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Research paper

Timing and depth of post-harvest soil disturbance can reduce seedbank and volunteers of oilseed rape

Shoubing Huang[a,b,*], Sabine Gruber[b], Wilhelm Claupein[b]

[a] China Agricultural University, College of Agriculture and Biotechnology, 100193, Beijing, China
[b] University of Hohenheim, Institute of Crop Science (340a), Fruwirthstr. 23, 70599, Stuttgart, Germany

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ABSTRACT

Appropriate timing of post-harvest tillage to oilseed rape (OSR, *Brassica napus* L.) is crucial for the creation of a soil seed bank and unwanted OSR volunteers. Existing recommendations, however, can contrast with needs for early post-harvest tillage *e.g.* for pest control. To specify and to systematically further improve preventive volunteer management through post-harvest tillage of imidazolinone-tolerant oilseed rape (Clearfield®; CL OSR), field experiments were set up at two locations in two separate trial periods at each location (2013–2014 and 2014–2015) in south-west Germany. After OSR harvest, and average harvest losses of 1500 m^{-2} seeds, or artificially broadcasting of 20 000 OSR seeds m^{-2}, stubble tillage was performed at weekly intervals (immediate (0), 1, 2, 3, and 4 weeks) at each of three depths (1–2, 6–8, and 15–17 cm). To depict a worst case scenario in which herbicides were ineffective, no herbicides were applied. There were significantly smaller soil seed banks found in spring the longer the period lasted between seed rain and stubble tillage; 265 *vs* 145 seeds m^{-2} referred to 0 week *vs.* 4 weeks on average. Depth of stubble tillage had no significant effects on the seed number in the soil. In the first spring after seed loss, 0–2.6 CL OSR volunteers m^{-2} were found in the winter wheat, and the number decreased with delayed timing depth of stubble tillage. These volunteers mainly emerged in the treatment of shallow stubble tillage (1–2 cm), with 0.7-0.9 flowering volunteer m^{-2}, while volunteers averaged less than 0.04 plants m^{-2} in the treatment "15–17 cm". OSR volunteers in winter wheat got ripened only in one out of the four fields, and produced 1.0 seed m^{-2} on average. The delay between harvest and stubble tillage can be limited to approximately three weeks if stubble tillage is performed at a depth of about 6–8 cm; further delay did not bring additional advantage. We recommend to retain the stubble for three weeks as further delay does not bring additional advantage, and then to apply stubble tillage deeper than 6 cm. Very superficial or shallow stubble tillage should be avoided. This procedure seems appropriate for avoiding oilseed rape volunteers without use of herbicides.

1. Introduction

The introduction of imidazolinone-tolerant oilseed rape (OSR, *Brassica napus* L.) into Europe (Clearfield® oilseed rape, CL OSR) has been met with skepticism. One of the objections is the possibility that volunteers from CL OSR harvest losses cannot easily be controlled by specific herbicides. CL OSR has shown not only tolerance to imidazolinone herbicides but also high cross-tolerance with other herbicides, such as sulfonylureas and triazolopyrimidines (Krato et al., 2012). These herbicides are widely used in Europe (Swanson et al., 1989; Pfenning et al., 2008), controlling a broad spectrum of particularly troublesome broadleaf weeds by inhibiting acetolactate synthase (Reade and Cobb, 2002). Due to its weed control effectiveness, CL OSR has been grown for years in many countries (Tan et al., 2005), but evidence for control of its volunteers is limited.

OSR volunteers in crops following harvest of OSR can emerge after up to 10 years (Messéan et al., 2007; Andersen et al., 2010) due to long-term seed persistence in the soil (Lutman et al., 2003; Hooftman et al., 2015). Large harvest losses and high potentials of secondary seed dormancy are the greatest contributors to the long-term soil seed bank in spring and winter OSR (Gulden et al., 2003a,b; Lutman et al., 2005; Weber et al., 2009). CL OSR showed similar seed dormancy levels as non-CL OSR (Momoh et al., 2002; Gruber et al., 2004a; Huang et al., 2016a). However, the herbicide tolerance trait would make CL OSR volunteers more difficult to control by chemicals. Outcrossing between CL and non-CL OSR (Krato and Petersen, 2012) would further increase this difficulty (Hall et al., 2000; Beckie et al., 2004), resulting in a new challenge for weed control.

