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Effects of tillage systems and crop rotation on weed density, weed species composition and weed biomass in maize

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Abstract. The field study was conducted over seven years in south-western Slovakia to investigate the effects of different soil tillage intensities and crop rotation on weed density, weed diversity and weed dry biomass in maize. Three basic tillage treatments were the following: mouldboard ploughing to a depth of 0.30 m (conventional tillage); offset disc ploughing to a depth of 0.15 m followed by combined cultivator; twice shallow loosening to a depth of 0.10 m (both reduced tillage). Annual broadleaf weeds (17 species) were clearly the dominant weed group under all soil tillage treatments, compared to perennial weeds (6 species) and annual grassy weeds (4 species). Dominant weed species were *Amaranthus retroflexus* and *A. powelli, Chenopodium album, Echinochloa crus–galli, Convolvulus arvensis* and *Cirsium arvense*. The number of species of the annual broadleaf and grassy weeds group was insignificant in conventional tillage and reduced tillage systems. Total weed density was significantly lower under the conventional tillage than the other reduced tillage systems. The main benefit of conventional tillage is a highly significant decline of perennial weeds. Only 2.6 perennial weed plants per quadrant in conventional tillage as compared to 7.5–9.0 in reduced tillage treatments were noted. Significantly less weed dry biomass was found in conventional treatment under mouldboard ploughing as compared to reduced tillage. Crop rotation did not have a significant influence on variability of species richness expressed according to Margalef's index in maize. Tillage system was more influential than crop rotations on the weed density and diversity and weed biomass.

Keywords: weed density, diversity, weed dry biomass, crop rotation, tillage.

INTRODUCTION

Weeds are one of the greatest limiting factors to efficient crop production. As a consequence of structural and financing problems the cultural condition of the soil deteriorates and weeds proliferate; many species are hard to kill (Farkas, 2006). Changes in tillage practices can cause shifts in weed species and densities. The effectiveness of interrow cultivation in suppressing weed density in maize is well documented (Wilson, 1993). The success of mechanical weed control may vary according to particular species. Líška et al. (2007) identified *Cirsium arvense* as the most harmful weed in maize. The highest competitive ability of *Cirsium arvense* was found mainly in dry conditions. Perron & Legere (2000) ascertained that tillage intensity did not affect seed production of *Echinochloa crus–gali* and *Chenopodium album* in the canopy of maize, with the exception that *E. crus galli* produced more seeds in chisel than in mouldboard plough tillage in soybean in a maize-soybean rotation.

Previous studies have documented that conservation tillage can increase the density of perennial weeds and some annual grasses. On the other hand Jasinskaite et al. (2009) discovered the advantage of two-layer ploughing in decreasing perennial weed density and weed biomass including *C. arvense*. Annual broadleaf species tend to adapt better to frequently disturbed habitats and are therefore more abundant in conventional tillage systems (Streit et al., 2003). Also, greater diversity prevents the domination of a few problematic weeds (Macák et al., 2005).

Crop rotation is considered as an essential component of integrated weed management systems (Clements et al., 1994). Weed diversity has been shown to increase under crop rotation compared to monoculture (Stevenson et al., 1997). It has also been suggested that weed densities are lower in crop rotational systems than in monocultures (Doucet et al., 1999). For these reasons, crop rotation is an important weed management tool in low input and organic systems.

The aim of this study was to investigate the effect of tillage systems and crop rotation on weed populations, weed density and diversity, and weed dry biomass.

MATERIAL AND METHODS

The study was conducted over seven years (1994–2000) in field trials at the Experimental Station of the Slovak Agricultural University in Nitra in south-western Slovakia. The experimental site belongs to a warm and moderately arid climatic region.

The main soil type is Orthic Luvisol with 2.3% of humus content and a good supply of accessible N, P and K and pH of 5.7 on average. The crop rotation treatments included continuous cropping of maize for grain (S1), double cropping of spring barley–maize for grain rotation (S2), a three crop rotation of common pea–winter wheat–maize for grain (S3), four crop rotation of spring barley–common pea–winter wheat–maize for grain (S4).

