm under ST_1 or ST_2, depending on when ST was applied. In CT, 75-85% of seeds were buried below 10 cm depth. In NT, 88% of seedlings emerged during the first 20 days after wheat planting (DAWP), but the rest continued to emerge until 45 DAWP, leading to a wide window of emergence. This produced multiple wild oat cohorts under NT with staggered phenology. In contrast, emergence of seedlings was completed within 20 DAWP from ST or CT and produced a single cohort of wild oat plants with matching phenology. Among the tillage plots, emergence was minimal in ST throughout the season. Strategic use of tillage was found to be effective to minimize wild oat infestation by burying seeds to a depth from where the seedlings could not emerge.

Keywords emergence pattern, seed burial, soil seedbank, tillage, wild oats infestation

INTRODUCTION

There has been a major transformation in broadacre crop production systems in Australia's Northern Grains Region (NGR; which comprises parts of Queensland and all of New South Wales) over the last 50 years (Walsh *et al*. 2019). About 90% of broadacre farmers of this region have already adopted conservation agriculture (CA) i.e., no- or reduced-tillage coupled with stubble retention (Llewellyn *et al*. 2012). However, due to the reduction in tillage operations, farmers are facing weed control challenges. Wild oats (*Avena sterilis* ssp. *ludoviciana* (Durieu) Nyman), a major difficult-to-control winter weed has already increased its abundance in CA systems, due to buildup of a persistent seedbank in the 0-2 cm soil layer (Widderick and McLean 2017).

In recent years, there has been increased interest in the use of strategic tillage (ST) in the no-tillage CA (NTCA) system to address the soil seedbank issue of wild oats (Walsh *et al*. 2019). The aim of ST is to bury wild oat seeds to a depth from where they cannot emerge (Walsh *et al*. 2019). However, application of any tillage operation, whether it is ST or conventional tillage (CT), can lead to a change in weed population dynamics by changing the vertical seed distribution pattern in the soil environment (Cousens and Mortimer 1995). A CT operation involves multiple passes of tillage each year.

The present study, therefore, aimed to evaluate the impact of different tillage treatments on the population dynamics of *A. sterilis* ssp. *ludoviciana* (hereafter *A. ludoviciana*) in a field setting. The study evaluated the seedbank dynamics (seed distribution pattern in 0 to 15 cm soil depth) and the emergence pattern of *A. ludoviciana* when growing in a wheat crop (*Triticum aestivum* L.). Knowing this information will enhance our understanding of the impact of different tillage practices on *A. ludoviciana* population dynamics and will assist in improving the effectiveness of its management program.

MATERIALS AND METHODS

Experimental site establishment The study was conducted at Gatton, Queensland for two consecutive years, 2019 and 2020. The experimental site had a history of growing different winter crops for fodder purposes using NTCA approach for the previous 15 years (2003 to 2018). The crop sequence planted from 2003 to 2018 was 1 year of wheat followed by 1 year of either lupin (*Lupinus albus* L.) or barley (*Hordeum vulgare* L.) before returning to wheat. The soil type at the site was a black Vertosol (48% clay, pH 8.2) and had 2.8% total C, 0.22% total N, 6.9, 2.4 and 5.4 mg kg^{-1} of P, K and S, respectively. An initial seedbank study confirmed the experimental site was free from *Avena* spp.

The field experiment was conducted using a randomized complete block design with four replications. The site with an area of 2,888 m^2 (38 m × 76 m; width/length) was first divided into four blocks. Each block was then sub-divided into four plots to carry four tillage treatments (Table 1). Each plot (5 m × 15 m) was separated by 2 m lateral alleys and 2 m block alleys. Each plot was artificially infested with *A. ludoviciana* seed (Westmar biotype) by broadcasting 30 viable spikelets m^{-2} (i.e., 30 viable primary and 30 viable secondary seeds; in total 60 viable seeds m^{-2}). The tillage treatments were then imposed randomly to the plots within a block.

Wheat crop establishment Immediately after completing tillage operations, wheat (cv. LRPB Lancer) was planted at the rate 60 kg seeds ha^{-1} with 25 cm row spacing and with 3 cm planting depth. To control broadleaf weeds, a tank mixture of selective in-crop herbicides, halauxifen and florasulam at 25 g a.i. ha^{-1} of Paradigm®, and ethylhexyl ester at 440 mL a.i. ha^{-1} MCPA 570 LVE® were applied by boom spray 45 days after wheat planting (DAWP) during the first year of the experiment. Paraffinic oil and alkoxylated alcohol non-ionic surfactants at the rate 0.5% v/v of Uptake® was also used in the tank mixture. Each year, the crop was irrigated four times.