* Corresponding author at: China Agricultural University, College of Agriculture and Biotechnology, 100193, Beijing, China.
E-mail addresses: huangshoubing@cau.edu.cn, huangshoubing@163.com (S. Huang).

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Drought, darkness, or oxygen deficiency can induce dormancy (secondary dormancy) in OSR seeds (Pekrun et al., 1997a, Gruber et al., 2004a) in addition to often comparatively low levels of primary (endogenous) dormancy (Momoh et al., 2002; Gruber et al., 2004a). These environmental factors would induce secondary dormancy in seeds from harvest losses. Therefore, the first post-harvest tillage operation (stubble tillage) and its timing is a critical factor in determining the build-up of a soil seed bank (López-Granados and Lutman, 1998; Gruber et al., 2004b; Pekrun et al., 2006). Stubble tillage performed immediately after harvest of OSR can build up a much larger soil seed bank than tillage treatments without stubble tillage (Gruber et al., 2010; Huang et al., 2016b) or with four-week delayed stubble tillage (Gruber et al., 2004b; Pekrun et al., 2006). Optimal timing and depths of first post-harvest soil disturbance to avoid build-up of a large OSR soil seed bank with different periods between harvesting and tillage have not yet been systematically tested.

Several studies have indicated that burial depth of OSR seeds in the soil has noticeable effects on soil seed bank dynamics (Pekrun et al., 1997b; Gulden et al., 2004; Gruber et al., 2010). Depending on burial depth, more or fewer OSR seeds can fall or stay dormant (Pekrun et al., 1997b; Gruber et al., 2010). Inversion tillage (*i.e.* mouldboard plough) and non-inversion tillage (*i.e.* chisel plough, rototiller, and no-tillage) had no significant difference on the build-up of soil seed bank of OSR in the first subsequent spring after OSR (Gruber et al., 2004b; Huang et al., 2016b). However, soil seed bank depletion was faster in non-inversion tillage than in inversion tillage once a soil seed bank of OSR has been established (Gruber et al., 2010). Tillage systems did not affect weed diversity in the long run in a long-term experiment in the Mediterranean (Plaza et al., 2011) and in central Europe (Gruber et al., 2012), but chisel plough can resulted in an increasingly larger soil seed bank than mouldboard plough if no effective weed control was conducted (Ball, 1992). In both OSR crops and weeds, non-inversion tillage resulted in much more OSR volunteers or weed seedlings than inversion tillage due to the shallow seed distribution (Mohler et al., 2006; Sosnoskie et al., 2006; Gruber and Claupein, 2009; Huang et al., 2016b).

Evidence of the effect of depth of post-harvest tillage on the soil seed bank of OSR in the time period from harvest of OSR to primary tillage for following crops is still limited. Farmers often see a conflict between the requirements for tillage shortly after harvest of OSR (stubble tillage) for control of rotational diseases such as clubroot (*Plasmodiophara brassicae*) on the one hand, and the requirement to leave the stubble undisturbed to avoid a soil seed bank on the other hand. Additionally, shallow tillage can stimulate weed seed germination before seeding the crop (false seedbed techniques) and thus reduce the occurrence of some weed species that have currently no or low seed dormancy level. Practice-related information to more exactly define the duration of the period between OSR harvest and first post-harvest tillage is still missing from field experiments. This knowledge which can be used for models such as from Pekrun et al. (2005), Begg et al., 2006, Colbach et al. (2008) and Middelhoff et al. (2011), or directly applied on-farm.

This study aimed to investigate the effects of timing and depth of stubble tillage on the build-up of a soil seed bank and occurrence of CL OSR volunteers in the subsequent crops after CL OSR.

Following hypotheses were tested: (i) the longer the period between seed rain and the first post-harvest tillage (stubble tillage), the smaller is the soil seed bank in next spring. (ii) The longer the period between seed rain and the first post-harvest tillage (stubble tillage), the lower is the density of OSR volunteers in next spring. (iii) Shallow stubble tillage results in smaller soil seed banks and thus lower volunteer density in next spring.

The results are based on field experiments at two locations and two trial periods each on different fields in the years 2013–2016; four separate approaches altogether to provide preventative management strategies for control of CL OSR volunteers.

