Weed suppression and crop productivity by different arrangement patterns of maize

M. Simić[1], Ž. Dolijanović[2], R. Maletić[2], L. Stefanović[1], M. Filipović[1]

[1]*Maize Research Institute, Zemun Polje, Belgrade, Serbia*
[2]*Faculty of Agriculture, University of Belgrade, Zemun, Belgrade, Serbia*

ABSTRACT

A field experiment was conducted in order to estimate the influence of different arrangement patterns of maize plants (*Zea mays* L.) in combination with low rates of herbicides on weed infestation and on production parameters of the crop. The maize was sown at 70-, 50-, and 35-cm row space with the same crop density. The weed biomass declined with smaller row spaces and was, on average, the lowest with the 35-cm row space; even though the arrangement patterns of the maize plants had no significant effect on the average values of the weed biomass. The interaction of the arrangement pattern and the herbicide rate significantly influenced weed biomass. Maize grain yield expressed the greatest variation under the effects of applied factors, but did not differ significantly between treatments with the full and the half rate of herbicides. The results indicate that it is possible to control weed infestation level if maize is grown with increased spatial uniformity and combined application of other practices such are herbicides. In such a way, maize plants are more competitive against weeds and even lower amounts of herbicides could be applied in order to achieve high yields.

Keywords: crop arrangement; competitive ability; weeds; herbicides; maize yield

Maize (*Zea mays* L.) and majority of crops are sown in rows, which means variations in density, i.e., the number of plants per ha, and variations in the arrangement patterns of the crop. Theoretical and practical studies showed that the plant arrangement of crops had significant effects on the balance in the competition between crops and weeds (Fisher and Miles 1973, Kropff and van Laar 1993, Liebman et al. 2001). In a completely uniform crop stand with an equal distance between the plants, the competition against weeds will occur earlier than in conventional row cultivation, while the intraspecies competition will start later (Fisher and Miles 1973). As the within row plant distance mainly depends on the crops' requirement, this means in practice that a change in the arrangement patterns in row crops leads to an alteration of the inter-row space. If weeds are present in crop grown in rows, the intraspecies competition is increased due to the interspecies competition and all negative aspects of crop cultivation in rows with large inter-row spaces and poor crop uniformity will be expressed (Weiner et al. 2001). The area percentage on which weeds are present increases with increasing crop rectangularity and depending on the crop density, emergence time and growth intensity of crops and weeds (Rambakudzibga 1999). The majority of field experiments showed that crop cultivation at a lower inter-row distance decreased weed infestation; some found that there were no effects, while others showed that there were no regularities (Liebman et al. 2001). A parameter that often decreases with reduction in the inter-row space is weed biomass (Mulugeta and Boerboom 2000, Simić et al. 2007).

Maize grown in narrow rows could suppress weeds and increase the consistency of weed control by herbicides applied at reduced rates (Teasdale 1995). Some most important weeds in maize (*Abutilon theophrasti*, *Chenopodium album*, *Solanum nigrum*, *Xanthium strumarium*, *Amaranthus retroflexus*) could be satisfactorily controlled with reduced doses (Pannaci and Covarelli 2009). Knowledge of different factors affecting herbicide efficiency, e.g., weed species present, competitiveness of the crop, variety, weather conditions, increases the accuracy

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and reliability of using a herbicide dose below the recommended one (Salonen 1992). Boström and Fogelfors (2002) showed that, in most of the years, half of the full dose appears to perform nearly as well as the full dose.

The yield was higher and the biomass of mixed annual weeds was lower when maize was grown in 50 cm than in 76 cm inter rows space (Murphy et al. 1996). Weed biomass production was reduced more by early-maturing hybrids than late-maturing, large leaf maize hybrids (Begna et al. 2001). Inter row space often change leaf angle and maize grown in 38 cm rows closed one week earlier than that of maize grown in 76 cm rows (Teasdale 1995). Westgate et al. (1997) suggested that hybrids with a greater capacity of altering the leaf display angle or with a whorled leaf display might be better suited for efficient light interception in narrow rows. Maize hybrids with rapid initial growth rate are more competitive than the other hybrids and, careful selection of a competitive hybrids could dramatically reduce grain yield loss and weed seed production (Travlos et al. 2011).

The aim of this study was to estimate the influence of different arrangement patterns of maize hybrids in combination with lower herbicide rates on the weed fresh matter and the crop productivity.

MATERIAL AND METHODS

Site description. Field experiments were conducted during the period 2004–2007 at the Maize Research Institute, Zemun Polje, in the vicinity of Belgrade (44°52'N, 20°20'E). The soil was slightly calcareous chernozem with 47% of clay. The winter wheat was the previous crop. Field received the usual compound of mineral fertilizer (120 kg N per ha, 90 kg P per ha and 90 kg K per ha) in each year. The experimental area was ploughed in autumn, followed by one pass each of a disk harrow and a field cultivator prior to sowing. The crop was hand sown on the 28^{th}, 22^{nd}, 26^{th} and 19^{th} April in each year.

