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Weed Dynamics in No-Till Rainfed Crops in Chaouia, Semi-Arid Morocco

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Abstract

Three on-farm research-managed trials were conducted in Settat province, Chaouia, semi-arid Morocco, from 2012-13 to 2014-15, to investigate the dynamics of germinable soil seedbank, weed density, and community composition of weeds in 3 crop rotations: continuous durum wheat, barley + pea/durum wheat/durum wheat, and canola/durum wheat/durum wheat. Initial germinable weed seedbank density estimated in September 2012, before no-till planting in November 2012 was 1890 seeds m^{-2}. After two growing seasons, seedbank reductions were 23% in continuous durum wheat, 68% in canola/durum wheat/durum wheat, and 72% in barley + pea/durum wheat/durum wheat. In continuous durum wheat, weed densities before no-till planting were 273, 46, and 59 plants m^{-2} in November 2012, December 2013, and November 2014, respectively. In herbicide-free barley + pea/durum wheat/durum wheat, weed densities before no-till planting durum wheat were 128 and 42 plants m^{-2} in December 2013 and November 2014, respectively. In canola/durum wheat/durum wheat, weed densities before no-till planting wheat were only 20 and 25 plants m^{-2} in December 2013 and November 2014, respectively. This study demonstrated the combined merits of pre-plant glyphosate, herbicide use in wheat, herbicide-free barley + pea haying, and durum wheat rotation with either canola or barley + pea to manage weeds in no-till systems in semi-arid Morocco.

Keywords: weed seedbank, weed density, crop rotation, no-till, Morocco

1. Introduction

Conservation agriculture (CA) is based on minimum soil disturbance, permanent soil cover, and crop rotation; it is promoted as a sustainable alternative to systems involving conventional tillage (Kassam, 2014; Loss et al., 2015; Nichols et al., 2015). In Morocco, much of the CA work done since the early 1980s has shown that yields can be improved with no-till systems (Abail et al., 2013; Belmekki et al., 2014; Boughlala et al., 2011; El Gharras et al, 2010; Labbaci et al., 2015; Moussadek, 2011; Mrabet, 2008; Mrabet et al., 2012; Ramdani et al., 2010; Schwilch et al., 2015). However, CA adoption was quite low in Morocco due to a general perception that no-till farming systems require more herbicides than conventional agriculture (El Brahli & Mrabet, 2000). Such increased use of herbicides may be considered by small farmers a major problem of no-till farming particularly in a time when the use of agrochemicals is considered by the general public as threat for human health and the environment (Friedrich, 2005).

A number of CA practices designed to replace or improve continuous wheat production intend to introduce nitrogen fixing crops, reduce soil disturbance, and retain surface crop residues (Kassam, 2014). Ultimately, these practices should improve crop yields, reduce costs of crop production, increase soil organic matter content, and improve long-term soil health. However, adoption of CA is often hindered by farmers' limited understanding of the changes in weed control practices and crop performance during the transition period. Integrated weed management under CA may include the combination of applied soil herbicides, crop rotation, and competitive crop varieties with weeds (Anderson, 2015; Blackshaw et al., 2005, 2015; Gulden et al., 2011; Harker & O'Donovan, 2013; Holm et al., 2006).

In crop/livestock integrated production systems, weed seeds are an important challenge since most weeds are considered as free forage for livestock and the weedy fallow is widely practiced (El Housni et al., 2013). No-till systems accumulate seeds near the soil surface where they are more likely to germinate but are also exposed to greater mortality risks through weather variability and predation. Assuming no seed input into the system, germinable seedbanks under no-till decrease more rapidly than under conventional tillage. Reducing tillage may shift seedbank densities and weed communities from annual broadleaves to annual grasses and/or perennials (Aibar, 2006; El Brahli & Mrabet, 2000; Gulden et al., 2011; Jose Maria & Sans, 2011; Murphy et al., 2006; Nichols et al., 2015; Recasens et al., 2016).

