NARDI FUNDULEA, ROMANIA ROMANIAN AGRICULTURAL RESEARCH, NO. 33, 2016
www.incda-fundulea.ro Print ISSN 1222-4227; Online ISSN 2067-5720

CROP ROTATION INFLUENCE ON ANNUAL AND PERENNIAL WEED CONTROL AND MAIZE PRODUCTIVITY

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ABSTRACT

Crop rotation is important part of integrated weed control strategy. Sequences with diverse crops require application of different measures that influence weed community composition.

The study was conducted in order to investigate the effects of crop rotation and low rate of herbicide application on maize infestation with annual and perennial weeds. A trial was settled on the experimental field of the Maize Research Institute Zemun Polje, Belgrade, Serbia in 2009. The basic treatment was a plant production system: maize continuous cropping (MC), maize-winter wheat rotation (MW), and maize-soybean-winter wheat rotation (MSW). Different weed control methods represented treatments in sub-plots. Number of weed species and their biomass were estimated 45 days after the application of herbicides when rotation cycle was closed in each cropping system – in 2011 for MW, in 2012 for MC and MSW.

Each crop rotation differently influenced number of weed species and weed biomass. The best effects showed MSW rotation in which biomass of perennial and annual weeds was significantly lower after three years, especially with the application of recommended rate of herbicides. Crop rotation significantly increased maize yield – MW by 20.1% and MSW by 29.6% in comparison to maize monoculture.

Key words: crop sequence, maize, weed suppression, yields.

INTRODUCTION

Agronomic and biological advantages of crop rotation are very important because of soil protection, minimization of agrochemicals use and higher and more stable yields (Liebman et al., 2001). Crop rotation is important strategy within IWMS. It requires planned and aimed implementation of different measures and advocates a combination of weed control methods. A single weed control measure is not feasible due to the number of different weed species and their highly variable life cycles. Sequences with row and grain crops, legumes and cereals, allow growing of many genotypes, application of different tillage practices, fertilizers and herbicides etc. All this influences weed community composition, abundance of individuals and even soil seed bank richness (Teasdale et al., 2004; Bohan et al., 2011). The alternation of crops breaks the life cycle and prevents high distribution of any single weed species (Bastiaans, 2010).

According to previous investigations, differences among the fall-sown crops (winter wheat) and two spring-sown crops (maize and soybean) with regard to planting and harvest dates and other management practices, may also affect weed distribution (Demjanova et al., 2009; Spasojević et al., 2012). Total weed density was significantly decreased for maize (66%) in rotation with winter wheat in comparison with continuous maize, with or without herbicide application (Covarelli and Tei, 1988). The density of grass weed *Setaria faberi* decreased as crop diversity in rotation increased from two to three crops (Schreiber, 1992). The primary drivers that suppress weed biomass and change species composition appear to be use of crop rotation and annual cover crops within the integrated system that also should reduce reliance on herbicides (Tracy and Davis, 2008). An ecological approach to weed management, which integrates knowledge of weed population dynamics with cultural tactics and long-term planning, has enabled producers to control weeds with 50% less herbicides (Anderson,

Received 8 August 2014; accepted 10 December 2015; First Online: March, 2016. DII 2067-5720 RAR 2016-149

2005). Crop rotation influences weed species diversity and community composition abundance with annual and perennial weeds (Anderson, 2006).

The production of high yielding maize is connected with hybrid maturity group and its fast developing canopy and rapid ground cover, which allow maize to compete better with weeds (Filipović et al., 2013). In accordance with level of weed infestation, maize yield is also influenced by crop rotation and herbicide application (Videnović et al., 2013). Previous results (Katsvairo and Cox, 2000) showed that in mouldboard plough maize in soybean – wheat/red clover – maize (9.2 t ha^{-1}) and soybean – maize (8.5 t ha^{-1}) rotations under low chemical, yielded more than continuous maize under high chemical inputs (7.9 t ha^{-1}).

Investigations were conducted in order to analyze the effects of crop rotation and low rate herbicide application on annual and perennial weed infestation and maize productivity.

