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RESEARCH ARTICLE

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Emergence dynamics of barnyardgrass and jimsonweed from two depths when switching from conventional to reduced and no-till conditions

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Abstract

A cylinder experiment was conducted in northern Greece during 2005 and 2006 to assess emergence dynamics of barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) and jimsonweed (*Datura stramonium* L.) in the case of a switch from conventional to conservation tillage systems (CT). Emergence was surveyed from two burial depths (5 and 10 cm) and with simulation of reduced tillage (*i.e.* by soil disturbance) and no-till conditions. Barnyardgrass emergence was significantly affected by burial depth, having greater emergence from 5 cm depth (96%) although even 78% of seedlings emerged from 10 cm depth after the two years of study. Emergence of barnyardgrass was stable across years from the different depths and tillage regimes. Jimsonweed seeds showed lower germination than barnyardgrass during the study period, whereas its emergence was significantly affected by soil disturbance having 41% compared to 28% without disturbance. A burial depth x soil disturbance interaction was also determined, which showed higher emergence from 10 cm depth with soil disturbance. Jimsonweed was found to have significantly higher emergence from 10 cm depth with soil disturbance in Year 2. Seasonal emergence timing of barnyardgrass did not vary between the different burial depth and soil disturbance regimes, as it started in April and lasted until end of May in both years. Jimsonweed showed a bimodal pattern, with first emergence starting end of April until mid-May and the second ranging from mid-June to mid-August from 10 cm burial depth and from mid-July to mid-August from 5 cm depth, irrespective of soil disturbance in both cases.

Additional key words: burial depth; conservation tillage; emergence timing; soil disturbance; soil seedbank

Abbreviations used: CT (Conservation Tillage); DATST (*Datura stramonium* L.); DSS (Decision Support Systems); ECHCG (*Echinochloa crus-galli* (L.) Beauv.); IPM (Integrated Pest Management)

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Introduction

Agricultural production worldwide has been intensified in recent decades. It is characterized by high productivity, high inputs (*i.e.* pesticides, fertilizers and water), increased mechanization (Le Féon *et al.,* 2010) and more simplified cropping sequences (Stoate *et al.,* 2001) where the crop choice is often market driven (Vasileiadis *et al.,* 2011). However, the long-term sustainability and environmental effects of the intensification of agricultural systems have raised public concerns in terms of negative consequences (Matson *et al.,* 1997).

Intensive tillage operations (*i.e.* with soil inversion) have been found to adversely affect soil structure and cause excessive breakdown of aggregates, leading to soil erosion in higher rainfall areas (Chauhan *et al.,* 2012), but also to have a negative impact on environmental quality by accelerating soil carbon loss and greenhouse gas emissions (Reicosky & Allmaras, 2003). Such concerns provided an incentive to investigate tillage systems that minimize negative impacts on the environment without reducing crop yields. These systems can be broadly termed conservation tillage (CT) systems and involve the reduction or suppression of primary tillage operations such as plowing, disking or chiseling (Chauhan *et al.,* 2012). CT is also stated as a tool in the general principles of integrated pest management (IPM) as documented in the Directive 2009/128/EC (EC, 2009). However, what are the implications switching from conventional to reduced or no tillage systems in terms of weed seedbank dynamics? Inversion tillage through moldboard plowing reduces weed populations by burying a large proportion of freshly shed seeds deep in the soil profile (Vasileiadis *et al.,* 2007). Conversely, chisel plowing retains them nearer the surface facilitating germination and emergence, thereby increasing the requirement of management inputs to control them (Ball, 1992; Vasileiadis *et al.,* 2007). Other studies indicate that weeds increase after several years of reduced tillage because of increased seed accumulation at the soil surface, the lack of disruption of underground vegetative reproductive organs (Cardina *et al.,* 1991; Bàrberi *et al.,* 1998) and changes in timing of weed emergence compared with inversion tillage (Bullied *et al.,* 2003). Indeed, the timing of weed seedling emergence in the field varies depending on, individual species germination requirements, seed burial depth, soil disturbance (Roberts & Feast, 1972) and environmental conditions (Forcella, 1992). Seeds in CT systems remain near the soil surface, rather than being deeply buried, thus are more likely to emerge and be depleted from the seedbank due to exposure to favorable conditions for germination (Morris *et al.,* 2010; Chauhan *et al.,* 2012).

