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Effect of Long-term Reduced Tillage on Yield and Weeds of Spring Barley

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ABSTRACT

The aim of this study was to evaluate the effect of long-term reduced tillage on yield and weeds of spring barley. Treatments consisted of three tillage systems including: (a) conventional tillage (CT), (b) reduced tillage (RT), and (c) herbicide tillage (HT) as the main plot, and two cultivars of spring barley (Tocada and Rastik) as subplots. The results showed that the yield of both cultivars was the highest in CT and the lowest in HT and RT tillage systems. Yield reductions in both HT and RT tillage systems were due to lower spikes per m^2 and 1,000 grain weight. Weeds numbers and dry weight were more in HT and RT than CT tillage.

Keywords: Weeds dry weight, Weed number, Species composition, Tillage systems.

INTRODUCTION

The necessity of minimizing expenditures incurred on agricultural production and the need for environmental protection against degradation lead to the search for unconventional solutions in tillage. Not all solutions, however, are optimal, whilst their efficacy depends on many natural and economic factors of a farm (Ozpinar and Ozpinar, 2011). This was confirmed in a research by Gruber *et al.* (2012), where no single tillage system was better than the other, but each was suitable for specific conditions of a farm.

The principal objective of tillage is providing plants optimal conditions for growth and yield (Morris *et al*., 2010; Farooq *et al*., 2011), but, still solutions used to this end are not always optimal. It has been demonstrated, for instance, that herbaceous weeds are the key problem in reduced tillage (Locke *et al.* 2002), and that tillage involving only a cultivator increased infestation with annual weeds (Pekrun and Claupein, 2006; Gruber and Claupein, 2009). Shedding grains are stored in the topsoil, from where they germinate, thus increasing weed infestation of the successive crop (Cardina, 2002; Chauhan *et al.,* 2006; Mohler *et al.,* 2006). Minimized tillage increases the seedbank in the topsoil (Tørresen and Skuterud, 2002). A solution to this problem is commonly herbicides application; however, their efficacy is influenced by many factors linked with biotope and agro-technical treatments applied (Deike *et al.,* 2008). In a study conducted in SW Germany, no-till system led to several times higher weed infestation than mouldboard plow (Gruber *et al.,* 2012). In turn, Woźniak and Haliniarz (2012) demonstrated that weed infestation was affected by reduced tillage system and grain species. Durum wheat was more infested by weeds than common wheat and oat, especially under conditions of reduced tillage. Buhler *et al.* (1994) indicated that reduced tillage systems increased the number and dry weight of weeds, mainly perennial. According to Brandsaeter *et al.*

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(2011), 25 cm plowing depth was more effectively (by 50%) reducing the number and dry weight of weeds than 15 cm. However, a greater advantage of the deeper plowing includes more effective eradication of *Cirsium arvense* (L.) Scop., i.e. even by 90% compared to the shallow plowing.

The objective of this study was to evaluate effects of long-term reduced tillage on yield and weed infestation of spring barley.

MATERIALS AND METHODS

A field experiment was conducted at the Agricultural Experimental Station of Uhrusk (51°18'12"N, 23°36'50"E) University of Life Science in Lublin, south-east of Poland from 2007 to 2011, when spring wheat and oat were sown on the plot following pea (*Pisum sativum* L.) under conditions of conventional tillage (CT), reduced tillage (RT), and herbicide tillage (HT). In 2012, two cultivars of spring barley were sown following pea, which enabled evaluating the effect of long-term reduced tillage on seed yield and weed number and dry weight of this cereal. The two-factor experiment was conducted with the method of randomized sub-blocks in three replications, in which the tillage systems treatments were conventional (CT), reduced (RT), and herbicide (HT) as the main plots and two barley cultivars (Tocada with husked grain and Rastik with non-husked grain) as subplot. Blocks with sizes of 8×75 m were divided into 3 sub-blocks, and each of the sub-blocks into 2 plots. Both cultivars of barley are included in the Common Catalogue of Varieties of Agricultural Plant Species (EU 2009) and are released as feedstuff, however Tocada *cv.* is characterized by a very good fodder value, whereas Rastik *cv.* has a very high content of protein in grain. The tillage plan is presented in Table 1.