Under semi-arid Morocco conditions, our knowledge of the effects of crop rotation and herbicides on weed seedbank community size and structure is limited. Weed seedbank densities have been studied less frequently than weed plant communities because they require labor and greenhouse. Tanji et al. (2017) reported that integrated weed management combining glyphosate before no-till planting, post-emergence herbicide use in bread wheat, haying barley + pea mixture, within the crop rotation (barley + pea/bread wheat) reduced weed seedbank by up to 35%, species richness by up to 47%, and weed density prior to wheat harvest or forage haying by up to 83%. In this paper, we provide results from recent 3 on-farm trials related to the combined effects of crop rotation, pre-plant glyphosate, herbicide use in wheat, and herbicide-free barley + pea mixture on the weed seedbank and weed density.

2. Materials and Methods

2.1 General

On-farm trials were conducted from 2012-13 to 2014-15 in the Settat province, Chaouia, Morocco. The climate is semi-arid, and precipitations during the 3 cropping seasons varied from 232 mm to 455 mm with more than 60% occurring from November through April (Table 1). Under Mediterranean conditions, monthly minimal temperatures are usually 5 to 10 °C from December to February and monthly maximal temperatures are 25 to 30 °C from June to August. The soil is a vertisol with 55% clay.

Three farms were therefore selected in 2012 and 3 hectares (ha) in each farm were used to conduct no-till research-managed trials. One ha was no-till planted to durum wheat (*Triticum durum* Desf.), 1 ha was no-till planted to a forage mixture of barley (*Hordeum vulgare* L.) + pea (*Pisum sativum* L.), and 1 ha to canola (*Brassica napus* L.). Three crop rotations were managed using conservation management practices: continuous durum wheat, barley + pea/durum wheat/durum wheat, and canola/durum wheat/durum wheat. Prior to 2012-13, all fields have been planted with wheat or barley using conventional system.

Table 1. Monthly precipitation at Settat, Morocco, from 2012-13 to 2014-15

Month	2012-13	2013-14	2014-15
	-------------------------------- mm	--------------------------------	
September	23.4	6.8	9.5
October	124.0	1.6	6.6
November	91.2	27.7	164.0
December	6.5	18.4	50.3
January	36.0	98.4	55.9
February	20.5	27.8	8.9
March	111.5	9.5	57.9
April	41.6	42.1	0
May	0	0	15.5
June	0	0	9.0
July	0	0	0
August	0	0	0
Total	454.7	232.3	377.6

"Karim" durum wheat variety and local barley and pea seeds were no-till planted in November 2012, 2013, and 2014. The wheat crop was fertilized at 100 kg ha^{-1} of diammonium phosphate (18-46-0) and no-till planted at 120 kg ha^{-1} of seeds. The forage mixture was fertilized the same way as the durum wheat and no-till planted at 25 + 75 kg ha^{-1} of barley + pea seeds. Canola was fertilized the same way as the wheat and forage mixture and no-till planted at 3 kg of seeds ha^{-1}. Top dressing nitrogen was used at wheat tillering at the rate of 33 kg ha^{-1}. The utilized no-till seeder is a tine seed drill of 18 cm row spacing.

At wheat tillering, the broadleaf herbicide florasulam + 2,4-D (3.75 + 180 g ha^{-1}) was used in durum wheat fields. A foliar fungicide (epoxyconazol at 125 g ha^{-1}) was sprayed on wheat at the booting stage. Herbicides and fungicides were sprayed with a tractor-mounted sprayer, and volumes of spray were 120 L ha^{-1} for herbicides and 200 L ha^{-1} for fungicide. Glyphosate (720 g ha^{-1}) was applied in all fields prior to no-till planting.

2.2 Seedbank Assessment

The procedure used in the Oued Zem study (Tanji et al., 2017) was used in this study. Each year, ten soil cores (7.2-cm diameter by 10 cm deep) were randomly collected from each field, bulked, air dried, placed in polyethylene bags, and stored in the greenhouse at room temperature (25/10 °C) until November. Germinable weed seedbank determinations were conducted using the greenhouse emergence method (Blackshaw et al., 2005; Gulden et al., 2011; Smith & Gross, 2006; Tanji et al., 2017). Soil was spread onto plastic trays, placed in a greenhouse with a day/night temperature of 25/10 °C and watered as necessary to keep moist. Weed emergence counts were made twice a month from November to April. Seedlings that emerged were identified and removed. Total seedling counts in each soil sample, from November to April, were considered the germinable fraction of the weed seedbank.