MATERIAL AND METHODS

Experimental area

A field experiment was conducted during four years, 2009-2012, as a split-plot trial at Zemun Polje, in the vicinity of Belgrade (44°52'N 20°20'E), Serbia. A soil was slightly calcareous chernozem with 47 % clay and silt and 53 % sand. The 0-30-cm layer had 3.3 % organic matter, 0.21 % total N, 1.9 % organic C, 14 and 31 mg per 100 g soil of available P and extractable K, respectively, 9.7 % total $CaCO_3$ and pH 7.8.

The main plots encompassed the following plant production systems: maize continuous cropping (MC), maize-winter wheat rotation (MW), and maize-soybean-winter wheat rotation (MSW). The maize hybrid ZP606, winter wheat variety Takovčanka and soybean variety Lana were conventionally sown within optimal periods in all production systems, (Table 1). Conventional tillage was used in the trial. A total of 30 t ha^{-1} of manure was incorporated in autumn of 2008 and then every third year in maize monoculture and maize-soybean-winter wheat rotation. In autumn of 2008 and 2010, 20 t ha^{-1} of manure was incorporated in the two-crop rotation and every second year after. Immediately prior to ploughing in autumn, 150 kg ha^{-1} of MAP fertilizer (N:P = 11:52) was added in all plots, except those that were sown with winter wheat. Crop side dressing was done in spring in maize fields according to results obtained by the analysis of nitrogen available in soil in the 5-6 leaf stage of crop.

Table 1. The trial organization scheme and dates of sowing and harvest

Year/Date	Production systems		
	MC	MW	MSW
2009	Maize	Maize	Maize
Date of sowing	April, 25	April, 25	April, 25
Date of harvest	September, 28	September, 28	September, 29
2010	Maize	Winter wheat	Soybean
Date of sowing	April, 29	October, 28 2009	April, 29
Date of harvest	October, 8	July, 15	October, 22
2011	Maize	Maize	Winter wheat
Date of sowing	April, 21	April, 21	November, 16 2010
Date of harvest	October, 3	October, 17	July, 11
2012	Maize	Winter wheat	Maize
Date of sowing	April, 27	November, 8 2011	April, 27
Date of harvest	September, 12	July, 5	September, 12

In all production systems, sub-plot treatments were represented by different weed control methods applied in maize: HR - application of the combination of isoxaflutole and acetochlor (Merlin 750-WG + Trophy 768-EC) at recommended herbicide rate (105 g a.i. + 1536 g a.i.), after sowing and prior to maize emergence for control of broadleaf and grass weed seedlings; ½ HR – application of the same herbicide combination at half of the recommended rate (52.5 g a.i. + 768 g a.i.); WF - hand hoeing treatment (weed free) and Control – treatment without herbicide application (weedy check). Each treatment had four replications in maize crop. In winter wheat and soybean, usual combinations of herbicides for broadleaf and grass weed control were applied.

Measurements

The size of elementary plot was 28 m^2. The weed samples were collected in maize, 45 days after the application of herbicides after one cycle of rotation – in 2011 for MW (maize-winter wheat-maize) and in 2012 for MSW (maize-soybean-winter wheat-maize). The number of weed species and weed biomass was recorded after uprooting weeds manually from two randomly selected places in the middle of the each plot with a 0.25 m^2 quadrant. At the end of growing cycle, the maize grain yield was measured and calculated with 14 % of moisture.

Statistical analysis

The data were processed using the statistical package STATISTICA 8.0 for Windows (Analytical software, Faculty of Agriculture, Novi Sad, Serbia). The differences between the treatments were determined by analysis of the variance (ANOVA) and by the least significant difference test (LSD).

Meteorological conditions

The average monthly air temperatures during growing season were different in the three years of investigation; while a lower average air temperature from April to September was measured in 2009 (17.1 °C), in other two years the average monthly temperatures were higher than multiyear average, 21.1°C and 22.1°C, respectively (Table 2). The sum of precipitation was lower than ten year average in all three years, especially in 2011 (278.9 mm) and 2012 (282.9 mm). The most unfavourable precipitation distribution was in the period of maize generative development in 2012 (June, July and August), which was inconvenient for maize production in Central Serbia. In August, in the period of maize grain filling, sum of precipitation was extremely low in both years, 2011 (8.9 mm) and 2012 (4.0 mm).