The soil goup was Rendzic Phaeozem (IUSS Working Group WRB 2006) with texture of sandy loam, rich in available phosphorus (214 mg P kg^{-1}) and potassium (237 mg K kg^{-1}) and a slightly alkaline pH= 7.2. Inorganic N content was 1.03 g kg^{-1} and that of organic C was 7.60 g kg^{-1}. Annual total precipitation was 577.6 mm with a mean air temperature of 7.5°C (data of the years 1963-2010, Agrometeorological Station, Uhrusk). In the period between sowing and harvest i.e. April-August, the sum of precipitation reached 322 mm, with mean air temperature of 14.8°C.

Both cultivars of barley were sown in the first decade of April at the rate of 320 seeds m^{-2}. Fertilizers were applied as 70 kg N ha^{-1}, 26 kg P ha^{-1} and 83 kg K ha^{-1}. At the tillering stage (stage 22-23, Zadoks *et al.*, 1974), Chwastox Trio 540 SL (a.s. mecoprop+MCPA+dicamba) were applied at the rate of 1.5 L ha^{-1}.

On all plots, analyses were conducted to evaluate grain yield, biometric parameters, seed yield, and yield components, i.e. number of plants after tillers per m^2 (at scale of 12–13 in Zadoks), number of spikes per m^2 (at the scale of 90–91 in Zadoks), weight of grain, weight of 1,000 grains, and weed infestation of a plot. Grain was harvested with a plot harvester, Wintersteiger, numbers of plants

Table 1. Scheme of soil tillage.

Tillage systems[a]	Crops		
	After-harvest	Pre-winter	Spring
CT	Shallow plowing	Pre-winter plowing	Harrowing, set for pre-sowing tillage
RT	Cultivator (Twice)	No plowing	Cultivator, set for pre-sowing tillage
HT	Herbicide roundup, 360 SL (a.s. glyphosate)		

[a] CT= Conventional Tillage; RT= Reduced Tillage, HT= Herbicide Tillage.

and spikes per m^2 were determined at each plot twice in a frame area of 0.5×1.0 m.

Determination of 1,000 grains weight consisted of twofold counting out of 500 grains, whereas the weight of grains was determined as a mean value from 40 spikes collected at random from each plot.

Weed infestation was evaluated with the botanical-gravimetric method at the sprouting stage (at the scale of 12-13 in Zadoks) and at the wax maturity stage (83–85 in Zadoks scale). At the tillering stage, analyses were carried out for the number and species composition of weeds per m^2, while at the wax maturity stage, air-dry weight of weeds was also recorded. The botanical-gravimetric method consists in determining the species composition of weeds as well the number and dry weight of weeds per m^2 of a plot. This area was determined at random (twice) using a frame size of 1×0.5 m. In turn, determination of the dry weight of weeds consisted of collecting all weeds from the frame's surface, removal of their root system, and placing them in an airy and dry room until constant weight was reached (Woźniak, 2011).

Results were statistically analyzed with Statistical PL and the significance of differences between means were evaluated with the Tukey's HSD test (HSD–honestly significant difference), $P < 0.05$. Correlations between the parameters were evaluated with Pearson's correlation coefficients.

RESULTS AND DISCUSSION

The studied cultivars of barley responded to different tillage systems (Table 2). The yield of Tocada *cv.* was higher in CT and RT tillage system, and lower in the HT. Yield difference between CT and HT systems was 8.8%, and between RT and HT systems it was 8.0%. Also, the yield of Rastik *cv.* was significantly higher in CT than in HT and RT systems. The difference in yields between CT and HT systems was 10.2%, and between CT and RT systems it was 14.6%. Irrespective of the tillage system, a higher yield was noted in the case of Tocada *cv.* than Rastic *cv.*, and the difference amounted to 22.3%. The higher grain yield was differentiated to a greater extent by cultivar (F= 422.81), and to a lower extent by tillage system (F= 24.73). It seemed that the response of the two cultivars to tillage systems was genetically determined.