2.3 Weed Density

Weed densities were estimated in 10 randomly chosen (0.5 m × 0.5 m = 0.25 m^2) quadrats in each farmer‘s field at 3 periods (Tables 3 to 5):

- in November or December prior to application of glyphosate (720 g ha^{-1}) at crop planting,
- in January or February prior to Florasulam + 2,4-D (3.75 + 180 g ha^{-1}) application at wheat tillering, and
- in March or April prior to forage haying and wheat and canola harvests.

2.4 Satistical Analysis

This study was conducted in 3 farmers' fields in the same region, and each field was considered as one site or one replicate. There were 3 different crop rotations at each site (canola/durum wheat/durum wheat, barley + pea/durum wheat/durum wheat, and continuous durum wheat). Data presented for weed seedbank were means of the 3 sites. Mean weed densities were presented for each crop. Means +/- standard error were calculated using PROC UNIVARIATE with SAS software (SAS Institute v. 9.2, Cary, NC).

3. Results and Discussions

3.1 Weed Seedbank Diversity

The greenhouse germination study showed that the initial germinable soil weed seedbank from 3 farmers' fields was 1890 seeds m^{-2} (Table 2) in September 2012. Such high seed density might be due to the lack of appropriate weed management in the traditional cereal/cereal rotation. In fact, farmers were not familiar with herbicide use, and weeds in cereal fields were hand pulled for animal feed.

In September 2013, weed seedbank was 1009 seeds m^{-2} after one season of durum wheat (in continuous durum wheat), 719 seeds m^{-2} after barley + pea (in durum wheat/barley + pea rotation), and 564 seeds m^{-2} after canola (in durum wheat/canola rotation). In comparison to the initial seedbank that was estimated in September 2012 to 1890 seeds m^{-2}, seedbank reductions in the first year of this no-till study were 47, 62, and 70% after durum wheat, barley + pea forage, and canola, respectively.

In September 2014, seedbank in durum wheat was 1445 seeds m^{-2} after 2 growing seasons of durum wheat, while durum wheat after canola had 606 seeds m^{-2}, and durum wheat after barley + pea had only 520 seeds m^{-2}. Compared to the initial seedbank (1890 seeds m^{-2}) estimated in September 2012, seedbank reductions after two cropping seasons were 23% in continuous durum wheat, 68% in the durum wheat after canola, and 72% in durum wheat after barley + pea mixture. Nichols et al. (2015) reported that burial increases weed seed survival, while seeds on or close to the soil surface can lose viability due to desiccation and harsh weather. Rotation designs involving four years or more have been shown to drastically reduce weed density and herbicide use in both tilled and un-tilled systems (Anderson, 2015; Blackshaw et al., 2005, 2015; Murphy et al., 2006; Stone et al., 2006; Tuesca et al., 2001).

Table 2. Germinable weed seed density in no-till crops in 3 sites in Chaouia, Morocco, in September 2012, 2013, and 2014

