Fatal Germination in Barnyardgrass (*Echinochloa crus-galli*)

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Abstract

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Seeds of weeds buried by tillage may germinate at depths from which seedlings cannot establish. In barnyardgrass (*Echinochloa crus-galli*) we investigated how fatal germination was influenced by the depth and time of seed burial. The proportion of germinated seeds decreased with burial depth to 0–20% at ≥ 0.1 m depth which is fatal for seedling establishment. The percentage of fatal germination was greater for the seeds buried during the spring season than during autumn. Germination was influenced by seed pre-treatment, after ripening or stratification. Spring ploughing of non-dormant seeds below 0.1 m depth induces fatal germination, decreasing in this way seed bank of barnyardgrass.

Keywords: seedling emergence; soil; temperature; tillage

An alternative of protecting crops against weeds is creating situations that force weed plants to start developing with fatal consequences (Williams *et al*. 2012). This may be achieved at the stage of seed germination through agricultural practices that incite an untimely germination followed by death of the seedlings. In this study, we investigate the effects of the seed position in the soil (burial depth) and seed pre-treatment (stratification and after-ripening) on the emergence of barnyardgrass, *Echinochloa crus-galli* (L.) P. Beauv. This annual grass is a significant weed (Maun & Barrett 1986) with a worldwide distribution (Holm *et al*. 1997). It colonises sparse crop stands (e.g. root and tuber crops, maize, and rice), orchards, vineyards, and fallow ground. In cold temperate zones, seeds ripen in the late summer and drop to the ground where warm and dry conditions terminate the innate dormancy in a fraction of the seeds (after-ripening) (Taylorson & Dinola 1989; Martinková & Honěk 1995). Seeds then survive a moist and cold autumn-spring period when the remaining dormant seeds are activated by stratification. In spring seeds germinate at temperature > 10°C (Martinkova *et al*. 2006) or remain buried in the soil and pass through regular dormancy/non-dormancy cycles, with a germinability peak in May–June and a minimum in August–October (Honek *et al*. 1999). The seedlings are successfully established from depths lesser than 0.1 m at various percentages depending on the season (Li 1962; Brod 1968; Martinková & Honěk 1993). The position of seeds is disturbed by ploughing that is carried out from the time of seed dispersal until the next spring. It can bury seeds in up to 0.3-m depths, where they may suffer "fatal germination", i.e. germination when seedling has no chance to reach the ground surface. Fatal germination could efficiently support seed mortality thus helping the regulation of barnyardgrass abundance. In non-dormant seeds which survive in the soil fatal germination is likely prevented via mechanisms that employ seed thermal and light sensitivities (Pons 1991; Saatkamp *et al*. 2011).

Effects of burial depth on seedling emergence of barnyardgrass were studied in rice crops (Chauhan & Johnson 2011) where growing technology guarantees ample watering and continuous high

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temperature; however, little information exists as concerns seed behaviour in other crops and temperate conditions. In this work, we investigated the influence of burial depth and date of seed burial on germination under field conditions in Central Europe.

MATERIAL AND METHODS

The experiments were carried out within 1994 to 1996 in the Crop Research Institute, Prague-Ruzyně (Czech Republic) in an experimental field with sandy-loamy soil. For the burial experiments, 0.4 × 0.4 m experimental plots were established, each of which was used to bury the seed samples into a particular depth on a particular date.

The seeds were collected from barnyardgrass stands naturally established in different crops in Prague-Ruzyně (50°05'09''N, 14°17'50''E, 340 m a.s.l.) and Odolena Voda (50°13’37”N, 14°24’28''E, 280 m a.s.l.). The ripe seeds shed after mild shaking of the panicles were collected in August–September and “after-ripened” (desiccated and maintained in open paper bags at 25°C and 40% relative humidity). Germination percentage was established as a potential to complete germination at 25°C and 18 h light:6 h dark photoperiod. Lots of 50 seeds were placed in Petri dishes (0.1 m diameter) lined with filter paper and moistened with 3 ml of tap water. Germination was established in 2-day intervals and the count was terminated only after no germination had occurred for 6 preceding days.