In studies by López-Bellido *et al.* (1997), Tørresen *et al.* (2002), Jug *et al.* (2011) and Małecka *et al.* (2012), cereals sown in the conventional tillage system had higher yield than those cultivated in different modifications of the no-tillage system. Also, Knight (2004) reported lower yields of cereals in no-tillage systems than the conventional, whereas in dry and semi-desert areas, higher yields were obtained in the no-till than in plowing system (Guy and Cox, 2002). López-Bellido *et al.* (1996) showed that crop productivity in the no-tillage systems decreased with increased precipitation. The reason for yield decline were poorer conditions of plants growth in the no-tillage systems. According to Morris *et al.* (2010), the key objective of tillage is to provide optimal growth conditions for plants, but still the no-tillage systems sometimes fall short of expectations. Also, in our study, the conditions reported for Tocada *cv.* were worse in HT than in CT and RT systems, as indicated

Table 2. Grain yield of spring barley (t ha^{-1}).

Cultivar (C)	Tillage system (TS)			
	CT	RT	HT	Mean
Tocada	4.76	4.72	4.34	4.61
Rastik	3.90	3.33	3.50	3.58
Mean	4.33	4.03	3.92	-
$HSD_{0.05}$ values				
TS		0.16		
C		0.11		
TS×C		0.29		

CT= Conventional Tillage; RT= Reduced Tillage, HT= Herbicide Tillage.

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by a lower number of plants per m^{-2} after tillering: 17.2 and 14.7%, respectively (Table 3). There was no significant difference for the number of plants per m^2 in Rastik *cv*.

Similar observations were made for the number of spikes per m^2. HT system significantly reduced the number of spikes per m^2 (17%), compared to the CT in Tocada *cv*., while tillage system did not have significant effect on the number of spikes per m^2 in Rastik *cv*. This parameter was affected to a greater extent by barley *cv*. (F= 36.45) than by tillage system (F= 14.15).

Tillage system further influenced the weight of grain, with no significant difference for Tocada *cv*. (Table 4). In this cultivar, HT system increased grain weight compared to the CT and RT systems, due to a lower spikes per m^2, which was compensated for with a higher grain weight per spike, as shown by the value of Pearson's correlation coefficient (r= -0.82) (Table 5). Similar dependencies were noted in a study by Woźniak and Staniszewski (2007). The tillage systems also affected 1,000 grain weight. In both cases, the CT system increased 1000 grain weight compared to the RT and HT systems.

Weed infestation of barley crop was evaluated twice. At the tillering stage (12-13 in Zadoks scale), there was a significantly higher number of weeds per m^{-2} in HT than in RT and CT systems (Table 6). There was

Table 3. Number of barley plants and spikes following tillering.

Cultivar (C)	Number of plants per m^2 (12-13 in Zadoks scale)				Spikes per m^2 (90-91 in Zadoks scale)			
	Tillage system (TS)							
	CT	RT	HT	Mean	CT	RT	HT	Mean
Tocada	314	305	260	293	474	461	393	443
Rastik	271	253	248	257	409	382	374	388
Mean	292	279	254	-	442	422	384	-
$HSD_{0.05}$ values								
TS	19.5				29.5			
C	13.0				19.7			
TS×C	34.8				52.6			

CT= Conventional Tillage; RT= Reduced Tillage, HT= Herbicide Tillage.

Table 4. Weight of grain per head and weight of 1,000 grains of spring barley.

Cultivar (C)	Weight of grain (g)				Weight of 1000 grains (g)			
	Tillage system (TS)							
	[x]CT	RT	HT	Mean	CT	RT	HT	Mean
Tocada	1.01	1.02	1.20	1.08	47.9	44.5	44.8	45.7
Rastik	0.96	0.87	0.94	0.92	47.4	46.1	45.9	46.5
Mean	0.98	0.95	1.07	-	47.7	45.3	45.4	-
$HSD_{0.05}$ values								
TS	0.08				1.67			
C	0.06				NS			
TS x C	0.15				NS			

Table 5. Pearson's correlation coefficients.

