SEED DORMANCY AND GERMINATION PHENOLOGY OF GRASS WEEDS AND IMPLICATIONS FOR THEIR CONTROL IN CEREALS

K.F. KON, G.B. FOLLAS and D.E. JAMES

Syngenta Crop Protection Ltd, Tower 2, Level 7, Symonds Street, Auckland

Corresponding author: kee_fui.kon@syngenta.com

ABSTRACT

Seeds of Italian ryegrass, perennial ryegrass, wild oat, winter wild oat, phalaris and barnyard grass, collected during the 2005/06 season, were tested for dormancy and germination phenology between April and December 2006. In laboratory and outdoor environments, dormancy was widespread in grass weed but not in ryegrass seeds. The seeds of grass weeds had better germination in the outdoor environment than the laboratory. In the outdoor environment, only 15% of wild oat and winter wild oat, 19-63% of phalaris and 39% of barnyard grass seed germinated. Protracted germination varied between species in two to seven flushes. The earliest timing for effective post-emergence grass control under the experimental conditions appeared to be about 6 weeks after sowing for wild oats and ryegrasses, 12 weeks for phalaris and 14 weeks for barnyard grass. The extended germination periods of phalaris and barnyard grass are a challenge to growers in designing a cost-effective herbicide programme.

Keywords: seed dormancy, germination, *Avena fatua*, *Avena ludoviciana*, *Lolium perenne*, *Lolium multiflorum*, *Phalaris aquatica*, *Echinochloa crus-galli*, post-emergence herbicide.

INTRODUCTION

In the past 60 years, a huge volume of work has been published on the seed dormancy and germination of both crop and weed species (Ellis et al. 1985; Baskin & Baskin 1988, 1998; Bewley 1997; Buhler & Hoffman 1999; Fenner & Thompson 2005). For good practical reasons, most if not all studies dealt with a limited number of environmental factors associated with dormancy breaking and so a holistic picture on dormancy and germination remains confused (Finch-Savage & Leubner-Metzger 2006). In the last decade, advances in genomics have provided better insight into seed dormancy and germination at the physiological and molecular level (Fennimore et al 1999; Foley 2001; Nikolaeva 2001; Bentsink and Koorneef 2002; Koorneef et al. 2002; Gu et al. 2003; Baskin & Baskin 2004; Finch-Savage & Leubner-Metzger 2006). Seed dormancy and germination are complex heritable traits controlled by multi-genes, mediated by the plant hormones, abscisic acid, gibberelin and ethylene, and affected by developmental and environmental factors before and after the seed is formed (Koorneef et al. 2002; Finch-Savage & Leubner-Metzger 2006). Following shedding, seed dormancy continues to change under the influence of the ambient environment, including agricultural practices such as tillage, cropping, irrigation and fertilisation, making the study of seed dormancy and germination extremely challenging.

Seeds of annual grass weeds are small with a limited store of reserves and thus have one chance to germinate, develop and reproduce. Seed dormancy is thus one of the survival mechanisms of invasive annual grass weeds. Except for a few species that germinate mostly in a single flush (Gill & Blacklow 1985; Kon & Blacklow 1988; Allen & Meyer 2002), many grass weeds have residual dormancy that protracts germination

over several flushes during the cropping season and/or over several cropping seasons. A protracted germination phenology with weed cohorts of different growth stages during the season complicates weed control for the growers. The comprehensive dormancy classification of Nikolaeva (2001) and Baskin & Baskin (2004) ascribes the dormancy classes of non-dormancy and physiological dormancy to grass plants (Finch-Savage & Leubner-Metzger 2006).

It is an axiom that early control of small weeds is easier and less expensive than late removal of fast-growing large weeds in cereals. Furthermore, yield loss can be significant with successive delay in weed removal. For example, wheat yield decreased by 6% and 16%, respectively, if wild oats were removed at GS32 (two nodes) and GS39 (emergence of flag leaf) as compared to GS30 (start of stem elongation) (Syngenta 1998). This is the basis on which Syngenta New Zealand recommends the application of a selective post-emergence grass herbicide in cereals no later than GS30 of the grass weeds (Syngenta 2006).