Table 1
Dates of seed rain of Clearfield® oilseed rape (CL OSR), timing of stubble tillage and primary tillage, and the sowing date of the first following crop winter wheat (WW) at Ihinger Hof (IHO) and Goldener Acker (GA) in the first and second trial periods (P_1, P_2); wk: week after seed rain of CL OSR; n.d. not determined (the treatment was not conducted because of the heavy rainfall).

Treatments	P_1		P_2	
	GA	IHO	GA	IHO
Seed rain[a]	06/08/2013	01/08/2013	12/08/2014	08/09/2014
0-wk[b]	07/08/2013	02/08/2013	12/08/2014	08/09/2014
1-wk	14/08/2013	10/08/2013	19/08/2014	17/09/2014
2-wk	21/08/2013	16/08/2013	n.d.	25/09/2014
3-wk	28/08/2013	24/08/2013	02/09/2014	02/10/2014
4-wk	04/09/2013	29/08/2013	09/09/2014	07/10/2014
Primary tillage[c]	25/10/2013	25/10/2013	23/10/2014	24/10/2014
Sowing WW	28/10/2013	31/10/2013	27/10/2014	30/10/2014

[a] Actual harvest losses of 1585 seeds m^{-2} at GA and 1523 seeds m^{-2} at IHO were used in P_1, and artificial seed rain 20 000 seeds m^{-2} in P_2.
[b] 0-wk: stubble tillage was performed immediately after seed rain of oilseed rape.
[c] The same primary tillage was performed by mouldboard plough (25–27 cm) with a working width of 2 m in all treatments.

2. Materials and methods

2.1. Site description and experimental design

Field trials were conducted at the experimental station Ihinger Hof (IHO, 48°74′N, 8°94′E; altitude 450 m a.s.l.) and the experimental field Goldener Acker (GA, 48°72′N, 9°21′E; 389 m a.s.l) of the University of Hohenheim between autumn 2013 and spring 2016. Mean long-term annual precipitation at IHO and GA is 690 mm and 632 mm, and mean annual temperature 7.9 °C and 10.2 °C, respectively.

The experiment was set up in a randomized complete block design with two factors, timing and depth of stubble tillage, in four replicates. Working depths of stubble tillage were 1–2 cm conducted with a spike harrow (working width 2 m) and 6–7 cm and 15–17 cm with a chisel plough (working width 2 m). At each treatment of tillage depth, five timings (*i.e.* 0 (immediate), 1–4 weeks after seed rain of OSR) were performed (Table 1). The plot size was 6 m × 12 m at IHO, and 10 m × 10 m at GA in both trial periods. Primary tillage was performed uniformly with a mouldboard plough (four bodies, working width 1.4 m) at a depth of 25–27 cm after stubble tillage in all treatments. The following crop was winter wheat (*Triticum aestivum* L.) with a sowing density of 300 seeds m^{-2} at all the experimental fields.

The experiment was comprised of two trial periods per location; the first period (P_1) started in autumn 2013 and ended in summer 2014, and the second period (replicate in time, on other fields but at same locations) started in autumn 2014 and ended in summer 2015 (P_2). Altogether four different experimental fields (2 locations × 2 periods) were used, on which OSR had not been grown for more than five years. Soil textures of the fields in P_1 and P_2 were loam at IHO, and silt clay in P_1 and loam in P_2 at GA. Prior to each experiment, imidazolinone-tolerant (Clearfield; CL) OSR was sown in the respective year before (*i.e.* in 2013 for the actual tillage experiment in 2014–2015, and in 2014 for the experiment in 2015) and harvested in order to cause harvest seed losses. During P_1, CL winter OSR variety 1 (variety name known to the authors) was grown and its incidental harvesting seed loss was used for the subsequent actual experiment at two locations. During P_2, variety 1 was replaced by variety 2 (also CL winter OSR). Variety 1 had a potential secondary seed dormancy of 57% and variety 2 had a potential secondary dormancy of 91%. Both varieties, therefore, were suitable to initiate a soil seed bank due to their high disposition to secondary dormancy. The dormancy level was determined in a previous laboratory test, which was comprised of three processes, dormancy induction in darkness, germination in darkness, and viability test of potentially dormant seeds (Weber et al., 2010).