Parameter[a]	CY	NP	NH	GMH	TGW	NW1	NW2
NP	0.67	1.00					
NH	0.67	0.97	1.00				
GMH	-0.19	-0.82	-0.82	1.00			
TGW	0.89	0.50	0.50	0.10	1.00		
NW1	-0.84	-0.87	-0.86	-0.60	-0.73	1.00	
NW2	-0.73	-0.41	-0.41	-0.11	-0.88	0.53	1.00
ADM	-0.75	-0.41	-0.40	-0.11	-0.80	0.53	0.98

[a] CY= Crop yield; NP= Number of barley plants m^{-2} after sprouting; NH= Number of heads m^{-2}, GMH= Grain weight per head, TGW= 1,000 grain weight, NW1= Number of weeds m^{-2} at the tillering stage of barley; NW2= Number of weeds m^{-2} before harvest; ADM= Air-dry weight of weeds.

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a strong negative correlations between the number of weeds m^{-2} and the number of barley plants after tillering (r= -0.87). It means that the increase in weed number during barley emergence had a negative impact on the number of barley plants and, consequently, on the number of spikes per m^{-2} (r= -0.86). Also, the number of weeds per m^{-2} in the CT system was the lowest before harvest, compared to RT system (Table 7).

Changes in the air-dry weight of weeds were similar to the number of weeds per m^2. In CT system, air dry weight was lower than HT system by more than twofold, and threefold lower than in the RT system, similar to the results reported by Woźniak and Haliniarz (2012), Tørresen and Skuterud (2002), and Vakali *et al.* (2011). Also, Gruber *et al.* (2012) reported that the no-till system increased weed infestation compared to tillage made with a mouldboard plow at a depth of 20-25 cm. As reported by Locke *et al.* (2002), the most severe problem of the no-tillage system was increased weed infestation of crops. The increase in the number and weight of weeds reduced the number of spikes per m^{-2}, weight of grain, 1,000 grain weight, and, consequently, grain yield in this study. Correlations between those parameters are presented in Table 5.

Tillage system also influenced species composition of weeds. There were only annual weeds, predominately *Stellaria media* (L.) Vill. and *Veronica persica* Poir, in CT system at the tillering stage of Tocada *cv.* (Table 8). While the prevailing weeds species in RT and HT systems were *Avena fatua* L., *Stellaria media* (L.) Vill., and *Veronica persica* Poir. Totally, 6 species of mainly spring and winter weeds were noted in each of the tillage systems. In the case of Tocada *cv.*, at the pre-harvest stage (83-85 in Zadoks stage), weed species predominating in CT system included: *Echinochloa crus-galli* (L.) P.B., *Euphorbia helioscopia* L. and *Veronica persica* Poir, those prevailing in the RT system included: *Avena fatua* L., *Amaranthus retroflexus* L. and *Galium aparine* L., and finally those in the HT system were *Avena fatua* L. and *Fallopia convolvulus* (L.) A. Löve. At this stage, mainly annual spring weeds were noted on all plots. In the case of Rastik *cv.*, at the tillering stage on plots cultivated in the CT system, there were only 3 species of weeds, i.e. *Stellaria media* (L.) Vill., *Veronica persica* Poir., and *Poa annua* L. (Table 9).

Table 6. Number of weeds per m^2 at the tillering stage of spring barley (12-13 in Zadoks scale).

Cultivar (C)	Tillage system (TS)			
	CT	RT	HT	Mean
Tocada	6.7	9.6	13.7	10.0
Rastik	3.8	10.7	21.5	12.0
Mean	5.2	10.2	17.6	-
HSD$_{0.05}$ values				
TS		4.1		
C		NS		
TS×C		6.3		

Table 7. Weed number and weight of spring barley before harvest (83–85 in Zadoks scale).