Experiment 1 investigated the percentage of germinated seeds buried at different depths in autumn and spring. Lots of 200 seeds (Prague-Ruzyně, collected during 1991, after-ripened, 64% germination) were mixed with soil and wrapped in nylon fabric in flat bags of a ~0.06 m diameter and < 0.005 m thickness. A total of 5 bags were buried at depths of 0.02, 0.05, 0.1, 0.2, and 0.3 m on December 7, 1994 and April 16, 1995. The bags were exhumed on May 25, 1996. The germinated seeds were counted, non-germinated seeds from each depth were mixed, and germination percentage established for 6 lots by 50 seeds of each mixed sample. Experiment 2 investigated the percentage of fatal germination in seeds buried to 0.25 m depth in monthly intervals from autumn 1995 to spring 1996. Seeds from Prague-Ruzyně (collected in 1991, after-ripened, 64% germination) and Odolena Voda (collected in 1995, after-ripened, 2% germination) were packed into bags as in Experiment 1. Five lots of 200 seeds per each seed origin were buried at a depth of 0.25 m on November 9 and December 7, 1995, and January 9, February 6, March 8, April 5, and May 5, 1996. All of the bags were exhumed on May 30, 1996, and the germinated seeds were counted. The germinability of non-germinated seeds was established as in Experiment 1.

The arithmetic means and standard errors (SE) were calculated. The effects of the burial depth and date of burial on percentage germination of buried seeds and germinability of non-germinated seeds were tested using Two-way ANOVA, with the percentage germination as the response variable and burial depth and date as factors. The relationship between percentage germination and sowing depth was fitted by power function ($y = a \times b^x$) in Experiment 1, linear regression ($y = a + bx$) of the percent germination on the date of burial was calculated in Experiment 2. The tests were

Table 1. Two-way ANOVA of variation in germination of seeds buried on December 7, 1994 and April 16, 1995 (date of burial) that germinated at 0.02, 0.05, 0.1, 0.2, and 0.3 m depths (depth of burial)

Source of variation	Percentage germination in the field					Germinability of seeds that failed to germinate in the field				
	DF	SS	MS	*F*	*P*	DF	SS	MS	F	*P*
Date of burial	1	1280.2	1280.2	38.16	< 0.001	1	39 938.4	39 938.4	1398.40	< 0.001
Depth of burial	4	5219.8	1304.9	38.90	< 0.001	4	6 868.9	1 717.2	60.13	< 0.001
Date × depth	4	508.9	127.2	3.79	0.01	4	3 598.3	899.6	31.50	< 0.001
Residual	40	1341.9	33.5			50	1 428.0	28.6		
Total	49	8350.8	170.4			59	51 833.6	878.5		

Percentage germination in the field and germinability of seeds that failed to germinate in the field and germinated after exhumation, at constant 25°C and 18 h light:6 h dark photoperiod

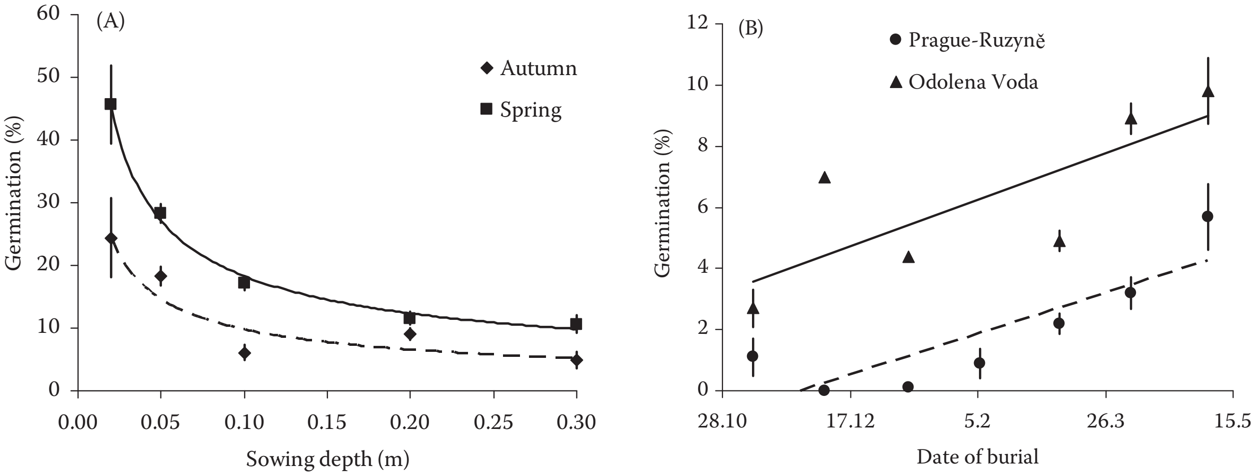

Figure 1. Percentage germination (± SE) (A) after-ripened seeds that germinated at 0.02, 0.05, 0.1, 0.2, and 0.3 m depths buried on December 7, 1994 (autumn, – – – a = 2.64, b = –0.570, R^2 = 0.799) and April 16, 1995 (spring, ––, a = 4.97, b = –0.566, R^2= 0.990) and exhumed on May 25, 1995; (B) seeds of Prague-Ruzyně (– – –, a = –0.81, b = 0.027, R^2= 0.715) and Odolena Voda (––, a = 3.21, b = 0.030, R^2 = 0.601) buried at 0.25 m depth at 7 dates between November 9, 1995 and May 5, 1996 and exhumed on May 30, 1996

performed using SigmaStat 3.5 (Systat Software, Inc., Point Richmond, USA), which accounts for testing for normality and equal variance of the data sets and selecting the appropriate methods of testing differences.