Weed species	Weed seedbank in September 2012	Weed seedbank in September 2013			Weed seedbank in September 2014		
		Rotation 1	Rotation 2	Rotation 3	Rotation 1	Rotation 2	Rotation 3
	Conventional durum wheat in 2011-12	durum wheat in 2011-12 /durum wheat in 2012-13	durum wheat in 2011-12 /barley + pea in 2012-13	durum wheat in 2011-12 /canola in 2012-13	durum wheat in 2011-12 /durum wheat in 2012-13 /durum wheat in 2013-14	durum wheat in 2011-12 /barley + pea in 2012-13 /durum wheat in 2013-14	durum wheat in 2011-12 /canola in 2012-13 /durum wheat in 2013-14
	Germinable weed seeds m^{-2} (average of 3 sites)						
Anisantha rigida (Roth) Hyl.	221	224	23	0	676	121	0
Papaver rhoeas L.	205	203	82	152	348	236	206
Lysimachia arvensis (L.) U.M.&A.	306	39	36	24	18	18	73
Misopates orontium (L.) Raf.	65	55	14	6	112	24	97
Melilotus sulcatus Desf.	49	3	5	152	3	0	48
Lolium rigidum Gaud.	95	3	0	0	36	0	6
Calendula stellata Cav.	27	73	45	6	52	18	0
Cichorium intybus L.	11	12	0	0	0	12	0
Scorpiurus muricatus L.	5	33	5	6	18	12	0
Vaccaria hispanica (Mill.) R.	8	3	9	30	6	0	12
Medicago polymorpha L.	44	12	14	0			
Plantago afra L.	3	55	18	0			
Diplotaxis tenuisiliqua Delile	38	0	68	0			
Emex spinosa (L.) Campd.	14				3	0	12
Chenopodium murale L.	76						
Avena sterilis L.	33						
Glebionis coronaria (L.) Spach	30						
Anacyclus maroccanus Ball	22						
Malva parviflora L.	19						
Senecio vulgaris L.	16						
Diplotaxis assurgens (Del.) T.	14						
Rhagadiolus stellatus (L.) G.	11						
Spergula fallax (Lowe) E.H.L.K.	11						
Eryngium ilicifolium Lam.	8						
Glaucium corniculatum (L.) J.H.R.	8						
Heliotropium europaeum L.	8						
Ridolfia segetum (Guss.) Moris	5						
Convolvulus arvensis L.	3						
Ecballium elaterium (L.) A.R.	3						
Others	532	294	400	188	167	79	152
Total (seeds m^{-2})	1890	1009	719	564	1445	520	606
Standard error	488	269	333	136	519	143	170

The canola/durum wheat and barley + pea/durum wheat crop rotations contributed to the rapid decrease in the readily germinable fraction of weed seedbank compared with continuous durum wheat. Higher seedbank reductions in these two crop rotations were essentially due to glyphosate pre-plant and florasulam + 2,4-D post-emergence in wheat. In fact, herbicides were found to be among the main factors controlling arable seedbanks, because they limit both weed growth and weed seed production (Jose Maria & Sans, 2011; Tanji et al., 2017).

The crop rotation as a weed management strategy showed that starting with canola or a forage mixture reduced the seedbank gradually while starting with a cereal crop showed an increase in rigid brome (*Anisantha rigida*) seed in the soil seedbank. Rigid brome seedbank density was 221 seeds m^{-2} in September 2012 and 676 seeds m^{-2} in September 2014. Therefore, in barley + pea/durum wheat and canola/durum wheat rotations, rigid brome seedbank diminished while continuous durum wheat increased three-fold rigid brome seedbank density in two seasons. In no-tilled wheat fields in Meknès, North Central of Morocco, Hamal et al. (2001) found 876 seeds of rigid brome m^{-2}. Recasens et al. (2016) found that *Bromus diandrus* density increased in no-till crop rotation of barley/bread wheat/barley during three seasons. However, greater rotational crop diversity resulted in easier weed management (Nichols et al., 2015).

In September 2012, more than 29 weed species were identified in soil seedbank (Table 2). The 5 major weeds were *Anisantha rigida*, *Lysimachia arvensis*, *Melilotus sulcatus*, *Misopates orontium*, and *Papaver rhoeas*. More than 16 weed species were not found in September 2013 and September 2014. For example, seedbank decreased for *Chenopodium murale*, *Cichorium intybus*, *Diplotaxis tenuisiliqua*, *Emex spinosa*, *Glebionis coronaria*, *Lysimachia arvensis*, and *Melilotus sulcatus*. However, seed of *Anisantha rigida*, *Calendula stellata*, *Misopates orontium*, *Papaver rhoeas*, and *Scorpiurus muricatus* increased. In a crop rotation study, Lutman et al. (2002) reported that annual seed loss rates varied from 20 to 99% for 15 weed species.