Table 2. Average monthly air temperatures (°C) and monthly precipitation sum (mm) from April to September at Zemun Polje

Months	Temperature (°C)				Precipitation (mm)			
	2009	2011	2012	1989-2008	2009	2011	2012	1989-2008
April	16.2	14.6	14.5	12.9	5.6	11.1	66.7	31.9
May	19.8	17.3	17.9	18.1	35.0	62.6	127.5	77.8
June	21.2	22.4	24.6	21.4	153.0	40.4	13.9	97.0
July	24.1	24.2	27.1	23.2	79.6	107.4	39.4	67.1
August	24.1	24.8	26.2	23.0	44.8	8.9	4.0	27.9
September	21.1	23.2	22.1	17.6	4.6	48.5	31.4	33.9
Av./Sum	17.1	21.1	22.1	19.4	322.6	278.9	282.9	335.6

RESULTS AND DISCUSSION

The predominance of row crops in rotations, such as maize and soybean, has resulted in weed community dominated by summer annual weeds. Based on analysis of weed biomass, *Chenopodium* sp.. *Datura stramonium* and *Amaranthus* sp. among annual and *Convolvulus arvensis, Cirsium arvense* and *Sorghum halepense* as perennials were dominant in all production systems.

Results obtained in maize monoculture showed that weed species number and biomass of their individuals decreased after three years of maize cultivation and still was different according to herbicide application level (Table 3). Differences between annual and perennial weeds abundance were connected, and biomass of annual weed species decreased in 2012 in comparison to 2009, while biomass of perennials increased in the treated and untreated variants as well.

Table 3. Weed species abundance (Biomass, g m^{-2}) in maize monocultur

Specification	2009			2011			2012		
	Control	½ HR	HR	Control	½ HR	HR	Control	½ HR	HR
Annual weed species									
CHEHY*	1509.9	142.2	137.6	389.8	149.7	43.6	321.4	356.9	116.6
CHEAL	361.9	4.6		466.1	170.7	50.9	379.7		14.7
DATST	1133.7	73.3	47.9	257.2	170.1		616.5	146.0	
ABUTE	272.1	19.9	7.0	150.1		9.4	47.1	16.6	1.0
SOLNI	59.1	2.5		111.9			170.4		
AMARE	104.6		28.1	124.1			65.2	8.4	
AMAHY	230.9	91.1		294.1	7.4		201.4	2.4	
HIBTR	144.1	123.3		15.1	66.3		16.6	56.2	
POLCO								78.9	91.5
IVAXA	106.3	55.2							
No of species	10	8	4	12	6	3	10	9	5
Biomass	3929.9	512.1	220.6	1839.5	572.1	103.9	1844.4	698.1	227.5
Perennial weed species									
CIRAR	84.5	17.3	30.8	71.5	27.7		119.0	53.4	
CONAR	122.9	147	188.7	44.9	49.0	51.3	96.9	62.1	52.4
SORHA	25.9	5.5		121.9		262.3	585.5	129.4	262.7
CYNDA									5.7
No of species	3	3	2	3	2	2	3	3	3
Biomass	233.3	169.8	219.5	238.0	76.7	314.0	801.4	244.9	314.2
Total									
No of species	13	11	6	15	8	5	13	12	8
Biomass	4163.2a	681.9b	440.1b	2077.5a	648.8b	417.9b	2645.8a	955.6b	541.7b
	$LSD_{0.05}$ = 991.7			$LSD_{0.05}$ = 390.7			$LSD_{0.05}$ = 621.2		

*Biomass of ten most abundant annual weed species.

Applied herbicides were especially efficient against *Amaranthus* sp., *Hibiscus trionum* and *Solanum nigrum*. Maize growing in continuous monoculture favoured extending distribution of perennial species *Sorghum halepense*, regardless of herbicide application. This competitive and thermophile species is highly adapted to agro ecological conditions present in maize field. Namely, after significant decreasing of annual weeds as a result of intraspecific competition, *S. halepense* increased its abundance and spreading in maize. It is known that dominance of a single problem weed occurrs with continuous cropping, but not with a rotation of crops (Liebman et al., 2001). Continuous cropping favours a very few weeds that are well adapted to that crop. Diverse rotation will tend to favour any given species only in certain years, while relative abundance of species will tend to be more equal.