Experimental design and treatments. The experiment was a split-split plot design with three replications. The main plots encompassed the following arrangement patterns of maize (AP): AP_1 – row space 70 cm and 25 cm between the plants in a row (east-west orientation); AP_2 – row space 50 cm and 35 cm between the plants in a row (east-west orientation) and AP_3 – row space 35 cm and 50 between the plants in a row (north-south orientation). The crop density was the same in all arrangement patterns (57.143 plants/ha). The subplots included application of herbicides for complete pre-emergence broadleaf and grass weed control: isoxaflutole (Merlin 750–WG, 750 g a.i. (active ingredient) per kg, Bayer Crop Science) + acetochlor (Trophy-EC, 768 g a.i. per L, Dow AgroSciences, Indianopolis, USA). Herbicides were applied at three herbicide rates (HR): the full rate (101.25 g/ha + 1536 g a.i./ha), half a rate (50.625 g a.i./ha + 768 g a.i./ha) and an untreated control. The herbicides were applied on the 29^{th}, 24^{th}, 27^{th} and 20^{th} April in each year with a hand-held sprayer calibrated to deliver 15 L at 300 kPa (3 bar) with a flat-fan nozzle (Teejet, Wheaton, USA, 1.4 mm E 04-80). The sub-subplots included maize hybrids with different time of growing season (HY): ZP 434 (FAO 400), ZP 578 (FAO 500) and ZP 735 (FAO 700).

Measurements. The elementary plot size for maize grain yield observation was 29.4 m^2 and weed samples were taken with two 0.25 m^2 quadrants placed in the middle of the each plot. Whole biomass of weed plants (weed biomass) was recorded after uprooting weeds manually from randomly selected two places with a 0.25 m^2 quadrant measuring per elementary plot. The weed samples were collected one month (June), and two months after herbicide application (July). Because the characteristic maize plant stand was not completed in the first measurement, only the results for weed biomass from the second measurement are presented. At the same time, the maize biomass and height were measured. In 2007, due to the low amount of precipitation (3.8 mm in April) and a poor emergence of the maize plants, the maize plant biomass and height were not measured. The maize leaf area was measured at tasseling, when all the leaves were completely developed by a LI-COR 3100C area meter. The maize grain yield was obtained at the end of the growing season and calculated with 14% of moisture.

Statistical analysis. The data were processed by a mathematical statistical procedure 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 standard errors of differences between means (SED).

Meteorological conditions. The average monthly air temperatures during the maize growing season were optimal in the first three years of the investigation; while a higher average air temperature (20.7°C) from April to September was measured in 2007 (Table 1). The sum and distribution of the precipitation were the most optimal in 2004. The most unfavourable precipitation distribution (3.8 mm) was in 2007, especially during crop emergence (April).

Table 1. Average monthly air temperature (°C) and monthly precipitation sum (mm) from April to September at Zemun Polje (Serbia)

Months	Temperature				Precipitation			
	2004	2005	2006	2007	2004	2005	2006	2007
April	12.9	12.4	13.4	14.9	27.2	28.2	19.4	3.8
May	16.0	17.6	16.9	19.5	53.6	3.2	15.2	79.0
June	20.3	20.1	20.0	23.8	125.0	65.0	57.8	107.6
July	21.9	22.4	17.5	25.8	66.4	44.0	6.2	17.5
August	21.0	20.6	21.1	24.2	39.4	64.0	113.1	72.5
September	15.7	19.5	19.7	16.2	35.8	21.4	17.7	84.1
Average/sum	18.0	18.8	18.1	20.7	347.4	225.4	229.4	364.5

RESULTS

The dominant species in the maize weed community in the investigated field were *Datura stramonium* L., *Solanum nigrum* L., *Amaranthus retroflexus* L., *Chenopodium hybridum* L., *Chenopodium album* L., *Xanthium strumarium* L., and *Abutilon theophrasti* Medik. The more robust annual species *D. stramonium*, *X. strumarium* and *A. theophrasti* had the best response to the changes in the inter-row distances, i.e. the plant arrangement pattern. The weed biomass changed in dependence of the arrangement pattern of maize plants (Table 2). In most of the investigated years, the total weed biomass declined with decreasing row space and was, on average, the lowest (1576.97 g/m^2) for the 35-cm row space. The herbicide rate had a significant influence on the weed infestation level ($P < 0.01$) in all years. The interaction between the arrangement patterns and the herbicide rate had a significant impact on the weed biomass in 2007 and on average for all years. In 2006 the selection of hybrids significantly ($P < 0.05$) affected total weed biomass. The hybrid and herbicide rate interaction also induced very significant differences ($P < 0.01$) in weed biomass.