3.2 Weed Diversity in Wheat Fields

In continuous durum wheat, weed densities before applying glyphosate and planting were 273, 46, and 59 plants m^{-2} in November 2012, December 2013, and November 2014, respectively (Table 3). Compared to the initial weed density (273 plants m^{-2} recorded in November 2012), reductions in weed densities were 83 and 78% after one and two seasons, respectively. Glyphosate sprayed before or at planting at 720 g ha^{-1} provided excellent control of volunteer crops and annual weeds. Perennial weeds such as *Arisarum vulgare*, *Launaea nudicaulis*, and *Silene vulgaris* were partially controlled with glyphosate. Weed densities before herbicide treatments in durum wheat were 115, 25, and 36 plants m^{-2} in January 2013, February 2014, and January 2015, respectively. Weed densities after herbicide treatments were 57, 18, and 49 plants m^{-2} in April 2013, March 2014, and April 2015, respectively.

In herbicide-free barley + pea/durum wheat/durum wheat, weed densities before applying glyphosate and planting durum wheat were 128, and 42 plants m^{-2} in December 2013 and November 2014, respectively (Table 4). Glyphosate sprayed before or at planting provided excellent control of volunteer crops and annual weeds. After durum wheat emergence, weed densities were 101 and 15 plants m^{-2} in February 2014 and January 2015, respectively. Weed densities after herbicide treatments in durum wheat were 59 and 10 plants m^{-2} in March 2014 and April 2015, respectively. In barley + pea forage mixture/durum wheat rotation, volunteer barley and pea were among weeds found in wheat plots.

In canola/durum wheat/durum wheat, weed densities before applying glyphosate and planting wheat were 20 and 25 plants m^{-2} in December 2013 and November 2014, respectively (Table 5). Pre-plant glyphosate provided excellent weed control. After wheat emergence, weed densities were 27 and 22 plants m^{-2} in February 2014 and January 2015, respectively. Weed densities after herbicide application in wheat were 12 and 6 plants m^{-2} in March 2014 and April 2015, respectively.

After crop emergence, 97 weed species were identified in all durum wheat plots during the 3 cropping seasons (Table 3). Major weed species found in durum wheat were *Anisantha rigida*, *Calendula stellata*, *Diplotaxis tenuisiliqua*, *Malva parviflora*, *Melilotus sulcatus*, *Scorpiurus muricatus*, volunteer barley, and volunteer pea. Weed control with postemergence herbicides florasulam + 2,4-D provided excellent control of annual broadleaf weeds in wheat.

Weed species that had low densities in durum wheat in the second and/or third year of various crop rotations included *Bupleurum lancifolium*, *Calendula stellata*, *Cichorium intybus*, *Lysimachia arvensis*, *Melilotus sulcatus*, *Misopates orontium*, *Papaver rhoeas*, etc. However, rigid brome (*Anisantha rigida*) had increased density in the second and third year of no-till, essentially in the continuous durum wheat. No-till systems favor species that can successfully germinate on the soil surface such as annual grasses (Nichols et al., 2015; Recasens et al., 2016).

Table 3. Weed density in continuous no-till durum wheat in 3 sites in Chaouia, Morocco, from 2012-13 to 2014-15