However, weed control at GS30 could pose a problem to growers if grass weed seeds continue to germinate after the largest established weed cohort has reached GS30. As such, it is essential to understand the dynamics of seed dormancy and germination phenology of the key grass weeds in the important cereal production areas in New Zealand. These key grass weeds are wild oat (*Avena fatua*), winter wild oat (*A. ludoviciana*), Italian ryegrass (*Lolium multiflorum*), perennial ryegrass (*L. perenne*), barnyard grass (*Echinochloa crus-galli*) and several canary grasses including phalaris (*Phalaris aquatica*). Their importance in cereals is common knowledge in the industry.

In New Zealand, McWha et al. (1976) studied only the seed dormancy of wild oats and this was done in the laboratory. The objectives of this work were (1) to determine dormancy and germination phenology of several key grass weeds and populations in both the laboratory and outdoor environments, and (2) to predict the optimum herbicide application timing to maximise the biological efficacy of selective post-emergence herbicides. Given the dynamic nature of seed dormancy and germination, it is only possible to conduct seed studies that simulate, rather than are the same as or even close to, the natural field conditions at the seed sources (Ellis et al. 1985; Baskin & Baskin 1998). This paper reports on species and population differences in seed dormancy and germination phenology, normalised in one location within a uniform set of conditions. A rich database with germination phenology from various outdoor and field locations can provide practical information on post-emergence grass weed management.

METHODS

From December 2005 to January 2006, seeds of the grass weeds, wild oat, winter wild oat and phalaris, were collected from Canterbury, and barnyard grass collected from Wanganui (Table 1). Seeds of perennial ryegrass and Italian ryegrass of the 2005/6 season were obtained from a seed producer in Canterbury. Wild oats were identified according to Edgar (1980), while the other species were confirmed according to Wilding et al. (1998). The seeds were cleaned and stored in opaque envelopes in the dark at room temperature until use.

The germination phenology of these nine weed populations was studied at 4-weekly intervals from 10 April to 18 December 2006 in the laboratory. Twenty seeds of each population were placed on a double layer of paper towel, saturated with 50 ml tap water. After folding in half, each paper towel was placed in a plastic sleeve to avoid drying out. The sleeves were placed in a box file and kept upright in the dark. There were two replicates of each population in a randomised block design. The temperature was regulated at 20±2°C. After 2 weeks, germinated seeds were counted and recorded. Each remaining seed that had not germinated was examined for viability. The seed was considered viable if the embryonic structure remained hard in the imbibed phase when pressed between fingers (Taylor et al. 2003). The standard tetrazolium test for viability has been reported to be unreliable for some seeds (Hilhorst 1997).

On 20 November 2006, additional paper-towel tests subjected the seeds to artificial dormancy-breaking, simulating the two main field factors: winter chilling and scarification during soil cultivation (McWha et al. 1976; Ellis et al 1985), using three seed treatments. These were (1) untreated seeds, (2) seeds that had imbibed and then been stratified (pre-chilled) at 4°C in the refrigerator for 8 weeks and (3) seeds that had their seed covering structures scarified by cutting off the upper quarter of seed, had imbibed and then been stratified at 4°C in the refrigerator for 8 weeks. These treatments were replicated twice. After 2 weeks, germinated seeds were counted and recorded. Each remaining seed that had not germinated was examined for viability as before.

TABLE 1: Populations of grass weeds and ryegrasses sourced from Canterbury and Wanganui.

Species	Common name	Variety/location	Region
Lolium perenne	Perennial ryegrass	Cannon[1]	Canterbury
Lolium multiflorum	Italian ryegrass	Crusader[2]	Canterbury
Avena fatua	Wild oat	Highbank	Canterbury
Avena ludoviciana	Winter wild oat	Highbank	Canterbury
Avena fatua	Wild oat	Irwell	Canterbury
Avena ludoviciana	Winter wild oat	Irwell	Canterbury
Phalaris aquatica	Phalaris	Eiffelton	Canterbury
Phalaris aquatica	Phalaris	Tai Tapu	Canterbury
Echinochloa crus-galli	Barnyard grass	Wanganui	Wanganui

[1]Diploid cultivar for all-year round grazing.
[2]Diploid cultivar for short-rotation grazing.