The total weed biomass was significantly lower on herbicide treatments than on the untreated control. Differences in weed biomass between the treatments of full and half herbicide rate were no significant on average 2004–2007 (214.06 and 630.75 g/m^2). The AP × HR interaction had a significant effect on the weed biomass, which was the lowest at the 35-cm row space and with the application of the full rate of herbicides (132.68 g/m^2) (Table 3). For each selected hybrid, the

Table 2. Weed biomass (g/m^2) in relation to arrangement pattern, herbicide rate and hybrid

Maize arrangement patterns		Years				Average
		2004	2005	2006	2007	
AP_1		2546.30	1168.93	1923.42	3558.94	2299.40
AP_2		2628.77	1161.32	1130.27	2898.25	1954.65
AP_3		1971.57	940.80	1721.15	1674.37	1576.97
Average		2382.21	1090.35	1591.61	2710.52	1943.67
SED		365.81	158.67	276.95	298.80	258.74
ANOVA	*df*			*P*-value		
AP	2	0.21^{ns}	0.48^{ns}	0.20^{ns}	0.00^{**}	0.00^{**}
HR	2	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}	0.00^{**}
AP × HR	4	0.42^{ns}	0.70^{ns}	0.06^{ns}	0.02^{*}	0.00^{**}
HY	2	0.87^{ns}	0.54^{ns}	0.02^{*}	0.37^{ns}	0.32^{ns}
AP × HY	4	0.93^{ns}	0.75^{ns}	0.67^{ns}	0.67^{ns}	0.88^{ns}
HR × HY	4	0.99^{ns}	0.86^{ns}	0.00^{**}	0.73^{ns}	0.86^{ns}
AP × HR × HY	8	0.98^{ns}	0.93^{ns}	0.60^{ns}	0.99^{ns}	0.99^{ns}

AP – arrangement pattern; HR – herbicide rate; HY – hybrid; SED – standard errors of the differences between the means; *df* – degrees of freedom; ^{ns}not significant; $^{*}P < 0.05$; $^{**}P <$ at 0.01

Table 3. Influence of the arrangement pattern (AP), herbicide rate (HR), hybrid (HY) and their interaction on weed biomass (g/m^2)

2004–2007	Arrangement patterns			Average
	AP_1	AP_2	AP_3	
Full rate	345.35	164.17	132.68	214.06
Half rate	723.26	781.18	387.82	630.75
Control;	5829.58	5338.62	4210.44	5126.21
Average	2299.40	2094.65	1576.97	1990.34
SED	280.73	258.02	211.64	145.89
HY_1	2028.00	1969.83	1521.30	1839.71
HY_2	2498.58	2203.91	1548.38	2083.62
HY_3	2357.15	2110.21	1660.95	2042.77
Average	2294.58	2094.65	1576.88	1988.70
SED	485.13	256.27	157.69	269.99

SED – standard errors of the differences between the means

total weed biomass declined with decreasing row space and was the lowest for the 35-cm row space.

Maize parameters changed with the tested factors (Table 4). Plant height, biomass and leaf area average values for all four years, were not statistically different dependently on maize arrangement pattern but grain yield of maize was significantly higher in AP_3. Herbicide application induced a significant increase of all maize evaluated parameters in treatments treated at full and half rate of herbicides compared to untreated control. As a result of diversity between tested hybrids, the statistical differences of evaluated parameters of maize have occurred. The earlier hybrid HY_1 had the uppermost height (63.25 cm) and grain yield (10.21 t/ha), in average, while HY_3 had the greatest leaf area (7246.40 cm^2) and grain yield (10.15 t/ha). According to interactions between investigated factors, interaction of herbicide rate and hybrid type affected signifacntly leaf area and grain yield of maize. Effect of hybrid and arangement pattern interaction was significant for maize yield.

DISCUSSION

According to results obtained in studies performed at Zemun Polje during 2004–2007, the arrangement pattern of the maize plants had a noticeable impact on the weed biomass in each year of investigation while the observed differences were significant in 2007 and on average for all years. Inter-row distance decreased weed biomass, especially of *D. stramonium*, *X. strumarium* and *A. theophrasti*. The increase of crop seeding rate and/or decrease crop row spacing in high-weed abundance areas is good measure to maximise crop-weed competition (Olsen et al. 2005). Murphy et al. (1996) also showed that a decrease in maize inter-row distance influenced and decreased weed biomass of 41%.