Weed species	Rotation 1: continuous durum wheat								
	2012-13			2013-14			2014-15		
	Date of weed density measurement								
	16 Nov 2012	17 Jan 2013	16 Apr 2013	24 Dec 2013	9 Feb 2014	8 Mar 2014	24 Nov 2014	15 Jan 2015	1 Apr 2015
	Plants m^{-2} (average of 3 sites)								
Anisantha rigida (Roth) Hyl.	58	7	5	9	5	15	11	10	45
Melilotus sulcatus Desf.	3	10	2	4	6	0	0	0	0
Hordeum vulgare L. (barley)	0	0	0	0	2	1	17	2	1
Calendula stellata Cav.	1	4	1	12	0	0	0	0	0
Scorpiurus muricatus L.	3	9	13	0	3	0	0	6	2
Avena sterilis L.	48	9	17	0	0	0	0	0	0
Papaver rhoeas L.	17	23	2	0	0	0	0	1	0
Arisarum vulgare Targ.-Tozz.	8	4	1	1	1	0	0	2	0
Cichorium intybus L.	29	4	0	2	0	0	1	0	0
Lolium rigidum Gaud.	17	3	1	0	0	0	0	0	0
Pisum sativum L. (pea)	0	0	0	3	0	0	0	0	0
Lysimachia arvensis (L.) U. M. & A.	25	2	3	0	0	0	0	0	0
Rhagadiolus stellatus (L.) Gaertn.	2	4	0	1	0	0	0	0	0
Glebionis coronaria (L.) Spach	1	0	1	0	0	0	0	0	0
Geropogon hybridus L.	2	2	1	0	0	0	0	0	0
Silene vulgaris (Moench) Garcke	1	1	0	2	0	1	1	0	0
Vaccaria hispanica (Mill.) Rauschert	1	4	0	0	1	0	0	0	0
Malva parviflora L.	1	0	0	0	0	0	13	0	0
Diplotaxis tenuisiliqua Delile	1	0	0	1	0	0	4	6	0
Calendula arvensis L.	2	1	0	0	0	0	1	0	0
Cynodon dactylon (L.) Pers.	4	0	1	0	0	0	0	0	0
Sonchus oleraceus L.	2	1	0	3	2	0	0	0	0
Convolvulus althaeoides L.	1	1	0	3	0	0	3	0	0
Sinapis arvensis L.	7	0	0	1	0	0	0	0	0
Ecballium elaterium (L.) A. Richard	0	0	0	0	1	0	0	0	1
Bupleurum lancifolium Hornem.	0	7	3	0	1	0	0	0	0
Vicia sativa L.	0	1	0	0	1	1	0	0	0
Medicago polymorpha L.	0	0	0	0	0	0	1	6	0
Triticum aestivum L. (bread wheat)	1	0	0	0	0	0	0	0	0
Misopates orontium (L.) Raf.	2	1	0	0	0	0	0	0	0
Convolvulus arvensis L.	1	1	1	0	0	0	0	0	0
Plantago afra L.	1	1	0	0	0	0	0	0	0
Silybum marianum (L.) Gaertn.	2	1	1	0	0	0	0	0	0
Euphorbia exigua L.	4	1	0	0	0	0	0	0	0
Galium verrucosum Huds.	0	3	0	0	0	0	0	0	0
Emex spinosa (L.) Campd.	2	1	0	0	0	0	0	0	0
Phalaris minor Retz.	2	2	0	0	0	0	0	0	0
Teucrium resupinatum Desf.	3	0	0	0	0	0	0	0	0
Other weeds	21	7	4	4	2	0	7	3	0
Total (plants m^{-2})	273	115	57	46	25	18	59	36	49
Standard error	97	24	16	12	6	7	22	13	46

Table 4. Weed density in no-till crops in rotation 2 (barley + pea/durum wheat/durum wheat) in 3 sites in Chaouia from 2012-13 to 2014-15