Cultivar (C)	Number of weeds per m^2				Dry weight of weeds (g m^{-2})			
	Tillage system (TS)							
	CT	RT	HT	Mean	CT	RT	HT	Mean
Tocada	5.7	13.1	10.0	9.6	8.4	37.1	17.3	20.9
Rastik	15.2	20.4	19.0	18.2	7.8	11.7	20.5	13.3
Mean	10.5	16.8	14.5	-	8.1	24.4	18.0	-
HSD$_{0.05}$ values								
TS		6.1				9.8		
C		4.3				8.0		
TS×C		NS				13.9		

CT= Conventional Tillage; RT= Reduced Tillage, HT= Herbicide Tillage.

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Table 8. Species composition and number of weeds per m^2 in spring barley of Tocada *cv*.

Species composition	Growth stage in Zadoks scale							
	12-13				83-85			
	Tillage system							
	CT	RT	HT	Mean	CT	RT	HT	Mean
I. Annual weeds								
1. *Stellaria media* (L.) Vill.	3.5	2.8	4.5	3.6	-	0.5	1.0	0.5
2. *Veronica persica* Poir.	1.2	1.0	1.5	1.2	1.0	0.5	-	0.5
3. *Poa annua* L.	0.5	0.8	1.5	0.9	0.5	-	-	0.2
4. *Lamium amplexicaule* L.	0.5	0.5	0.5	0.5	-	-	-	-
5. *Galinsoga parviflora* Cav.	0.5	-	-	0.2	0.5	-	-	0.2
6. *Viola arvensis* Murr.	0.5	-	-	0.2	0.5	-	-	0.2
7. *Avena fatua* L.	-	3.5	5.2	2.9	-	9.0	5.0	4.7
8. *Galium aparine* L.	-	1.0	0.5	0.5	-	1.0	0.5	0.5
9. *Echinochloa crus-galli* (L.) P.B.	-	-	-	-	1.2	0.5	-	0.6
10. *Euphorbia helioscopia* L.	-	-	-	-	1.0	0.2	1.0	0.7
11. *Fallopia convolvulus* (L.) A. Löve	-	-	-	-	0.8	-	2.0	0.9
12. *Amaranthus retroflexus* L.	-	-	-	-	-	1.2	-	0.4
13. *Lycopsis arvensis* L.	-	-	-	-	-	0.2	-	0.1
Number of annual weeds (I)	6.7	9.6	13.7	10.0	5.5	13.1	10.0	9.5
II. Perennial weeds								
1. *Sonchus arvensis* L.	-	-	-	-	0.2	-	-	0.1
Number of perennial weeds (II)	-	-	-	-	0.2	-	-	0.1
Total I+II	6.7	9.6	13.7	10.0	5.7	13.1	10.0	9.6
Number of species	6	6	6	8	8	8	5	13

CT= Conventional Tillage; RT= Reduced Tillage, HT= Herbicide Tillage.

Table 9. Species composition and number of weeds per m^2 in spring barley of Rastik *cv*.