These prerequisites call for investigation on the timing of seedling emergence for key weed species when implementing CT systems, but also for the construction-calibration of decision support systems (DSS) for efficient weed management decisions in these systems. By developing such DSS, a decision-making process that will determine ‘‘if’’, ‘‘how’’ and ‘‘when’’ weed control is needed can be established, thus optimizing the time of weed control while reducing redundant herbicide applications or mechanical interventions (Masin *et al.,* 2011; Vasileiadis *et al.,* 2011). There is considerable information on emergence timing of cool temperate weed species (*e.g.* Roberts & Boddrell, 1983; Froud-Williams *et al.,* 1984; Ogg & Dawson, 1984; Egley & Williams, 1991), whereas comparable information is limited for species of more Mediterranean distribution, especially under CT system conditions. Such research is thus necessary for specific geographic locations subject to different environmental conditions, soil types and CT conditions. Hence, this study aimed at investigating the seedling emergence dynamics of barnyardgrass (*Echinochloa crus-galli* (L.) Beauv. ECHCG) and jimsonweed (*Datura stramonium* L. DATST), two common annual weed species prevalent in spring-sown arable cropping systems of northern Greece, in the case of a switch from conventional tillage to reduced or no tillage conditions and from 5 and 10 cm depth scenarios, given that 1) seeds shed the previous year would be distributed in the top 5-10 cm soil layer after a transitional soil cultivation using reduced tillage implements (*i.e.* 10 cm working depth of these implements) and 2) seeds of most weeds would germinate and emerge from the top 3 cm of the soil layer anyway.

Materials and methods

Experimental site and design

A cylinder type experiment was conducted during 2005 and 2006 at Neochori (latitude 40°39’58’’N, longitude 22°26’45’’E, altitude 2 m), Imathia, northern Greece, to investigate the emergence dynamics of two common annual weed species after burial at two depths (5 and 10 cm depth) and subject either to reduced tillage (*i.e.* soil disturbance) or no tillage conditions (*i.e.* no disturbance). The species chosen for the study were barnyardgrass and jimsonweed. These species were selected on the basis of their differential seed size, germination characteristics and because of their widespread and economic importance in most spring-sown crops in northern Greece. The experimental site was characterized by a temperate Mediterranean climate (Table 1) and a sandy loam soil texture, typical for the

Table 1. Monthly precipitation and temperature for the two years of the study.

Years	J	F	M	A	M	J	J	A	S	O	N	D
	Total precipitation (mm)											
2005	26.1	36.7	57.9	10.7	33.0	7.7	18.8	11.9	75.0	28.0	35.3	35.2
2006	74.8	127.8	54.0	61.0	10.8	26.2	63.1	42.2	45.5	108.8	10.7	19.2
	Mean temperature (°C)											
2005	5.4	4.8	9.6	15.1	20.2	23.7	26.8	25.3	21.7	15.6	8.9	6.5
2006	2.6	4.9	9.8	14.9	20.6	23.5	25.9	26.1	21.2	16.3	9.9	5.7

major part of the region, containing 13.6% clay, 53% silt, 33.4% sand and 1.17% organic matter. The experimental design was completely randomized with three replicates of two burial depths and two soil tillage regimes for each species requiring a total of 24 cylinders.

The cylinder experiment

For this experiment, open-ended, plastic cylinders 25 cm in diameter and 30 cm long were sunk in the ground outdoors so that their rims were approximately 8 cm above ground level. Tygan mesh was previously placed at the base of each cylinder to prevent soil fauna from entering the cylinders and disrupting seed distribution. Nets were also placed on the top of each cylinder to prevent birds from predating the seeds (Roberts & Feast, 1972; Roberts & Boddrell, 1983).

The soil excavated for placing the cylinders was the one used for filling them after sterilizing it first with the use of methyl bromide for two weeks. In this way many soil diseases (fungi, bacteria), nematodes, insects and most weed seeds, if not dormant, can be well controlled. After positioning the cylinders, they were filled with sterilized soil to the appropriate depth of seed placement. Spaces between and around the cylinders were also filled with sterilized soil to minimize emergence of indigenous weed seedlings.