Weed species	Rotation 2: barley + pea/durum wheat/durum wheat								
	barley + pea in 2012-13			durum wheat in 2013-14			durum wheat in 2014-15		
	Date of weed density measurement								
	16 Nov 2012	17 Jan 2013	2 Apr 2013	24 Dec 2013	9 Feb 2014	8 Mar 2014	24 Nov 2014	15 Jan 2015	1 Apr 2015
	Plants m^{-2} (average of 3 sites)								
Anisantha rigida (Roth) Hyl.	6	1	1	5	1	1	13	0	3
Melilotus sulcatus Desf.	80	9	2	8	1	0	0	0	0
Hordeum vulgare L. (barley)	0	0	0	52	56	37	15	1	1
Calendula stellata Cav.	104	1	2	0	0	0	0	0	0
Scorpiurus muricatus L.	2	10	14	0	1	0	1	1	2
Avena sterilis L.	0	7	18	0	0	0	0	0	0
Papaver rhoeas L.	6	5	1	2	0	0	0	1	0
Arisarum vulgare Targ.-Tozz.	11	5	0	1	0	1	2	4	0
Cichorium intybus L.	30	4	1	2	1	0	1	0	0
Lolium rigidum Gaud.	56	8	1	0	1	0	0	0	0
Pisum sativum (pea)	0	0	0	44	34	18	0	0	0
Andryala integrifolia L.	50	9	1	0	0	0	0	0	0
Lysimachia arvensis (L.) U.M. & A.	5	7	0	0	0	0	0	0	0
Rhagadiolus stellatus (L.) Gaertn.	1	2	2	3	2	1	0	3	0
Glebionis coronaria (L.) Spach	19	2	2	0	0	0	0	0	0
Geropogon hybridus L.	2	4	3	0	1	1	0	1	1
Silene vulgaris (Moench) Garcke	2	0	0	1	0	0	0	3	0
Vaccaria hispanica (Mill.) Rauschert	1	2	1	1	0	0	1	0	0
Malva parviflora L.	26	2	0	0	0	0	0	0	0
Diplotaxis tenuisiliqua Delile	2	2	2	0	0	0	3	0	0
Cynodon dactylon (L.) Pers.	0	1	0	0	1	0	0	0	0
Sonchus oleraceus L.	9	0	1	3	1	0	0	0	0
Convolvulus althaeoides L.	1	0	0	1	0	0	2	0	1
Sinapis arvensis L.	10	0	0	2	0	0	0	0	0
Ecballium elaterium (L.) A. Richard	0	0	0	0	0	0	2	0	0
Bupleurum lancifolium Hornem.	0	1	0	0	0	0	0	0	0
Vicia sativa L.	0	1	4	0	1	0	1	1	0
Medicago polymorpha L.	2	0	0	0	0	0	0	0	0
Triticum aestivum L. (bread wheat)	3	0	0	0	0	0	0	0	0
Misopates orontium (L.) Raf.	6	0	0	0	0	0	0	0	0
Convolvulus arvensis L.	2	0	0	0	0	0	0	0	0
Plantago afra L.	1	0	0	0	0	0	0	0	1
Silybum marianum (L.) Gaertn.	1	0	0	0	0	0	1	0	0
Euphorbia exigua L.	6	0	0	0	0	0	0	0	0
Galium verrucosum Huds.	3	1	0	0	0	0	0	0	0
Emex spinosa (L.) Campd.	5	1	0	0	0	0	0	0	0
Phalaris minor Retz.	0	1	0	0	0	0	0	0	1
Hippocrepis multisiliquosa L.	11	0	0	0	0	0	0	0	0
Teucrium resupinatum Desf.	5	0	1	0	0	0	0	0	0
Other weeds	21	1	2	3	0	0	0	0	0
Total (plants m^{-2})	489	87	59	128	101	59	42	15	10
Standard error	329	26	17	15	10	10	3	2	1

Table 5. Weed density in no-till crops in rotation 3 (canola/durum wheat/durum wheat) in Chaouia from 2012-13 to 2014-15

Weed species	Rotation 3: canola/durum wheat/durum wheat								
	Canola in 2012-13			Durum wheat in 2013-14			Durum wheat in 2014-15		
	Date of weed density measurement								
	1 Nov 2012	17 Jan 2013	2 Mar 2013	24 Dec 2013	9 Feb 2014	8 Mar 2014	24 Nov 2014	15 Jan 2015	1 Apr 2015
	Plants m^{-2} (average of 3 sites)								
Anisantha rigida (Roth) Hyl.	0	0	0	1	1	2	0	0	4
Melilotus sulcatus Desf.	3	2	1	2	0	0	0	11	0
Hordeum vulgare (barley)	1	0	0	0	0	0	8	0	0
Calendula stellata Cav.	2	1	0	0	0	0	0	1	0
Scorpiurus muricatus L.	2	21	10	0	0	0	1	0	0
Papaver rhoeas L.	1	2	7	3	0	0	0	1	0
Arisarum vulgare Targ.-Tozz.	5	4	4	0	3	2	1	1	0
Cichorium intybus L.	3	0	0	0	0	0	1	0	1
Lysimachia arvensis (L.) U.M.&A.	1	1	1	0	0	0	0	0	0
Rhagadiolus stellatus (L.) Gaertn.	1	11	3	0	0	0	0	1	1
Geropogon hybridus L.	0	15	1	0	0	0	0	0	0
Silene vulgaris (Moench) Garcke	3	0	0	0	11	0	3	0	0
Vaccaria hispanica (Mill.) Rauschert	2	5	10	0	1	0	0	0	0
Malva parviflora L.	0	0	0	0	0	0	0	0	0
Diplotaxis tenuisiliqua Delile	0	0	0	0	0	0	1	3	0
Cynodon dactylon (L.) Pers.	1	3	1	3	4	4	3	1	0
Sonchus oleraceus L.	3	0	1	1	0	0	0	0	0
Convolvulus althaeoides L.	2	2	1	1	0	0	0	0	0
Ecballium elaterium (L.) A. Richard	2	1	1	1	1	1	3	1	0
Bupleurum lancifolium Hornem.	0	0	0	0	3	0	0	0	0
Vicia sativa L.	1	2	0	0	1	0	0	1	0
Medicago polymorpha L.	0	0	0	0	0	0	0	1	0
Triticum aestivum L. (bread wheat)	11	1	0	0	0	0	0	0	0
Misopates orontium (L.) Raf.	2	0	2	0	0	0	0	0	0
Plantago afra L.	0	0	0	1	0	0	0	0	0
Silybum marianum (L.) Gaertn.	1	0	0	0	0	0	2	0	0
Euphorbia exigua L.	0	1	2	0	0	0	0	0	0
Emex spinosa (L.) Campd.	1	0	0	0	0	0	0	0	0
Phalaris minor Retz.	1	3	1	0	0	0	0	0	0
Teucrium resupinatum Desf.	1	0	0	0	0	0	0	0	0
Others	8	7	2	7	2	1	2	0	0
Total (plants m^{-2})	58	82	49	20	27	12	25	22	6
Standard error	9	32	9	3	5	4	2	7	5