Herbicide rate also affected the weed biomass which was significantly lower when herbicide was applied at the full and half rate (214.06 and 630.75 g/m^2, respectively) compared to untreated control (5126.21 g/m^2). Average values for weed biomass at full herbicide rate were different from those at half herbicide rate for all years. The lowest weed biomass was obtained with the smallest inter-row space and with herbicide application at the full rates. Interaction between herbicide rate and arrangement pattern of maize (AP × HR) significantly influenced weed biomass in 2007, due to dry spring with 3.8 mm of precipitation in April, made a difference in herbicide efficacy. In 2006, extremely low amount of precipitation in July (6.2 mm) induced a significant influence of the interaction of herbicide rate and maize hybrid on weed biomass, probably becasue hybrids respond differently to dry conditions. Enhancing of the competitive ability of a crop may allow for a reduction in the amount of herbicide required (Forcella et al. 1992, Teasdale 1995, Nordblom et al. 2003).

Arrangement pattern changes the morphological and productive traits of crops, which indirectly affects the weed infestation level. In this study, the measured parameters of maize, such as plant height, plant biomass and leaf area were not significantly different according to crop arrangement patterns. All values were significantly lower at untreated control in comparison to full and half rate of herbicides and individual comparisons by the *LSD* test showed

Table 4. Plant height (cm), crop biomass (g), leaf area (cm^2) and grain yield (t/ha) of maize in relation to the arrangement pattern (AP), herbicide rate (HR) and hybrid (HY) – Average 2004–2007

	Plant height	Crop biomass	Leaf area	Grain yield
Arrangement patterns				
AP_1	61.65^a	270.80^a	5957.95^a	9.68^a
AP_2	63.39^a	271.29^a	6064.06^a	9.37^a
AP_3	61.65^a	271.33^a	6081.83^a	10.98^b
Herbicide rate				
Full rate	65.85^a	332.29^a	6815.48^a	11.25^a
Half rate	66.53^a	346.91^a	6720.07^a	11.20^a
Control	54.30^b	134.22^b	4568.28^b	7.59^b
Hybrids				
HY_1	63.25^a	261.81^a	5391.23^a	10.21^a
HY_2	63.06^a	299.19^b	5466.21^a	9.67^b
HY_3	60.37^b	252.42^a	7246.40^b	10.15^a
Average	62.23	271.14	6034.61	10.01
SED	0.72	12.88	153.78	0.22
ANOVA	*P*-value			
AP	0.19^{ns}	1.00^{ns}	0.16^{ns}	0.00***
HR	0.00***	0.00***	0.00***	0.00***
AP × HR	0.88^{ns}	0.87^{ns}	0.33^{ns}	0.24^{ns}
HY	0.00***	0.00**	0.00***	0.00**
AP × HY	0.47^{ns}	0.97^{ns}	0.72^{ns}	0.01*
HR × HY	0.76^{ns}	0.09^{ns}	0.01*	0.00***
AP × HR × HY	0.01*	0.76^{ns}	0.69^{ns}	0.55^{ns}

Maize plant biomass and height are averaged for 2004–2006. Means in columns followed by the same letter are not significantly different according to Fisher's protected *LSD* values (P = 0.05); SED – standard errors of the differences between the means; ^{ns}not significant; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$

that differences between the full and half rate were not significant in spite of their different effect on weed biomass (Simić et al. 2007). Maize grown in narrow rows could suppress weeds and increase the consistency of weed control by herbicides applied at reduced rates (Teasdale 1995). Genotype influenced significantly maize parameters. Increase of either the leaf area index, coverage degree or plant height at which the maize leaf appears could enhance crop tolerance in relation to their competitive ability towards weeds (Lindquist and Mortensen 1998). At genotypes with a greater leaf area and a more developed habitus, the distribution of weed species and their plants per species is lower (Simić et al. 2002).

The four-year results obtained at Zemun Polje show that maize arrangement patterns, as well as herbicide rate, hybrids and some of their interactions significantly influenced maize grain yield. Interactions of the hybrid type with the arrangement pattern and the herbicide rate significantly influenced grain yield of maize. Several field studies suggested a slight to moderate yield advantage when growing maize in narrow rows (< 76 cm) compared to wide rows (> 76 cm) (Bullock et al. 1988, Murphy et al. 1996, Porter et al. 1997).

Results of this study have several implications on weed management in maize production. The potential decreases in weed biomass and increases in maize grain yield have led many producers to consider using enhanced arrangement patterns, aspiring, first of all, to decrease the inter-row distance. Weed infestation level could be lowered if maize is grown with increased spatial uniformity and combined application of other practices such as herbicides. In such a way, maize plants are more competitive against weeds and even lower amounts of herbicides could be applied. This should ensure harvesting efficiency and provide optimum crop yields and benefit integrated weed management and environment protection (Wilson et al. 2009).

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Corresponding author:

Dr. Milena Simić, Senior Research Associate, Maize Research Institute, Zemun Polje, Slobodana Bajića 1, 11080 Belgrade-Zemun, Serbia
phone: + 381 113 756 708, fax: + 381 113 756 707, e-mail: smilena@mrizp.rs