Seed samples and recording

Fully ripened seeds of the two species were collected in mid-September 2004, from plants growing in fields near the experimental site, by gently shaking the plants over a container (Froud-Williams *et al.,* 1984). After collection, seeds were cleaned, air dried, weighed and counted into twelve batches of 300 seeds per species, each batch to be buried in each of the cylinders. The weight per 1000 seeds of barnyardgrass and jimsonweed was 3.5 g and 6.7 g, respectively.

Seeds were buried in the cylinders, according to the experimental design, within a few days of collection to avoid any physiological changes that might occur during dry storage and to allow seeds to overwinter and so break dormancy naturally. Seeds were buried at two depths (5 and 10 cm) with six replicates for each depth. After burial, three of the replicated cylinders for each depth were disturbed to a depth of 20 cm (*i.e.* maximum working depth of non-inversion tillage implements) in early March and October 2005 and again in early March 2006 to simulate reduced tillage conditions and the timing of local soil cultivation practices, whereas the other cylinders remained undisturbed. Soil was disturbed using a trowel and carefully mixed within the cylinder in order to avoid any soil loss. Crusting and soil consolidation of the undisturbed cylinders was not a serious issue during the study period. All emerged seedlings were counted every two weeks and removed from early March until late August during 2005 and 2006. Cylinders and the surrounding area (to enable similar soil moisture conditions) were watered every two weeks during the summer months to simulate local irrigation practices.

Statistical analysis

Statistical analysis of the experimental data was undertaken by means of the statistical package Statistica 10. Total seedling emergence data (sum of emergence per species after two years for each replicate) were subjected to factorial analysis of variance (ANOVA) and main effects (burial depth and tillage regime) and interactions were tested for significance. In order to investigate the effect of burial depth and tillage regime over the two years, ANOVA was also performed including the factor year and calculating the emergence data for Year 2 as the exact % of remaining seeds from Year 1 from each respective treatment combinations. Since seeds buried in the first year were not exhumed at the end of the year to determine remaining viable seeds for the second year the before mentioned calculation was done without considering fatal germination or seed predation. Treatment means obtained by ANOVA were compared using Fisher's protected LSD test at $p=0.05$ level of significance. All % emergence data were arcsine-square root transformed prior to ANOVA procedures.

Results

Total barnyardgrass seedling emergence after two years showed only a significant effect of burial depth ($p<0.001$) (Table 2). Emergence was significantly greater when seeds were buried at 5 cm depth, attaining 96% of emergence compared to 78% from 10 cm burial depth. Soil disturbance resulted in 89% emergence, whereas 85% emergence was determined when soil was not disturbed. The interaction between factors showed no significant difference and total emergence of this weed species ranged from 97% at 5 cm depth with soil disturbance to 75% when at 10 cm depth without disturbance. The % emergence of this weed species was stable across years from the different depths and tillage regimes (Fig. 1).

Table 2. Mean of total emergence (%) per species from two years and arcsine-square root transformed emergence (in parentheses) as affected by burial depth, soil disturbance and their interaction (ANOVA performed on arcsine-square root transformed data).

Factors	Levels	DATST[1]	ECHCG[2]
		Emergence (%)	
Depth	5 cm	32 (0.60)	96 (1.37) a
	10 cm	37 (0.65)	78 (1.09) b
	F-test	NS[b]	***
Soil disturbance (SD)	SD	41 (0.69) a	89 (1.26)
	NoSD	28 (0.56) b	85 (1.20)
	F-test	**	NS
Depth × Soil disturbance	5 cm × SD	34 (0.62) b	97 (1.40)
	5 cm × NoSD	30 (0.58) b	95 (1.34)
	10 cm × SD	48 (0.76) a	81 (1.13)
	10 cm × NoSD	26 (0.53) b	75 (1.05)
	F-test	*	NS

[1] DATST, jimsonweed. [2] ECHCG, barnyardgrass. Treatment significant at * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$; NS, not significant. Mean values in the same column not sharing the same lowercase letter are significantly different at $p < 0.05$ according to Fisher's protected LSD test.