3.3 Weed Diversity in Barley + Pea Fields

In forage mixture barley + pea, weed densities were 489, 87, and 59 plants m^{-2} in November 2012, January 2013, and April 2013 few days before haying, respectively (Table 4). By using pre-plant glyphosate, planting no-till herbicide-free forage mixture barley + pea would decrease selection pressure for herbicide resistance. Furthermore, barley + pea mixture was an appropriate choice as a crop in crop/livestock integrated dryland production systems because of its potential for high yield and competitiveness with weeds. Barley and pea are well adapted to semiarid regions, and may be a good approach for forage production and weed management. Indeed, barley + pea produce good yields with nutritive values suitable for sheep and cattle (Carr et al., 2004; Lenssen, 2008).

Table 4 shows that major weed species associated to barley + pea mixture were *Anisantha rigida*, *Avena sterilis*, *Calendula stellata*, *Cichorium intybus*, *Glebionis coronaria*, *Lolium rigidum*, *Lysimachia arvensis*, *Melilotus sulcata*, *Papaver rhoeas*, and *Scorpiurus muricatus*. All these weeds were palatable and not toxic to livestock.

3.4 Weed Diversity in Canola Fields

In 2012-13, weed densities were 58 plants m^{-2} before glyphosate application at planting (Table 5). Weed density was 82 plants m^{-2} in January after crop emergence, and 49 plants m^{-2} in April 2013 at the flowering stage. The 5 major weed species associated to canola were *Geropogon hybridus*, *Rhagadiolus stellatus*, *Scorpiurus muricatus*, *Vaccaria hispanica*, and volunteer wheat. Such weeds are common in rainfed canola fields in Morocco (Tanji & El Brahli, 2017).

4. Conclusion

This study showed that the initial soil weed seedbank was 1890 seeds m^{-2}. Seedbank reductions after two cropping seasons were 23% in continuous durum wheat, 68% in the durum wheat after canola, and 72% in durum wheat after barley + pea mixture. Such reductions were due to glyphosate use before no-till planting, post-emergence herbicide application in durum wheat, mowing barley + pea mixture for hay. Continuous durum wheat increased rigid brome (*Anisantha rigida*) density and seedbank. For a good integration crop/livestock production system, grazed weedy fallow should be replaced by barley + pea forage mixture. This study demonstrated the combined merits of pre-plant glyphosate, herbicide use in durum wheat, herbicide-free barley + pea haying, and durum wheat rotation with either canola or barley + pea to manage weeds in no-till systems in semi-arid Morocco. Further research is needed concerning the effects of the weed-suppressive potential of longer (> 3 years) rotations.

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