In double crop rotation (MW), the number of perennial weed species decreased in 2011 but number of annual species increased, which is probably consequence of cattle manure application in 2010 (Table 4). Abundance of annual weeds was high in 2011, mainly because of *S. nigrum*, *Chenopodium* sp. and *A. hybridum*, while biomass of *D. stramonium* was lower after rotation.

Generally, the number of species of both groups of weeds was lower in variants with herbicide application, especially in treatment with application of recommended rate of herbicides. Total biomass of weeds decreased on treated variants significantly and was lower in 2011 (290.7 and 120.7 g m^{-2}) than in 2009 (812.1 and 535.3 g m^{-2}).

Table 4. Weed species abundance (Biomass, g m^{-2}) in maize two crop rotation (MW)

Specification	2009			2011		
	Control	½ HR	HR	Control	½ HR	HR
Annual weed species						
CHEHY*	573.0	33.2	36.5	505.3	35.2	
CHEAL	463.9			290.1	62.0	
DATST	1064.1	131.5		329.6	57.8	
ABUTE	158.2			26.9		
SOLNI	3.0			256.4		
AMARE	23.0	8.0		79.0	22.9	
AMAHY	18.3			193.7		
ATRPA	188.3					
POLCO	51.8			141.9	59.0	17.3
IVAXA	76.9	116.6				
No of species	11	4	1	14	8	1
Biomass	2648.3	289.3	36.5	1993.4	268.2	17.3
Perennial weed species						
CIRAR	168.3	134.9	10.8	28.5		
CONAR	132.8	312.6	419.0	13.4	22.5	103.4
SORHA	443.3	75.3	69.0	79.1		
No of species	3	3	3	3	1	1
Biomass	744.4	522.8	498.8	121.0	22.5	103.4
Total						
No of species	14	7	4	17	9	2
Biomass	3392.7a	812.1b	535.3b	2114.4a	290.7b	120.7b
	$LSD_{0.05}$ = 860.7			$LSD_{0.05}$ = 311.3		

*Biomass of ten most abundant annual weed species.

The best effect on weed infestation level showed MSW rotation in which winter wheat, as a cereal crop, was preceding crop of maize. The biomass of perennial and annual weeds was significantly lower after three years, especially with the application of recommended rate of herbicides (Table 5). Weather conditions in 2012 supported chemical weed control strategy through pretty high sum of precipitation in the period of pre-emergence herbicide application (66.7 mm in April and 127.5 mm in May). Because of this, total weed biomass on the control treatment was still high in 2012 (3628.5 g m^{-2}) in comparison to 2009 (5861.6 g m^{-2}). At the same time, herbicide application was very effective. Extremely high weed abundance at the beginning of investigation period expressed as 1454.7 g m^{-2} of total weed biomass with application ½ HR and 555.6 g m^{-2} with application HR, was significantly decreased in 2012 after one rotation cycle, to 564.3 and 189.4 g m^{-2}. In MSW cropping system, winter wheat cultivation showed effective influence on *Convolvulus arvensis* as perennial weed species.

Table 5. Weed species abundance (Biomass, g m^{-2}) in maize in three crop rotation (MSW)

Specification	2009			2012		
	Control	½ HR	HR	Control	½ HR	HR
Annual weed species						
CHEHY	1502.4	86.6	107.7	637.7	249.4	66.5
CHEAL	910.6			1290.6	60.4	
DATST	604.4	257.2	171.8	386.4		15.7
ABUTE	139.6	110.3		75.2	41.2	
SOLNI	70.9			241.0	47.0	
AMARE	223.5	51.1		208.9		12.3
AMAHY	25.1	188.0		192.6		
IVAXA	964.3	181.8				
HIBTR	10.5				26.7	
POLCO	108.8		9.5	26.3		20.5
No of species	14	6	4	13	7	4
Biomass	5496.4	875.0	352.2	3532.8	467.2	115.0
Perennial weed species						
CINDA			33.7			
CONAR	329.7	519.8	148.4	13.0	42.0	26.4
SORHA	35.5	59.9	21.3	82.7	55.1	48.0
No of species	2	2	3	2	2	2
Biomass	365.2	579.7	203.4	95.7	97.1	74.4
			Total			
No of species	16	8	7	15	9	6
Biomass	5861.6a	1454.7b	555.6c	3628.5a	564.3b	189.4b
	$LSD_{0.05}$ = 849.9			$LSD_{0.05}$ = 407.7		

*Biomass of ten most abundant annual weed species.