Soil sample collection for seedbank study To determine the distribution of *A. ludoviciana* seeds present across different soil depths, 10 intact soil cores (each 5 cm diameter, 0 to 15 cm depth) were extracted across the experimental site at random (immediate after wheat planting) from the centre 3 m × 10 m of each 5 m × 15 m plot in both years. The intact cores were divided into three sub-samples *viz.* 0 to 5, 5 to 10 and 10 to 15 cm. Each sub-sample was spread thinly within a shallow germination tray. The trays were watered daily to field capacity and observed at 2- day intervals to count *A. ludoviciana* seedling emergence. The number of emerged seedlings was recorded replication-wise.

Seedling emergence of *Avena ludoviciana* To count the number of in-crop *A. ludoviciana* seedling emergence, two 1 m × 1 m permanent quadrats were established in each plot during May to October in both years. The seedling emergence data were recorded weekly and especially after an irrigation/rainfall event. Emerged seedlings were tagged to avoid double counting and distinguish between cohorts.

Statistical analysis The data of all parameters were analyzed separately year-wise, as the year effect was found significant ($P \leq 0.05$) for the parameters used. The data were subjected to analysis of variance (ANOVA) using Minitab software. Means were separated using Fisher's protected least significant difference (LSD) test at $P \leq 0.05$. All graphs were prepared using SigmaPlot software.

RESULTS

Soil seedbank dynamics of *Avena ludoviciana* The effect of tillage treatments was found to significantly affect ($P \leq 0.001$) the seedbank dynamics of *A. ludoviciana* in both years of study for every soil depth except 10-15 cm in 2019 (Figure 1). In 2019, as expected, the seeds broadcasted in the NT and ST_2 (which was still NT in first year) were all concentrated in the 0-5 cm soil depth. In contrast, seeds were distributed mainly in the 5-10 cm soil depth (75% of total seeds) followed by the 0-5 cm depth (25%) under ST_1. In CT, 50% of seeds were buried in the 10-15 cm depth and the rest were

Table 1. Details of tillage treatments on a long-term no-tillage field at Gatton, Queensland to determine the impact of different tillage treatments on the population dynamics of *Avena sterilis* ssp. *ludoviciana*.

Tillage treatments	Description of tillage operations	Operational depth of tillage (cm)	Code
No-tillage (with crop residue retention) in both years	No pre-sowing tillage	-	NT
Strategic tillage in first year, no-tillage (with crop residue retention) in second year	Pre-sowing tillage imposed with one-pass tine implement on two occasions during April, 14-days apart	10 cm (first year), no-tillage in second year	ST_1
No-tillage (with crop residue retention) in first year, strategic tillage in second year	Same tillage operation as described in ST_1, but imposed in second year of the trial	No-tillage in first year, 10 cm in second year	ST_2
Conventional tillage in both years	Two-passes of disc implement followed by one-pass rotary hoe, and one-pass harrow conducted during April to May; each tillage 14-days apart	15 cm in both years	CT

distributed equally to the other two depths. In 2020, 96% of the seeds of NT were retained in the 0-5 cm depth and the rest were buried to the 5-10 cm depth (Figure 1). In the ST_1 (which became NT in second year), 86% of seeds were distributed in the 0-5 cm depth, 13% in the 5-10 cm, and only 1% in the 10-15 cm depth. When ST was applied to NT plot in the second year (i.e., ST_2), 88% of seeds were buried at 5-10 cm with only 10% of seeds distributed at 0-5 cm, and 2% were distributed at 10-15 cm. In CT, half of the total seeds were buried in the 10-15 cm depth followed by 37% at 5-10 cm whereas only 13% of seeds were distributed at 0-5 cm.

Seedling emergence The tillage treatments were found to significantly affect the seedling emergence of *A. ludoviciana* in a cropping environment in both years ($P \leq 0.001$) (Figure 2). In 2019, 60% of seedlings of NT and ST_2 emerged during the first 20 DAWP, 30% of seedlings emerged during 20-40 DAWP, and 10% emerged from 40-50 DAWP (Figure 2). In 2020, 88% of seedlings of NT and ST_1 emerged during the first 20 DAWP, 8% of seedlings emerged during 20-40 DAWP, and 4% emerged from 40-50 DAWP (Figure 2). Application of ST or CT restricted seedling emergence to within 20 DAWP in both years. Strategic tillage (either ST_1 or ST_2) was able to reduce seedlings load by almost half compared to NT or CT in both years (Figure 2). Applying ST in year one and then returning to practicing NTCA in the second year resulted in 25% less seedling emergence of *A. ludoviciana* than a continuous NTCA practice.

