Long term effects of different soil tillage systems on maize (*Zea mays* L.) yields

Ž. Videnović, M. Simić, J. Srdić, Z. Dumanović

Maize Research Institute, Zemun Polje, Belgrade, Serbia

ABSTRACT

The effects of three tillage systems: no-tillage (NT), reduced tillage (RT) and conventional tillage (CT), and three levels of fertilization (0, 258 and 516 kg/ha NPK (58:18:24)), on the maize yield during ten years (1999–2008) were analyzed on the chernozem soil type in Zemun Polje, Serbia. Statistical analyses showed significant effects of all three factors i.e., year, soil tillage and amount of fertilizers, and their interactions on the maize yield. The ten-year averages showed that the highest yields were observed with CT (10.61 t/ha), while the averages with RT and NT were lower (8.99 t/ha and 6.85 t/ha, respectively). The results of the influence of the amount of the applied fertilizers on maize yield showed that the lowest yield was in the zero level of fertilization 7.71 t/ha, while the yield was raised when the 258 kg/ha and 516 kg/ha NPK were applied (9.18 t/ha and 9.56 t/ha, respectively). Analyzing the influence of the soil tillage systems on maize production with respect to the amounts of applied fertilizers, this research revealed the benefits of CT under the presented agroecological conditions, irrespective of the level of applied fertilizer.

Keywords: maize; no-tillage; tillage; conventional tillage; levels of fertilizer

Application and research of different soil tillage systems is very popular worldwide. There are several reasons for this, including soil and moisture conservation and, moreover, cost and labor savings. Thereby, a balance between the soil tillage systems and the produced effects is the aim. On the other hand, one of the biggest challenges that the world must face in the next 20 years is climate change and the consequence could be that Europe, as a whole, will have to provide a higher percentage of the world's food production than is the case today (Fernandez-Quantinilla et al. 2008, Marshall 2010). This could move crop production practices back towards a strategy of maximizing yield and would highlight the importance of effective weed control practices. Lal et al. (2007), discussing the evolution of agriculture and farming, stated that soil management systems of the future will have to be developed to address emerging issues of the 21st century: the global climate change, accelerated soil degradation and desertification, decline of biodiversity and achieving food security for the expected population of 10 billion in 2050.

Hitherto, many studies have proved that rationalization and the forgoing of certain steps in soil tillage systems demand that all the other factors reach a satisfactory level (Videnović et al. 1986). The prevention of soil erosion and organic content loss relies on selecting appropriate strategies for soil conservation, suitable tillage system, application of efficient fertilization and implementation of sustainable crop rotations (Liu et al. 2010). Conservation tillage systems are better applied on light, coarse-textured soils and on well-drained soils (Dick et al. 1997, Hill 2000, Duiker et al. 2006). Results suggest that continuous maize yields obtained with no-tillage (NT) should at least equal those obtained with conventional tillage (CT) on such soils. On the other hand, reduced maize yield observed at NT in comparison with CT is characteristic on poorly drained soils in general (Vyn et al. 1994, Dick et al. 1997). Based on a long-term experiment, Boomsma et al. (2010) observed that substantial crop residue cover and cool, moist early-season soil conditions are common characteristics of continuous maize NT systems, which often delay seed germination, seedling emergence, and early root and stem development. Residue removal had also a significant impact on the noon temperature and water content in the

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soil and may cause delay in the seed germination but it may be advantageous when winter precipitation is less than adequate. The large difference was between unmulched and mulched treatments (Duiker and Lal 2000). Ussiri et al. (2009) concluded that average N_2O emissions from plough tillage and chisel tillage practices were almost two times higher than from NT. Niehues et al. (2004) found that the use of starter fertilizer containing N, P, K, and S significantly increases grain yield in continuous NT maize production compared with a broadcast N-only program. Reduced tillage without the weed management benefits of more tillage intensive practices, often have a greater reliance to herbicides (Videnović and Stefanović 1994, Melander et al. 2007). The yield potential of hybrids under NT is from 92 to 96% of those under CT, depending on the soil type (Carter and Barnet 1987). Results of Duiker et al. (2006) indicate that superior-yielding hybrids under CT are also good choices with NT.