Species composition	Growth stage in Zadoks scale							
	12-13				83-85			
	Tillage system							
	CT	RT	HT	Mean	CT	RT	HT	Mean
I. Annual weeds								
1. *Stellaria media* (L.) Vill.	2.5	2.9	4.0	3.1	0.5	-	-	0.2
2. *Veronica persica* Poir.	1.1	2.6	6.0	3.2	3.0	10.0	6.0	6.3
3. *Poa annua* L.	0.2	-	3.0	1.1	0.2	-	3.0	1.1
4. *Lycopsis arvensis* L.	-	0.2	-	0.1	3.0	-	-	1.0
5. *Galium aparine* L.	-	1.0	2.0	1.0	-	1.0	2.0	1.0
6. *Lamium amplexicaule* L.	-	1.0	1.0	0.7	-	1.0	1.0	0.7
7. *Avena fatua* L.	-	3.0	3.0	2.0	-	3.0	3.0	2.0
8. *Viola arvensis* Murr.	-	-	2.0	0.7	-	-	2.0	0.6
9. *Sonchus oleraceus* L.	-	-	0.5	0.2	-	-	-	-
10. *Fallopia convolvulus* (L.) A. Löve	-	-	-	-	6.0	1.0	-	2.3
11. *Euphorbia helioscopia* L.	-	-	-	-	1.2	1.0	-	0.7
12. *Echinochloa crus-galli* (L.) P.B.	-	-	-	-	0.5	-	-	0.2
13. *Galinsoga parviflora* Cav.	-	-	-	-	0.2	-	-	0.1
14. *Galeopsis tertrahit* L.	-	-	-	-	0.2	1.2	-	0.5
15. *Amaranthus retroflexus* L.	-	-	-	-	0.2	2.2	1.0	1.1
16. *Solanum nigrum* L.	-	-	-	-	-	-	1.0	0.3
Number of annual weeds (I)	3.8	10.7	21.5	12.0	15.0	20.4	19.0	18.1
:. Perennial weeds								
. *Sonchus arvensis* L.	-	-	-	-	0.2	-	-	0.1
Number of perennial weeds (II)	-	-	-	-	0.2	-	-	0.1
Total I+II	3.8	10.7	21.5	12.0	15.2	20.4	19.0	18.2
Number of species	3	6	8	9	11	8	8	16

CT= Conventional Tillage; RT= Reduced Tillage, HT= Herbicide Tillage.

In the RT system, 6 species were noted out of which the prevailing ones were *Avena fatua* L., *Stellaria media* (L.) Vill., and *Veronica persica* Poir. The number of species detected in the HT system reached 8, with *Veronica persica* Poir., *Stellaria media* (L.) Vill., *Avena fatua* L., and *Poa annua* L. showing prevalence. At the pre-harvest stage, in CT plots of Rastik *cv.*, there were 11 species of weeds, with the prevailing ones being: *Fallopia convolvulus* (L.) A. Löve, *Veronica persica* Poir., and *Lycopsis arvensis* L. In RT system, the number of weed species reached 8, including *Veronica persica* Poir., *Avena fatua* L., and *Amaranthus retroflexus* L.. There were 8 weed species in HT system, the most abundant of which were: *Veronica persica* Poir., *Poa annua* L., and *Avena fatua* L.

In summary, it can be concluded that, irrespective of the tillage system, in crops of spring barley there were mainly annual species of weeds. An exception was *Sonchus arvensis* L., though its presence in the crops was sporadic. Additionally, in RT system of both barley cultivars, the prevailing weed species was *Avena fatua* L., which may be explained by the accumulation of its seeds in the topsoil, thereby providing convenient conditions for tillering. This is consistent with findings of Tørresen and Skuterud (2002) who demonstrated the impact of surface (shallow) tillage on increased seedbank in the topsoil.

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اثر خاکورزی کمینه دراز مدت روی عملکرد و علف های هرز جو بهاره

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چکیده

هدف این پژوهش ارزیابی اثر خاکورزی کمینه دراز مدت روی عملکرد و علف های هرز جو بهاره بود.تیمارهای آزمایش شامل سه نوع خاکورزی بود:۱)خاکورزی مرسوم (CT) ، ۲)خاکورزی کمینه(RT) ،۳) کار برد علف کش (HT). این تیمارها در کرت های اصلی و دو کالتیوار جو بهاره به نام های (توکادا و راستیک) در کرت های فرعی بودند. نتایج نشان داد که بیشترین عملکرد هر دو کالتیوار در تیمار خاکورزی مرسوم وکمترین آن در تیمار علف کش و تیمار خاکورزی کمینه بود. علت کاهش عملکرد در تیمارهای HT و RT، کمتر بودن تعداد سنبله در متر مربع و وزن هزار دانه بود. نیز، تعداد علف های هرز و وزن خشک آنها در تیمارهای HT و RT بیشتر از تیمار خاکورزی مرسوم (CT) بود.