DISCUSSION

Seedbank dynamics The NT treatment helped to retain > 95% of *A. ludoviciana* seeds on or close to the soil surface in both years (Figure 1). However, 4% of the seeds were found in the 5-10 cm depth in this treatment. Possibly those seeds fell into the cracks of the Vertosol soil during the time of their shedding. Medd (1996) reported that in a Vertosol soil a functional seedbank of wild oats can exist below 5 cm depth. When a ST operation was applied in NT plots, 10% less seeds were retained in the 0-5 cm depth in the following year compared to NT (Figure 1). A ST operation could bury as many as 88% of seeds to a 5-10 cm depth as observed in the second year (Figure 1). On the other hand, several passes of tillage with a disc, rotary hoe and power harrow under CT distributed *A. ludoviciana* seeds at different depths in the soil profile with 75-85% of seeds concentrated to 10 cm or greater depths (Figure 1). A greater number of seeds buried to 10 cm or greater depth means they would germinate but fail to reach the surface and die (Cousens and Mortimer 1995). However, 15-25% seeds were also found to be retained in 0-5 cm depth under CT in both years, which favoured more seedlings to emerge (20 and 50% higher than NT and ST, respectively in both years) from this treatment (Figure 1).

Seedling emergence The maximum number of seedlings were able to emerge immediately after planting the wheat crop from all tillage treatments in both years (Figure 2). However, seedlings continued to emerge up to 50 DAWP in no-tillage plots (Figure 2). In contrast, no seedlings were found to emerge after 20 DAWP in CT or ST (ST_1 in first year, ST_2 in second year; Figure 2). The staggered nature of germination under NT was attributed mainly to poor seed-soil contact (Froud-Williams 1983). This staggered nature of germination was found to stop in the tillage-operated environment (CT or ST; Figure 2). Between the two types of tillage, seedling emergence of *A. ludoviciana* was increased under CT than ST probably due to increased seed-soil contact (Figure 2). By applying a selective in-crop herbicide, seedling emergence during 20 DAWP could be minimized. Applying a ST operation was found to lower the population density of *A. ludoviciana* from the beginning, thereby offering less competition with the crop as well as reducing the production cost related to herbicide application.

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Figure 1. Effect of different tillage treatments (NT: no-tillage in both years; ST_1: strategic tillage in first year and no-tillage in second year; ST_2: no-tillage in first year and strategic tillage in second year; CT: conventional tillage in both years) on *Avena sterilis* ssp. *ludoviciana* seed distribution pattern at soil depths of 0-5, 5-10, and 10-15 cm. Error bars represent standard errors of the mean of four replicate plots.

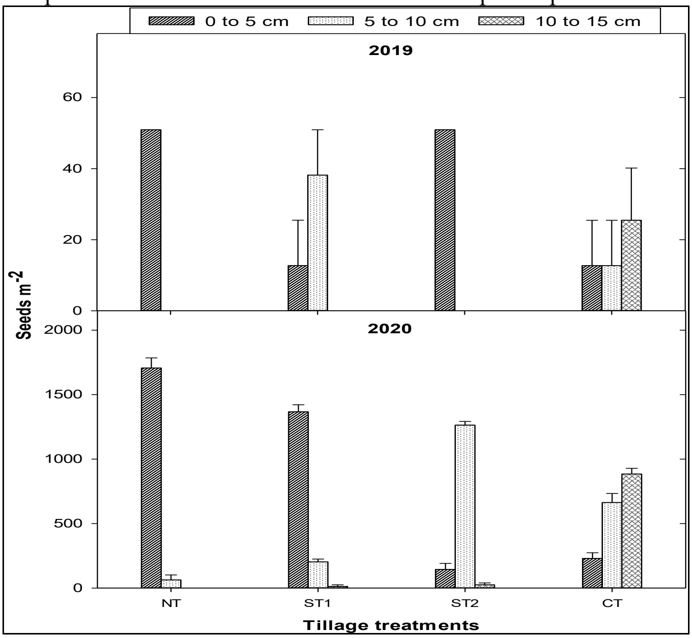

Figure 2. Seedling emergence of *Avena sterilis* ssp. *ludoviciana* under different tillage treatments (NT: no-tillage in both years; ST_1: strategic tillage in first year and no-tillage in second year; ST_2: no-tillage in first year and strategic tillage in second year; CT: conventional tillage in both years). Error bars represent standard errors of the mean of four replicate plots.