Although different soil tillage managements have been widely investigated on different soil types in the USA and Canada, there are relatively few studies that have been conducted on the soils of South-East Europe. The objectives of this research were to determine effects of: (1) meteorological conditions, (2) different soil tillage systems and (3) three amounts of fertilizers and their interactions on the yield of maize.

MATERIALS AND METHODS

Site description and experimental design. The research was conducted within the ongoing, long-term tillage experiment initiated in 1978, in the period of ten years from 1999 until 2008 (factor A) in Zemun Polje, in the vicinity of Belgrade in Serbia (44°52'N, 20°20'E). The soil was slightly calcareous chernozem with 47% clay and silt. The 0–30 cm layer of soil contained 3.3% organic matter, 0.21% total N, 1.9% organic C, and 14 and 31 mg per 100 g soil of available P and extractable K, respectively, 9.7% total $CaCO_3$ and pH 7.8, on average.

The field experiment was arranged in a split plot design with four replicates. The size of the elementary plot was 19.6 m^2, i.e., 2.8 m wide and 7 m long, with four maize rows in each with 32 plants. The planting dates ranged from the 20^{th} to 25^{th} April, depending on the weather conditions and all plots were planted on the same day. Planting of all treatments was realized with a four row planter for direct maize planting, John Deere 7200. The plant density was 64 935 plants/ha. The same maize hybrid ZPSC 704 was planted in each year. The following tillage systems were investigated (factor B): NT – no-tillage, RT – reduced tillage and CT – conventional tillage. In the NT treatment, sowing was performed with a direct drill, without preceding soil tillage. In the RT treatment, tillage was performed with a rotavator in the autumn to a depth of 10–12 cm. The CT treatment consisted of shallow plowing to a depth of 15 cm, immediately after wheat harvesting, primary tillage in the autumn to a depth of 25 cm, seedbed preparation in the spring with a Rau-combi (composed of a harrow, cultivator and rollers). Fertilizers treatments were (factor C): F_0 = control, F_1 = 258 kg/ha (N 150 kg/ha, P 46 kg/ha and K 62 kg/ha) and F_2 = 516 kg/ha (N 300 kg/ha, P 92 kg/ha and K 124 kg/ha).

Cultural practices and measurements. Every year the preceding crop was winter wheat and the harvest residues were removed from the plots in order to prevent Fusarium infection. Prior to planting on NT, total herbicide Roundup (glyphosate 480 g a.i.) was applied as necessary to control vegetation in amounts of 5 L/ha. Pre-emergence application of herbicide Atrazine 500 SC in amount 1 L/ha (atrazine 500 g a.i.) and Harness 2 L/ha (acetochlor 900 g a.i.) were carried out on all treatments, until 2007 when atrazine was replaced with terbuthylazine. During vegetation, inter-row cultivation was applied to control weeds so they would not affect growth and development of the plants or depress the maize yields. The maize grain yield was measured at the end of the growing cycle from the two inner rows and calculated with 14% of moisture.

All observed data were analyzed using the analysis of variance (ANOVA) and the experiment was considered as a split-split plot design with four blocks. Treatment means were compared using the Fisher's least significant difference (*LSD*) test (P = 0.05 and 0.01).

Meteorological conditions. In the ten-year period that encompassed this study, the weather conditions varied during the maize vegetation period. Considering the amounts and distribution of precipitation from April until October and according to long-term experience, three types of years were distinguished based on the favorability for maize production. The first group included the years with up to 300 mm precipitation, the second with 300–400 mm and the third with over 400 mm of precipitation in the vegetation period (Figure 1), four unfavorable (dry) years: 2000 with 154.9 mm of precipitation, 2003 with 210.0 mm, 2007 with 290.1 mm and 2008 with 224.6 mm. These amounts of