Table 1. Weather conditions during maize growing season in the years 1994–2000

Month/Year	Precipitation (mm)							Temperatures (˚C)						
	1994	1995	1996	1997	1998	1999	2000	1994	1995	1996	1997	1998	1999	2000
April	94	74	103	30	47	60	27	10.6	10.7	11.0	7.6	12.0	12.1	13.0
May	110	63	143	44	33	30	28	15.2	14.6	16.4	15.9	15.3	15.6	16.2
June	29	89	50	61	29	32	6	18.7	17.7	19.2	18.6	19.6	18.5	20.1
July	33	0	69	117	61	91	61	23.1	22.9	18.3	19.0	21.0	20.6	18.9
August	60	62	59	13	31	47	22	21.4	19.8	19.4	20.8	20.9	19.0	22.1
September	110	84	78	28	50	7	52	17.1	14.2	11.9	15.3	15.1	18.1	15.4
Total (mm)	436	372	502	292	251	267	196	-	-	-	-	-	-	-
Average (^{0}C)	-	-	-	-	-	-	-	17.7	16.7	16.0	16.2	17.	17.3	17.6

Three basic tillage treatments were as follows: mouldboard ploughing (CT) to a depth of 0.3 m (conventional tillage), offset disc ploughing (RT1) to a depth of 0.15 m followed by combined cultivator, twice shallow loosening (RT2) to a depth of 0.1 m (both reduced cultivation).

Common pest and disease control practices were applied. Herbicides (expressed in active ingredient) and inter-row tillage for weed control by stick harrow were as follows: 1994 mechanical weeding only, 1995 pre–emergence application of dicamba-DMA salt + s–metolachlor and post–emergence application of clopyralid + pyridate, 1996 post-emergence application of rimsulfuron + dicamba–DMA salt, 1997 mechanical weeding only, 1998 post–emergence application of rimsulfuron thifensulfuron methyl, 1999 pre–emergence application of atrazine + acetochlor diclormid and post-emergence application of clopyralid, 2000 post-emergence application of clopyralid + 2,4 D and metosulam. Plots for each tillage system were arranged in a split plot design. Plots were divided into subplots (11 x 40 m) and were subjected to tillage treatments with four replications.

Weed infestation was evaluated twice a year. The first evaluation, which consisted of weed counting, was conducted in spring before the herbicide application, the second evaluation before harvest of maize in September using the weight–counting method on the quadrant of 1 m^2 area in each replication. One quadrant for each replication (0.7 m by 1.5 m) to cover rows and inter–row cultivation was established in parallel maize rows in the middle maize rows. At the end of September, a destructive sample was taken in the quadrants and the weeds were identified, grouped into broadleaves, perennials and annual grasses and counted. These groups were counted separately and were oven dried at 70ºC for 48 hours and then weighed.

The data for weed density, weed diversity, and weed biomass for all tillage and crop rotation treatments, as well as their interactions, were subjected to an analysis of variance test using the statistical software statgraphics plus version 5.0. The F–test (Fisher`s protected LSD test) of significance was used to evaluate differences between treatment means. To describe species diversity we used Margalef`s index–D_{MG} as a measure of species richness, calculated according to the following formula:

$$D_{MG} = (S–1) \times (\log N)^{-1}$$

where S denotes the number of species and logN is the logarithm of average total weed density (plants m^{-2}) in each plot (Magurran, 1988).

RESULTS AND DISCUSSION

Twenty-seven weed species were counted in sampling frames during this experiment. Dominant weeds were *Amaranthus species* (*A. retroflexus* and *A. powelli*), *Chenopodium album, Echinochloa crus–galli, Convolvulus arvensis* and *Cirsium arvense;* each ranged from 1–87.4% of the total density and had a frequency of occurrence that ranged from 66-83% in at least 1 year of the experiment.

Effect of tillage systems and crop rotation on weed density and weed species composition

Significant influence of tillage, crop rotation and year on total weed density in maize has been noted (Table 2).

Table 2. F statistics from ANOVA for weed density, weed species richness (D_{MG}) during 1994-2000.