RESULTS

In the autumn-buried seeds, the percentage germination decreased from 24% at a 0.02 m depth to 6% at a 0.1 m depth, and was 9 and 5% in the seeds buried at 0.2 and 0.3 m depths, respectively. In the spring-buried seeds, the percentage germination decreased from 46% at 0.02 m to 17% at 0.1 m, and was 12 and 11% in the seeds buried at 0.2 and 0.3 m depths (Figure 1A). The Two-way ANOVA indicated a significant effect of the date of burial, burial depth, and interaction (Table 1). The seeds that did not germinate in the soil were germinable; seeds buried in autumn germinated at average 93 ± 4.7%, those buried in spring at 46 ± 20.3%, while the germinability was significantly affected by the date and depth of burial and their interaction (Table 1).

With proceeding date of burial percentage fatal germination at 0.25 m increased (Figure 1B) both in seeds from Prague-Ruzyně and Odolena Voda. The Two-way ANOVA indicated a significant effect of the seed origin, date of burial, and their interaction (Table 2). The germinable seeds that did not germinate in the soil germinated to 17 ± 15.1%

Table 2. Two-way ANOVA of variation in germination of seeds from Prague-Ruzyně and Odolena Voda (seed origin) buried at 0.25 m depth at 7 dates between November 9, 1995 and May 5, 1996 (date of burial)

Source of variation	Percentage germination in the field					Germinability of seeds that failed to germinate in the field					
	DF	SS	MS	*F*	*P*	DF	SS	MS	*F*	*P*	DF
Seed origin	1	268.8	268.8	90.87	< 0.001	1	50350.2	50350.2	1698.47	< 0.001	1
Date of burial	5	260.2	52.0	17.59	< 0.001	5	3684.7	736.9	24.86	< 0.001	5
Origin × date	5	47.8	9.6	3.23	0.014	5	28096.4	5619.3	189.56	< 0.001	5
Residual	48	142.0	3.0			60	1778.7	29.6			60
Total	59	718.8	12.2			71	83910.0	1181.8			71

Percentage germination in the field + germinability of seeds that failed to germinate in the field and germinated after exhumation, at constant 25°C and 18 h light:6 h dark photoperiod

(Prague-Ruzyně) and 67 ± 27.2% (Odolena Voda). The variation was also significantly affected by seed origin, date of burial, and their interaction (Table 2).

DISCUSSION

This study was focused on revealing factors that determine the percentage of fatal germination in barnyardgrass. As in earlier studies (Li 1962; Brod 1968; Martinková & Honěk 1993) an increased percentage of (prospectively successful) germination was observed at depths < 0.1 m. The proportion of seeds germinated in the field was greater when buried in spring. The seeds buried in autumn were subjected to natural stratification but mostly did not germinate in the soil, even at depths < 0.1 m where germination could be successful. This reluctance to germinate may be due to photoperiodic dormancy (Pons 1991) and/or sensitivity to temperature stimuli (Saatkamp *et al*. 2011), and requires further study.

The seedlings germinated at ≥ 0.1 m depths are unlikely to penetrate the soil and their germination has a fatal end. As with successful germination, the proportion of fatal germination is greater following spring than autumn burial. The autumn-buried seeds must postpone germination until spring because of low winter temperature. We suppose that due to this time lag the seeds have enough time to induce mechanisms that prevent fatal germination. Earlier studies revealed that there exists a variation in innate proportion of dormant seeds in local populations (Honěk & Martinková 1996). This variation, here manifested as difference of seeds from Prague-Ruzyně and Odolena Voda, influenced percentage of fatal germination but little affected seasonal trends of its change.

Fatal germination is an important factor of weed seed mortality (Schwinghamer & Van Acker 2008), and its frequency may be increased by tillage (Kurstjens 2007), which has valuable effects on decreasing seed survival in the soil (Gruber & Claupein 2006; Gruber *et al*. 2010). Our results indicate that a tillage that brings the seeds at ≥ 0.1 m depths could cause approximately 10–20% seed mortality by fatal germination. The date of cultivation that maximizes the fatal germination should be adjusted to the growing technology and agricultural practices (Guillemin & Chauvel 2011). A shallow cultivation of soil to 0.15–0.2 m depths in spring, in the present system of agronomical practices preferred to tillage because of minimizing negative effects on soil structure and other soil properties, is apparently an efficient mean to induce fatal germination in barnyardgrass.

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