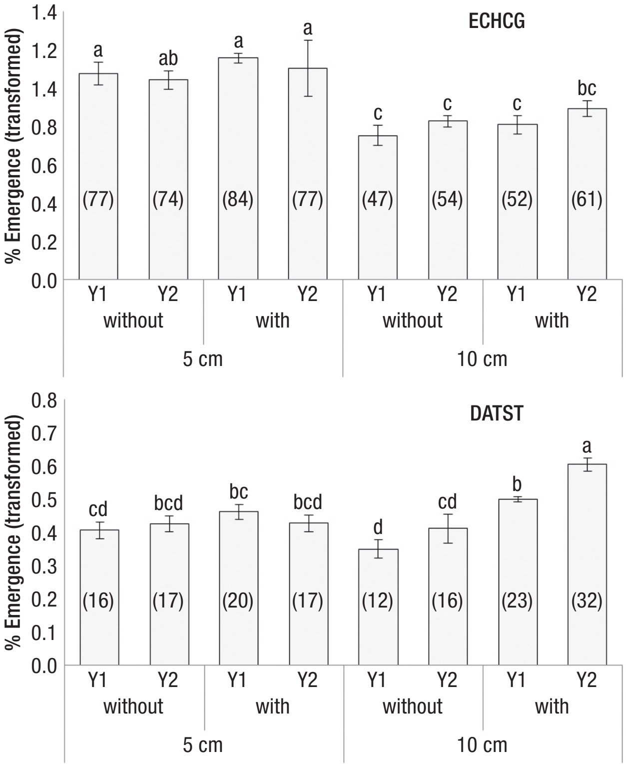

Figure 1. Mean of arcsine-square root transformed emergence and actual % emergence (in parenthesis) of barnyardgrass (ECHCG) and jimsonweed (DATST) per year under the various burial depth and soil disturbance regime scenarios. Y1, year 1; Y2, year 2 emergence calculated as % of remaining seeds from previous year. Mean values not sharing the same letter are significantly different at $p < 0.05$ according to Fisher's LSD Test.

Jimsonweed total seedling emergence (sum of emergence after two years) was significantly affected by soil disturbance (p<0.01) and by the interaction of the two factors (p<0.05). The emergence percentages were lower compared to barnyardgrass, with 32% from 5 cm depth and 37% from 10 cm depth. Soil disturbance resulted in 41% emergence, whereas 28% emerged when soil was not disturbed. The significant interaction showed higher emergence from an initial 10 cm burial depth when subject to disturbance (48%) and lower from 10 cm without disturbance (26%) (Table 2). Analysis of the dynamics of emergence across years identified a significantly higher emergence from 10 cm depth with soil disturbance in Year 2 (p<0.001) compared to all other treatments (Fig. 1).

Emergence timing of barnyardgrass did not vary for the different burial depths by soil disturbance regimes, as in both years of the study emergence started in April and lasted till the end of May (Fig. 2). Jimsonweed showed a bimodal pattern, with the first emergence starting end of April till mid-May, in both years of the study irrespective of burial depth and soil disturbance regime, and the second ranging from mid-June to mid-August from 10 cm depth and from mid-July to mid-August from 5 cm depth, irrespective of soil disturbance in both cases (Fig. 2).

Discussion

Previous trials under laboratory conditions in a silt-loam soil (23% sand, 52% silt, 25% clay) have shown no emergence of barnyardgrass from 10 cm depth without disturbance (Benvenuti *et al.,* 2001), which is not in agreement with the current study. However, this disparity could be explained by differences in soil type, environmental conditions (*i.e.* real field conditions *vs.* controlled conditions), bulk density and the fact that