All the above populations (except the wild oats from Irwell due to a shortage of seeds) were planted on 9 July 2006 to 1 cm depth at 100 seeds per free-draining garden tray (35 by 30 cm) filled with Yates Premium Compost Mix. Each population was replicated twice in a randomised block design in an outdoor environment in Auckland. The trays were watered to field capacity at the start of the trial, but subsequently subjected to the natural weather throughout the trial period from July to December. At 2-weekly intervals, germinated seedlings with at least one developed leaf (GS11) were counted as a germination flush and removed until the remaining germinated plants were no more than 2 plants/tray for wild oats, 3 plants/tray for annual ryegrasses and 4 plants/tray for phalaris. These final weed densities were the approximated species economic thresholds when the herbicide cost and yield gain near breakeven (Taye et al. 1997). These final weed densities also represented the earliest timings when weed control is considered effective with a minimum risk of further germination and requirement of a follow-up herbicide treatment.

The germination data were subjected to analysis of variance and LSD tests using the Analysis Tool Pack in Microsoft Excel. The daily rainfall and minimum grass temperatures from 1 July to 31 December 2006 for Auckland, Wanganui and Ashburton (representing Canterbury) were bought from NIWA and subjected to analysis of variance and regression analysis using the same statistical package.

RESULTS

Germination in the laboratory

There were significant differences (P<0.01) in germination between grass seed populations. Over 80% of the perennial and Italian ryegrass seeds germinated in the laboratory (Table 2). In contrast, most of the wild oat, winter wild oat and phalaris seeds were in dormancy with 13% or less germinated. All non-germinated seeds were viable.

TABLE 2: Germination (%) of crop and weed seeds after 14 days at 20°C in the laboratory. Seeds were tested over a period of 9 months at 4-weekly intervals, but only the results of 8-weekly intervals and the last test on 18 December are presented.

Species	Variety/ location	10 Apr	05 Jun	31 Jul	25 Sep	20 Nov	18 Dec
Perennial ryegrass	Cannon	90 a[1]	98 a	100 a	90 a	95 a	90 a
Italian ryegrass	Crusader	83 a	93 a	88 b	90 a	80 b	88 a
Wild oat	Highbank	0 c	0 c	0 c	5 c	8 cd	13 b
Winter wild oat	Highbank	0 c	0 c	0 c	0 c	0 d	0 c
Wild oat	Irwell	0 c	3 c	0 c	3 c	13 c	5 c
Winter wild oat	Irwell	0 c	0 c	5 c	0 c	3 d	0 c
Phalaris	Eiffelton	0 c	0 c	0 c	0 c	0 d	0 c
Phalaris	Tai Tapu	0 c	0 c	3 c	8 c	5 d	8 bc
Barnyard grass	Wanganui	0 c	0 c	0 c	0 c	0 d	0 c

[1]Means for species/location at each time point (down a column) followed by the same letter are not significantly different (P<0.05) from each other.

There were significant differences (P<0.01) in germination between seed treatments within some populations. Stratification or scarification followed by stratification largely removed dormancy from both populations of phalaris (70-88%), but not wild oat, winter wild oat, barnyard grass, perennial ryegrass or Italian ryegrass (Table 3). All non-germinated seeds were viable. There were significant differences (P<0.01) in germination between populations within each seed treatment, but means separation is not shown in Table 3.

Germination in an outdoor environment

There were significant differences in outdoor germination between populations and time points, with a strong interaction between population and time (P<0.01). For example, cumulative germination of barnyard grass was 0% in July but 39% by December, while wild oat only changed from 13 to 15% over the same period (Table 4).

The ryegrass seeds germinated poorer in the outdoor (67-85%) than laboratory (83-100%) environment (Tables 2 & 4). However, all the grass weeds showed higher proportion of germination in the outdoor environment than in the laboratory except for phalaris (70-88%) that were scarified and pre-chilled. Only 15% of wild oat and winter wild oat germinated in the field and less than 13% germinated under constant temperature in the laboratory. Similarly, phalaris germinated better in the outdoors than in the laboratory and the population from Tai Tapu (63%) had significantly better germination than that from Eiffelton (19%). Barnyard grass from Wanganui showed 39% germination but only from mid October when the temperatures had increased.

TABLE 3: Germination (%) of crop and weed seeds on 20 November 2006 after 14 days at 20°C in the laboratory. Seeds were given one of three prior treatments.

Species	Variety/ location	Untreated	Imbibed and stratified	Scarified, imbibed and stratified
Perennial ryegrass	Cannon	95 a	95 a	100 a
Italian ryegrass	Crusader	80 a	80 a	83 a
Wild oat	Highbank	8 ab	0 a	28 b
Winter wild oat	Highbank	0 a	0 a	0 a
Wild oat	Irwell	13 a	0 a	38 b
Winter wild oat	Irwell	3 a	0 a	10 a
Phalaris	Eiffelton	0 a	50 b	88 c
Phalaris	Tai Tapu	5 a	75 b	70 b
Barnyard grass	Wanganui	0 a	8 a	13 a

[1]Means for treatments within a population (across a row) followed by the same letter are not significantly different (P<0.05) from each other.