Maize productivity was different according to cropping system and meteorological conditions of the year (Table 6). In all three years, sum of precipitation during growing season was lower than ten years average, especially in 2011 and 2012. According to that, grain yield of maize was the lowest in 2012. On the other hand, grain yield of maize was the lowest in monoculture and higher in MW and MSW in all years. Crop rotations significantly increased maize yield and it was higher in MW by 20.1% than in maize monoculture and by 29.6% in MSW. Weed control treatments also influenced grain yield of maize, which was higher in all treatments (10.80, 10.01 and 10.45 t ha^{-1} in HR, ½ HR and WF, respectively) than in the control (7.81 t ha^{-1}). It is interesting to notice that differences in average grain yield of maize between different weed treatments were very low. The lowest maize yield for all years, production systems and weed control treatments was obtained in maize monoculture, in unfavourable 2012 and in the control variant – only 2.66 t ha^{-1}, the highest yield was detected in MW rotation in 2009 with application of recommended rate of herbicides – 15.26 t ha^{-1}.

Overall analysis indicates that crop rotation was found to strongly affect weed populations. The effectiveness of the cropping system i.e. weed biomass reduction in relation to weed infestation level at the beginning of the experiment, showed that most effective was MSW with application of recommended rate (65.9%) and half of recommended rate (61.2%) of herbicides. Even at MW rotation, herbicide application in recommended rate reduced weed biomass for 77.5% (Spasojevic et al., 2012). Some results showed that when herbicide use is reduced, rotations that include cereals or forage crops can facilitate suppression of some troublesome weeds (Heggenstaller and Liebman, 2005). Increased diversity from monoculture to two and three crops i.e. continuous maize, maize rotated with soybean and maize following winter wheat in a soybean-winter wheat-maize rotation, during a seven-year period, influenced the density of *Setaria faberi* (Schreiber, 1992). Density of this annual weed species was the highest in continuous maize, the lowest in the three crops rotation and intermediate in the two-year rotation. Winter wheat as a narrow-seeded crop and its production prior to maize and soybean, influenced weed abundance through competition and also through application of herbicides with different mode of action. Cereals and forage crops could facilitate successful integrated weed management strategies in maize (Heggenstaller and Liebman, 2005).

Table 6. Maize grain yield in investigated cropping systems (t ha^{-1})

Herbicide treatments	2009			2011		2012		Average
	MM	MW	MSW	MM	MW	MM	MSW	
HR	15.06	15.26	14.34	8.55	10.58	4.84	6.97	10.80
½ HR	13.44	13.62	14.87	7.88	9.17	4.46	6.65	10.01
WF	13.65	14.35	14.89	7.99	9.87	5.43	6.96	10.45
Control	13.03	10.26	12.32	4.94	7.32	2.66	4.15	7.81
Average	13.80	13.37	14.10	7.34	9.24	4.35	6.18	9.77
	$LSD_{0.05}$ 2009 = 1.648^{ns}			$LSD_{0.05}$ 2011 = 1.814*		$LSD_{0.05}$ 2012 = 1.161*		

ns - not significant; *significant at 0.05.

According to results of Crookston et al. (1991) a three-crop rotation is the most favorable for rotational yield benefits with maize and soybean. Rotation of maize and soybean increased grain yield of both crops approximately 10% compared to monocultures of each crop, whereas yields increased 15% if either crop was grown only once in three years. Maize rotated annually with soybean and first-year maize after 5 years of consecutive soybean, yielded 15% more than continuously grown maize (Pedersen and Lauer, 2003).

CONCLUSION

Crop rotation in combination with herbicides can reduce level of weed infestation in maize even in the simplest maize-winter wheat crop rotation. Type of rotation i.e. crop sequence composition is also important because rotations of crops facilitate the rotation of herbicides with the ability to control different weed species i.e. annual and perennial species. The production systems that include cereal and legume crops and especially maize-soybean-winter wheat rotation where wheat is preceding crop for maize are most effective according to weed suppression and achieved yield. A diverse crop rotation is a key component in integrated weed management program, but herbicide application and fertilization should be also appropriately applied for successful weed control.

Acknowledgements

This research was supported by the founds of the Ministry of Education, Science and Technological Development through the project TR31037.

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