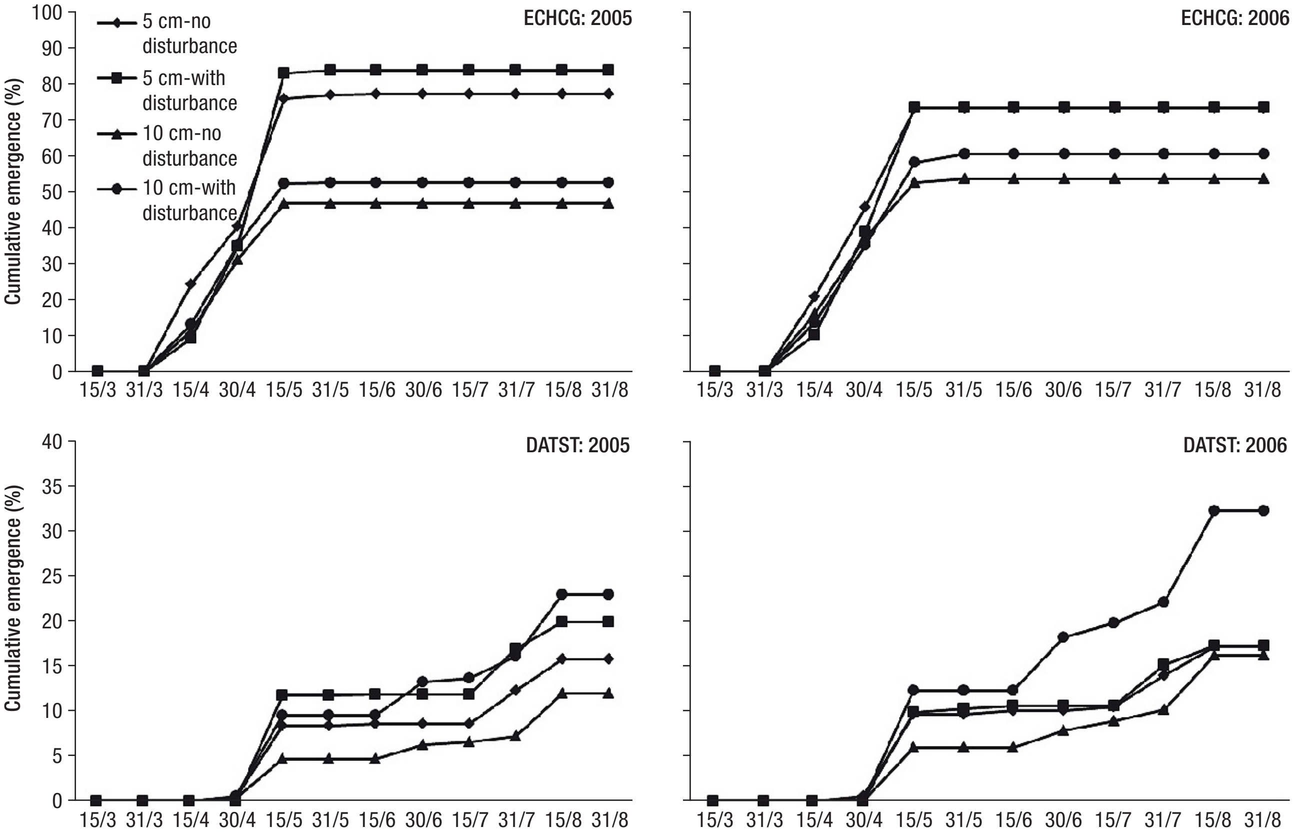

Figure 2. Cumulative emergence (%) of barnyardgrass (ECHCG) and jimsonweed (DATST) from two burial depths (5 and 10 cm) and two soil disturbance regimes (with and without) in 2005 and 2006. The 2006 emergence for the different scenarios was calculated using the 2005 percentage of remaining seeds from each burial depth by soil disturbance combination, respectively.

seeds were buried within a few days of collection avoiding any physiological changes that might occur during dry storage and allowing them to overwinter and break dormancy naturally. In fact, sandy soils as in this study have greater air permeability, which is also important in limiting hypoxia and removing germination-inhibiting volatile metabolites, thus enhancing seed germination (Benvenuti, 2003).

On the other, the decrease in germination of jimsonweed with increasing burial depth and no soil disturbance as identified in this study may be linked to poor gas exchange in the environment surrounding the buried seeds (Benvenuti, 2003), the lack of a light trigger (Benvenuti & Macchia, 1998) and the general ability of this weed species to build a persistent seedbank as a consequence of its survival strategy based on seed dormancy and longevity (Reisman-Berman *et al.*, 1991). Weaver & Warwick (1984) reported that jimsonweed seeds may remain viable for 39 years in the soil, whereas Toole & Brown (1946) similarly reported 91% of jimsonweed emergence after 38 years, thus confirming the persistence of this weed species. Presumably in the current investigation, soil disturbance re-distributed jimsonweed seeds from the initial 10 cm burial depth closer to the soil surface resulting in this significant interaction. This increased stimulation of jimsonweed germination after soil disturbance was possibly due to the loss of innate (primary) dormancy as in most summer annual species following exposure to low temperatures over winter (Murdoch & Ellis, 2000) and exposure to light prior to or during disturbance (Benvenuti & Macchia, 1998).