TABLE 4: Cumulative germination (%) of crop and weed seeds in an outdoor environment. Seeds were planted on 9 July and the first count of germinated seedlings was on 23 July 2006.

	Variety/ location	23 Jul	20Aug	17 Sep	15 Oct	12 Nov	10 Dec
Perennial ryegrass	Cannon	75 a[1]	83 a	85 a	85 a	85 a	85 a
Italian ryegrass	Crusader	57 ab	65 ab	67 ab	67 ab	67 ab	67 ab
Wild oat	Highbank	13 c	14 c	14 c	15 c	15 c	15 d
Winter wild oat	Highbank	0 c	13 c	15 c	15 c	15 c	15 d
Phalaris	Eiffelton	12 c	15 c	17 c	18 c	19 c	19 d
Phalaris	Tai Tapu	45 b	54 b	59 b	61 b	62 b	63 b
Barnyard grass	Wanganui	0 c	0 c	5 c	25 c	33 c	39 c

[1]Means for species/location at each time point (down a column) followed by the same letter are not significantly different (P<0.05) from each other.

Protracted germination in ryegrass produced three flushes (6 weeks) with over 85% germinated in the first flush (Table 5). Germination of wild oat, winter wild oat, phalaris and barnyard grass seeds was very variable and ranged from two to three flushes (4-6 weeks) in wild oat and winter wild oat to the very protracted six to seven flushes (12-14 weeks) in phalaris and barnyard grass (Table 5).

TABLE 5: Number of germination flushes and percentage of total seeds germinating in the first flush in an outdoor environment. Seeds were planted on 9 July and the first count of germinated seedlings was on 23 July 2006.

Species	Variety/ location	Main germination period	No. of flushes	First flush (%)	Predicted POST[1] (weeks)
Perennial ryegrass	Cannon	Autumn/winter/spring	3	88	6
Italian ryegrass	Crusader	Autumn & spring	3	85	6
Wild oat	Highbank	Autumn & spring	2	90	4
Winter wild oat	Highbank	Winter	3	27	6
Phalaris	Eiffelton	Autumn/winter/spring	5	61	10
Phalaris	Tai Tapu	Autumn/winter/spring	6	71	12
Barnyard grass	Wanganui	Spring	7	10	14

[1]Predicted POST = Predicted time (after sowing of a crop) for most effective herbicide treatment of this weed.

The daily minimum grass temperatures during the experimental period in Auckland and Wanganui were similar (Fig. 1), but significantly different from Ashburton ($P<0.01$). The respective correlation coefficients for Auckland, Wanganui and Ashburton were 0.57, 0.54 and 0.68, which showed temperature increases from July to December. On average, Auckland and Wanganui were 5 to 9°C warmer than Ashburton (Fig. 1). The cumulated total and monthly rainfalls were not significantly different ($P=0.53$) between the three stations (Table 6).

TABLE 6: Rainfall (mm) in Auckland, Wanganui and Ashburton during the experimental period from 1 July to 31 December 2006.

Rainfall measures	Auckland	Wanganui	Ashburton
Cumulated total rainfall (mm)	574	662	485
Average daily rainfall (mm)	3.1	3.6	2.6
No. rain days with rain >4 mm	34	49	25
No. rain storms with cumulated rain >20 mm	10	12	11

DISCUSSION

The paper-towel method under a constant temperature in the laboratory was conducive to the germination of ryegrass crop seeds that have been selected for high, uniform germination. It is a standard germination test for crop seeds (Ellis et al. 1985), but less useful for dormancy and germination study in weed seeds (Baskin & Baskin 1998). To confirm the requirement of cold temperatures for germination of some weed seeds, the treatment involving stratification for 8 weeks broke dormancy and induced significant germination of phalaris. Quail & Carter (1968) demonstrated in the laboratory that cooler optimum temperatures for germination were required for winter wild oat (5-10°C) compared to wild oat (15-20°C). Testing seeds in the outdoor environment helped to interpret dormancy and germination phenology of both ryegrass and other grass species, although soil surface temperatures were warmer in Auckland and Wanganui than Ashburton, and germination of wild oats and phalaris was probably higher than