Source of variation	Density	D_{MG}
Rotation	4.69 **	0.65 NS
Tillage management	33.54 **	13.87 **
Rotation x Tillage	2.00 NS	0.68 NS
Year	11.40 **	9.79 **
Rotation x Year	1.64 NS	1.13 NS
Tillage x Year	1.91 NS	0.49 NS

** significant at the $P < 0.01$ level, NS not significant at $P < 0.01$ level

All evaluated interaction rotation x tillage, rotation x year and tillage x year were insignificant. Total weed density generally decreased with increasing cropping intensity. Annual broadleaf weeds (17 species) were clearly the dominant group under all tillage treatments, compared with the perennials (6 species) and annual grassy (4 species) weeds. Total weed density was significantly lower under the CT than the reduced tillage systems (Table 3). In comparison with conventional soil tillage, reduced tillage treatments RT1 and RT2 increased weed density on average by 240.7 and 225.3%, respectively. Tolimir et al. (2006) also noted considerably lower weed infestation per square meter under conventional tillage (7 weeds) compared to reduced (39 weeds) and zero–tillage (46 weeds).

Similarly (Birkás et al., 2002) ascertained that soil condition – caused by shallow disk tillage - increased weed infestation in maize and in the case of maize cropping sequence. Findings concerning perennial weeds are in accordance with some reports (Knežević et al., 2003, Wrucke & Arnold, 1985) and results concerning the group of annual broadleaf weeds are contradictory to results in the same studies, but agree with other findings (Froud–Williams, 1981; Buhler, 1995). The main benefit of conventional tillage is highly significant decline of perennial weeds – 2.6 of perennial weeds in CT with comparison to 7.5 in RT2 and 9.0 in RT1 per quadrant.

Table 3. Weed density of different group of weeds in tillage systems and cropping sequences during 1994–2000 in no m^{-2}

	Tillage			
Weed groups	CT	RT1	RT2	Average
Annual grassy	4.8	11.0	14.3	10.0 b
Broadleaves	8.9	19.2	14.9	14.3 c
Perennials	2.6	9.0	7.5	6.4 a
Total weed density	16.3 a	39.2 b	36.7 b	
	Crop rotation			
Weed groups	S1	S2	S3	S4
Annual grassy	12.1	9.8	9.1	9.2
Broadleaves	16.9	12.1	13.1	15.3
Perennials	9.5	6.7	3.6	5.7
Total weed density	38.5 a	28.6 b	25.8 b	30.2a b

Means within columns or rows followed by the same letter are not significantly different at the P <0.05 probability level using the LSD–test.

Frequency of occurrence and density of dominant weeds *Amaranthus* species (*A. retroflexus* and *A. powelli*), *Chenopodium album* (broadleaf group), *Echinochloa crus-galli* (annual grasses), *Convolvulus arvensis* and *Cirsium arvense* (perennials group) were significantly greater in the reduced tillage (RT1, RT2) than in the conventional (CT) soil tillage system. Tillage management (Table 4) and year were the most important factors in determining weed density (26.82% and 27.36% respectively). Crop rotation accounted for only 5.63% of the total variance and the interaction of crop rotation and tillage accounted for an additional 4.8%.

The significantly higher weed density was noted in continuous cropping of maize in comparison with maize growing in the double-cropped and three-crop rotation (Table 3). The weed density in the canopy of continuous cropping of maize (S1) and four crop sequences (S4) was insignificant due to high density of the broadleaf group in four crop sequences.

Table 4. ANOVA of treatment effects evaluated, variance partitioning of total weed density and weed species richness (D_{MG}) among effects for 1994–2000

Component	Population density		D_{MG}	
	Sum of square	Variance (% of total)	Sum of square	Variance (% of total)
Rotation	1868.01	5.63	72.60	1.26
Tillage management	8899.99	26.82	1033.72	17.93
Year	9077.93	27.36	2188.58	37.97
Rotation x tillage	1595	4.80	152.45	2.65
Rotation x year	3927	11.80	758.84	13.16
Tillage x year	3040	9.16	217.34	3.77
Total	33185	–	5764.67	–

The lesser role played by crop rotation in the regulation of weed density comparison to tillage treatments is consistent with results reported from (Doucet et al., 1999).

Effect of tillage systems and crop rotation on weed diversity

As in the case of weed density, tillage management was the most important factor determining also species richness (17.93% of the total variance, excepting the year 37.97%) as we can see in Table 4. Crop rotation and the interaction of rotation with tillage management have minor effects on species richness, accounting for less than 4% of the total variance. The highly significant influence of tillage management and year suggests that tillage and weather played the main roles in regulating the relative abundance of weed species (Table 2). Crop rotation has insignificant influence on variability of species richness expressed according to Margalef`s index in the canopy of maize (Table 3).