In terms of emergence timing, the spring emergence flush of barnyardgrass and jimsonweed, during both years, was due both to the gradually warming soil in April through May that provided the temperatures required for seed germination of these species and the positive water balance as spring rainfall was adequate in both years (Table 1). The fact that only mature seeds were used in this study may also have influenced seed germination early in the season as after-ripening of seeds is known to decrease the level of primary dormancy (Murdoch & Ellis, 2000). On the other, the later midseason emergence flush of jimsonweed, during both years, indicates that some of the seeds possibly required a longer exposure to higher temperatures in order to germinate.

These results suggest that if a farmer makes the change from conventional to reduced or no tillage, considering only the seeds shed the previous year and distributed in the top 5-10 cm soil layer, after a transitional soil cultivation using reduced tillage implements and under similar climatic and soil conditions, he/she should expect a minimum of 75% emergence of barnyardgrass and 26% emergence of jimsonweed (*i.e.* from the worst case scenario of 10 cm depth without disturbance) in his/her field in the first two growing seasons and subsequent emergence of those seeds that didn't suffer fatal germination in the following years. Previous research on barnyardgrass and jimsonweed determined that fatal germination (*i.e.* the seed germinates, but the seedling dies before reaching the soil surface; Davis & Renner, 2007) of these weeds was approximately 25% and 17%, respectively, from a depth of 12 cm in a silt-loam textured soil (Benvenuti *et al.,* 2001). In fact, Gardarin *et al.* (2010) reported that the % of fatal germination is proportional to the soil structure (*i.e.* less in sandy soils) and greater for monocotyledonous than dicotyledonous species. Similarly, Martinková & Honěk (2013) reported that a shallow tillage that brings barnyardgrass seeds at ≥ 10 cm depths could cause approximately 10–20% seed mortality for by fatal germination.

As CT systems do not exhume weed seeds from the deeper soil profile nearer to the soil surface where conditions are favorable for germination, the farmer could eventually deplete barnyardgrass and jimsonweed from the seedbank by controlling these weeds during the growing season and avoiding any escapes that will shed new seeds. This statement can also be valid for the latter weed species that has a very persistent seedbank, but over a longer time span. This agrees with Popay *et al.* (1994), who reported fewer weeds emerging in uncultivated and shallow cultivated plots compared to deep cultivated plots over the initial 7-year period, stating that seeds under the CT conditions were probably near to the surface and germinated without being replaced due to weed control. But even if weed escapes happen, in an integrated weed management context, the increase of the seedbank from these weeds could be buffered by crop rotation, the specific crop practices implemented and a higher diversity level of the system (*i.e.* inclusion of winter and summer crops, cover crops) (Melander *et al.,* 2013; Vasileiadis *et al*., 2015). A good example comes from a field experiment adjacent to the cylinder experiment (*i.e.* same soil conditions but different years), where after two years of continuous cotton, cotton-sugar beet rotation and continuous tobacco, barnyardgrass seedbank and population density was significantly reduced by the crop specific management practices (*i.e.* pre-transplant herbicide and seedbed operations) in late established tobacco (*i.e.* transplanted end of May) compared to the other spring-sown crops (Vasileiadis *et al.,* 2007*,* 2012).

Under similar soil and climatic conditions and reduced or no tillage system conditions, this study identified mid-May as the best time for post-emergence herbicide application against both weed species. With careful choice of crop in the rotation in terms of competitiveness (*e.g.* sowing time, crop density and early canopy closure) and mechanical weeding in reduced tillage systems only (*e.g.* inter-row hoeing in corn; *Zea mays* L.) the later emerged jimsonweed could suffer competition and be suppressed by the already established crop and its related interventions, not causing any yield loss and having a reduced seed production.