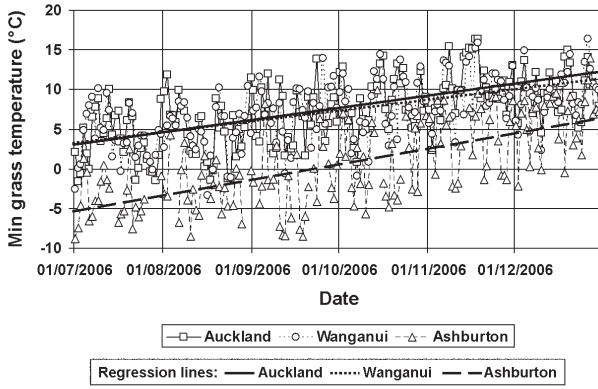

FIGURE 1: Daily minimum grass temperatures (°C) in Auckland (squares), Wanganui (circles) and Ashburton (triangles). The regression lines, Auckland (solid), Wanganui (dotted) and Ashburton (dash), are significant at P<0.01.

if the outdoor test has been conducted at the seed sources in Canterbury. Rainfall data suggest that soil moisture was not limiting and there were 10-12 significant rain storms to promote germination flushes in Auckland or locations of the seed sources.

Wild oats, phalaris and barnyard grass demonstrated pronounced physiological dormancy that could have allowed seed to persist until the next season. McWha et al. (1976) reported 7% germination of wild oats from Canterbury at 25°C in the laboratory, but scarification and/or stratification for 2½-8 weeks readily broke dormancy. Such results were not reproduced for wild oats in the present experiment, probably due to different seed ripening under varying seasonal and developmental factors that could have influenced the subsequent dormancy and germination (Koorneef et al. 2002; Finch-Savage & Leubner-Metzger 2006). The after-ripening conditions have been shown to greatly influence the loss of dormancy in wild oat and winter wild oat in Australia (Quail & Carter 1969). The difference in germination between the two populations of phalaris (Table 4) suggests their ecological adaptation to the different micro-climate or the influence of the micro-climate on the seed ripening and subsequent dormancy and germination (Koorneef et al. 2002; Finch-Savage & Leubner-Metzger 2006). Inherent variable dormancy and germination has been demonstrated in phalaris (Ellis et al. 1985) and *Phalaris paradoxa* populations from Australia and the United Kingdom (Taylor et al. 2004). High dormancy and variable germination were common for barnyard grass in many studies (Buhler & Hoffman 1999) as was found in the present experiment.

In the outdoor environment, ryegrass and wild oats required a relatively short time to peak germination. Winter wild oat seed from Highbank required about 4 weeks of exposure to cold temperatures before it germinated in winter, confirming the findings of Matthews (1976) and Quail & Carter (1968). However, Rolston (1981) observed early germination of winter wild oat in autumn, which suggests that colder temperatures in autumn could also trigger earlier germination of winter wild oat seeds. In a mild winter, wild oat would be expected to dominate, while winter wild oat would dominate during a cold winter.

On the contrary, phalaris and barnyard grass demonstrated protracted germination during the season. Several flushes of germination over the experimental period produced seedling cohorts at different growth stages. With protracted flushes over the season, the timing of a post-emergence herbicide application is critical for these two grass weeds.

Under the conditions of this study, the earliest timing for post-emergence grass control appeared to be 4-6 weeks after the first germination for wild oat, winter wild oat and ryegrass. For phalaris and barnyard grass, respectively, 12 and 14 weeks from first germination appeared to be the earliest effective timing. In these cases, the application of herbicide at GS30 of the largest cohort of phalaris and barnyard grass could miss the later germinated seedlings, particularly in later sown wheat in winter and spring. However, delayed grass control after GS30 is costly and may reduce crop yield (Syngenta 1998, 2006). In this situation, a pre-emergence herbicide that can control the early germinated phalaris and barnyard grass may be an option for integrated control with a post-emergence herbicide at GS30. More studies of germination phenology in different conditions and locations in New Zealand would further benefit the discussion around the effective timing of post-emergence grass weed control in cereals.

ACKNOWLEDGEMENT

Dr. Anis Rahman of AgResearch and Dr. Jean-Louis Allard of Syngenta kindly commented and suggested changes to the early draft.

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