The number of species of the annual broadleaf and grassy weeds was similar in CT and RT1, RT2. Perennial weeds showed the highest values under treatments with reduced tillage. Comparison based on the number of species did not reveal the significant differences between evaluated tillage treatments (Table 5). The number of species per square is relatively high (6.8–7.5). (Tyšer et al., 2006) state 0.4–1.6 species per square meter on conventional fields under row crops.

Table 5. Number of weed species under the three soil tillage systems in maize (1994–2000)

Weed species	Tillage treatments		
	CT	RT1	RT2
Annual grassy	1.2	1.1	1.2
Broadleaves	3.7	3.8	3.8
Perennials	1.9	2.4	2.5
Total	6.8 a	7.3 a	7.5 a

Effect of tillage systems and crop rotation on weed dry biomass

Weed dry biomass was affected by the soil tillage system. Significantly higher dry weight was measured in RT1 and RT2 than in CT. Also Abdin et al., (2000) stated generally higher weed biomass on the rows than between the rows probably due to inter-row cultivation. Our way of sampling, with the maize row in the middle of the square, avoided this difference.

Table 6. Weed dry biomass (g m^{-2}) of total weed population under three soil tillage systems in maize for the years 1994–2000

Crop rotation	Tillage systems			
	CT	RT1	RT2	Average
S1	46.9	153.4	113.4	104.56 a
S2	76.7	203.4	185.6	155.23 a
S3	89.2	128.1	140.2	119.17 a
S4	113.3	163.1	186.4	154.27 a
Mean	81.5 a	162 b	156.4 b	

Means within columns or rows followed by the same letter are not significantly different at the *P* <0.05 probability level using the LSD–test

The insignificant differences between weed dry biomass in the evaluated crop rotation have been revealed (Table 6). Spring barley decreases the competitiveness of crop rotation to weeds (S2 and S4) in comparison to maize growing in monoculture (S1) and maize growing in three crop sequences (S3). The data for weed dry biomass in evaluated years are summarised in table 7.

Table 7. Weed dry biomass (g m^{-2}) under different soil tillage systems (1994–2000)

Years	Tillage systems		
	CT	RT1	RT2
1994	38.5	90.2	116.8
1995	1.3	34.3	16.9
1996	107.0	179.7	171.1
1997	88.0	300.7	163.3
1998	48.8	101.0	126.3
1999	17.2	86.6	144.5
2000	201.0	243.7	240.5
Average	71.2 a	148.0 b	139.9 b

Means followed by the same letter are not significantly different at the *P* < 0.01 probability level using the LSD–test

Significantly less weed dry biomass was received in conventional treatment with mouldboard ploughing as compared to reduced tillage by offset disc ploughing or shallow loosening. As in a previous study (Swanton et al., 1999; Shrestha et al., 2002), this study demonstrated that the processes that determine weed shifts, composition, density, diversity and weed biomass are very complex issues.

CONCLUSIONS

Total weed density was significantly lower (16.3 plants m^{-2}) with a mouldboard primary soil tillage system than with reduced tillage systems (36.7–39.2 plants m^{-2}). When compared to mouldboard ploughing, disk ploughing and shallow loosening treatments increased weed density by 240 and 225%, respectively. Conventional tillage reduced the density of perennial weeds from 7.5–9.0 plants m^{-2} in reduced treatments to 2.6 plants m^{-2}.

Weed dry biomass was significantly lower in the conventional treatments with mouldboard ploughing compared to reduced soil tillage (disc ploughing or shallow loosening).

Annual broadleaf weeds (17 species) were clearly the dominant weed group under all soil tillage treatments, compared to perennial weeds (6 species) and annual grassy weeds (4 species).

Dominant weed species were *Amaranthus retroflexus* and *A. powelli*, *Chenopodium album*, *Echinochloa crus–galli*, *Convolvulus arvensis* and *Cirsium arvense*.

Weed species richness (D_{MG}) was influenced by primary soil tillage and the year in which the data were collected. Crop rotation did not have a significant effect on variability of species richness in maize.

Tillage system was more important than crop rotations in affecting the composition of the weed flora, weed density and weed biomass in maize.

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