The results obtained are of practical relevance for farmers willing to change from conventional to reduced or no tillage systems that retain weed seeds in the top 10 cm soil horizon. This study provides knowledge on the emergence dynamics of two important and troublesome weed species from various depths and soil disturbance regimes, and the timing of their emergence that allows for more sustainable weed management decisions in CT systems, making the best use of all principles of integrated weed management and maintaining weed populations at economically acceptable levels.

References

Ball DA, 1992. Weed seedbank response to tillage, herbicides and crop rotation sequence. Weed Sci 40: 654-659.

Bàrberi P, Cozzani A, Macchia M, Bonari E, 1998. Size and composition of the weed seedbank under different management systems for continuous maize cropping. Weed Res 38: 319-334. http://dx.doi.org/10.1046/j.1365-3180.1998.00098.x

Benvenuti S, 2003. Soil texture involvement in germination and emergence of buried weed seeds. Agron J 95: 191-198. http://dx.doi.org/10.2134/agronj2003.0191

Benvenuti S, Macchia M, 1998. Phytochromemediated germination control of *Datura stramonium* L. seeds. Weed Res 38: 199-205. http://dx.doi.org/10.1046/j.1365-3180.1998.00086.x

Benvenuti S, Macchia M, Miele S, 2001. Quantitative analysis of emergence of seedlings from buried weed seeds with increasing soil depth. Weed Sci 49: 528-535. http://dx.doi.org/10.1614/0043-1745(2001)049[0528:QAOEOS]2.0.CO;2

Bullied WJ, Marginet AM, Van Acker RC, 2003. Conventional and conservation tillage systems influence emergence periodicity of annual weed species in canola. Weed Sci 51: 886-897. http://dx.doi.org/10.1614/P2002-117

Cardina J, Regnier E, Harrison K, 1991. Long-term tillage effects on seedbanks in three Ohio soils. Weed Sci 39: 186-194.

Chauhan BS, Singh RG, Mahajan G, 2012. Ecology and management of weeds under conservation agriculture: A review. Crop Prot 38: 57-65. http://dx.doi.org/10.1016/j.cropro.2012.03.010

Davis AS, Renner KA, 2007. Influence of seed depth and pathogens on fatal germination of velvetleaf *(Abutilon* *theophrasti)* and giant foxtail *(Setaria faberi)*. Weed Sci 55: 30-35. http://dx.doi.org/10.1614/W-06-099.1

EC, 2009. Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:309:0071:0086:EN:PDF. [September 17, 2013].

Egley GH, Williams RD, 1991. Emergence periodicity of six summer annual weed species. Weed Sci 39: 595-600.

Forcella F, 1992. Prediction of weed seedling densities from buried seed reserves. Weed Res 32: 29-38. http://dx.doi.org/10.1111/j.1365-3180.1992.tb01859.x

Froud-Williams RJ, Chancellor RJ, Drennan DSH, 1984. The effects of seed burial and soil disturbance on emergence and survival of arable weeds in relation to minimal cultivation. J Appl Ecol 21: 629-641. http://dx.doi.org/10.2307/2403434

Gardarin A, Dürr C, Colbach N, 2010. Effects of seed depth and soil aggregates on the emergence of weeds with contrasting seed traits. Weed Res 50: 91-101. http://dx.doi.org/10.1111/j.1365-3180.2009.00757.x

Le Féon V, Schermann-Legionnet A, Delettre Y, Aviron S, Billeter R, Bugter R, Hendrickx F, Burel F, 2010. Intensification of agriculture, landscape composition and wild bee communities: a large scale study in four European countries. Agric Ecosyst Environ 137: 143-150. http://dx.doi.org/10.1016/j.agee.2010.01.015

Martinková Z, Honěk A, 2013. Fatal germination in barnyardgrass *(Echinochloa crus-galli)*. Plant Protect Sci 49: 193-197.

Masin R, Vasileiadis VP, Loddo D, Otto S, Zanin G, 2011. A single time survey method to predict the daily weed density for weed control decision-making. Weed Sci 59: 270-275. http://dx.doi.org/10.1614/WS-D-10-00148.1

Matson PA, Parton WG, Power AG, Swift MG, 1997. Agricultural intensification and ecosystem properties. Sci 227: 504-509. http://dx.doi.org/10.1126/science.277.5325.504

Melander B, Munier-Jolain N, Charles R, Wirth J, Schwarz J, van der Weide R, Bonin L, Jensen PK, Kudsk P, 2013. European perspectives on the adoption of nonchemical weed management in reduced-tillage systems for arable crops. Weed Technol 27: 231-240. http://dx.doi.org/10.1614/WT-D-12-00066.1

Morris NL, Miller PCH, Orson JH, Froud-Williams RJ, 2010. The adoption of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment - A review. Soil Tillage Res 108: 1-15. http://dx.doi.org/10.1016/j.still.2010.03.004

Murdoch A, Ellis RH, 2000. Dormancy, viability and longevity. In: Seeds. The ecology of regeneration in plant communities; Fenner M, (ed.). pp: 183-214. CABI Publ., Wallingford. http://dx.doi.org/10.1079/9780851994321.0183

Ogg AGJr, Dawson JH, 1984. Time of emergence of eight weed species. Weed Sci 32: 327-335.

Popay AI, Cox TI, Ingle A, Kerr R, 1994. Effects of soil disturbance on weed seedling emergence and its long-term decline. Weed Res 34: 403-412. http://dx.doi.org/10.1111/j.1365-3180.1994.tb02036.x

Reicosky DC, Allmaras RR, 2003. Advances in tillage research in North American cropping systems. J Crop Prod 8: 75-125. http://dx.doi.org/10.1300/J144v08n01_05

Reisman-Berman O, Kigel J, Rubin B, 1991. Dormancy patterns in buried seeds of *Datura ferox* and *D. stramonium*. Can J Bot 69: 173-179. http://dx.doi.org/10.1139/b91-025

Roberts HA, Feast PM, 1972. Fate of seeds of some annual weeds in different depths of cultivated and undisturbed soil. Weed Res 12: 316-324. http://dx.doi.org/10.1111/j.1365-3180.1972.tb01226.x

Roberts HA, Boddrell JE, 1983. Seed survival and periodicity of seedling emergence in ten species of annual weeds. Asp Appl Biol 102: 523-532. http://dx.doi.org/10.1111/j.1744-7348.1983.tb02723.x

Stoate C, Boatman ND, Borralho RJ, Rio Carvalho C, de Snoo GR, Eden P, 2001. Ecological impacts of arable intensification in Europe. J Environ Manage 63: 337-365. http://dx.doi.org/10.1006/jema.2001.0473

Toole EH, Brown E, 1946. Final results of the Duvel buried seed experiment. J Agr Res 72: 201-210.

Vasileiadis VP, Froud-Williams RJ, Eleftherohorinos IG, 2007. Vertical distribution, size and composition of the weed seedbank under various tillage and herbicide treatments in a sequence of industrial crops. Weed Res 47: 222-230. http://dx.doi.org/10.1111/j.1365-3180.2007.00564.x

Vasileiadis VP, Sattin M, Otto S, Veres A, Pálinkás Z, Pons X, Kudsk P, van der Weide R, Czembor E, Moonen AC, Kiss J, 2011. Crop protection in European maize-based cropping systems: current practices and recommendations for innovative integrated pest management. Agric Syst 104: 533-540. http://dx.doi.org/10.1016/j.agsy.2011.04.002

Vasileiadis VP, Froud-Williams RJ, Eleftherohorinos IG, 2012. Tillage and herbicide treatments with inter-row cultivation influence weed densities and yield of three industrial crops. Weed Biol Manag 12: 84-90. http://dx.doi.org/10.1111/j.1445-6664.2012.00440.x

Vasileiadis VP, Otto S, van Dijk W, Urek G, Leskovšek R, Verschwele A, Furlan L, Sattin M, 2015. On-farm evaluation of integrated weed management tools for maize production in three different agro-environments in Europe: agronomic efficacy, herbicide use reduction and economic sustainability. Eur J Agron 63: 71-78. http://dx.doi.org/10.1016/j.eja.2014.12.001

Weaver SE, Warwick SI, 1984. The biology of Canadian weeds. 64. *Datura stramonium* L. Can J Plant Sci 64: 979-991. http://dx.doi.org/10.4141/cjps84-132