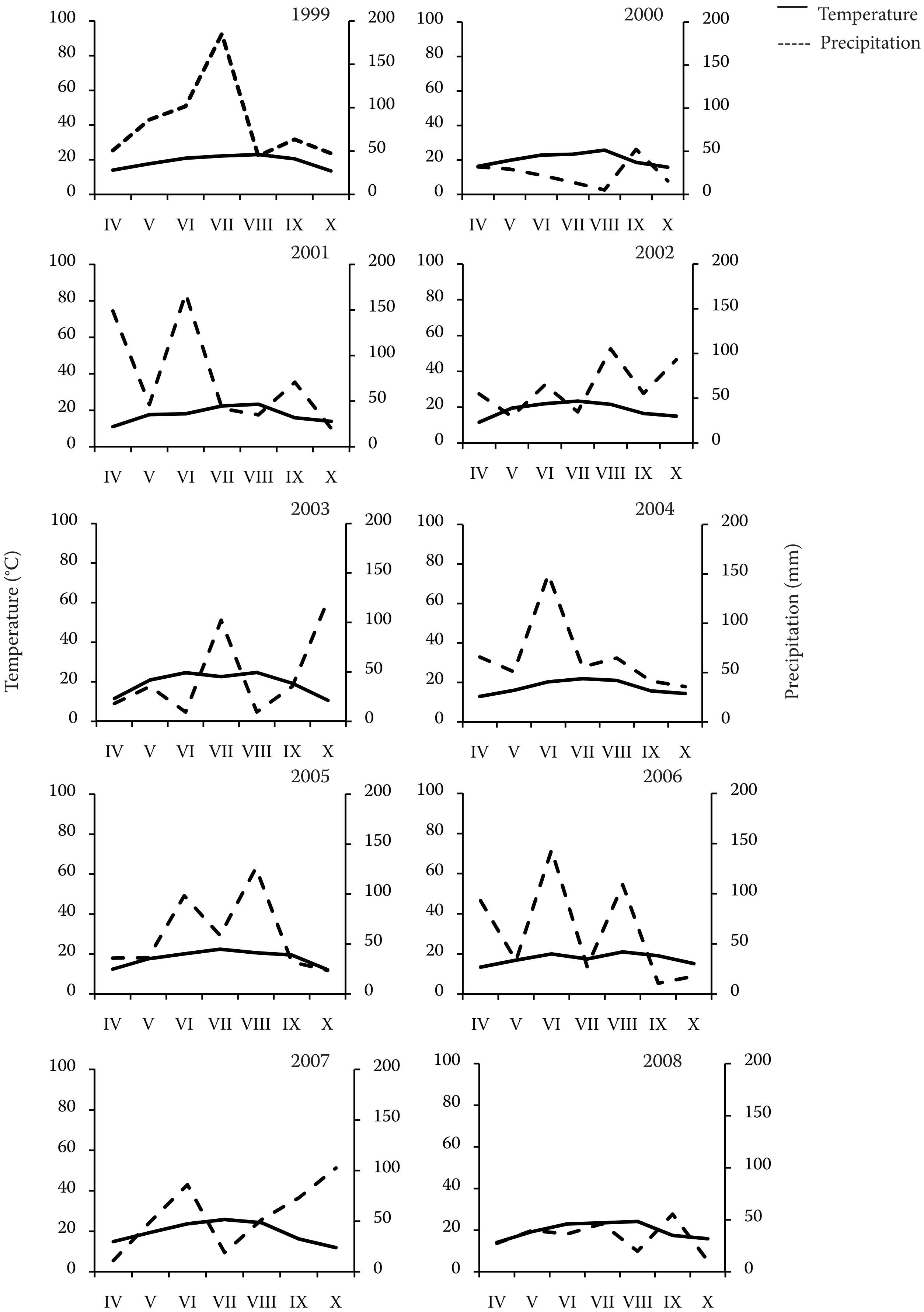

Figure 1. Walter's diagrams of precipitation and average air temperatures from April until October in the 10-year period (1999–2008) A (F_0)

precipitation were insufficient for satisfactory maize production under Zemun Polje agroecological conditions. During vegetation there were certain periods with an extreme lack of precipitation, especially in critical periods of maize development. Two moderately favorable years were: 2002 with 344.6 mm and 2005 with 387.4 mm of precipitation. In these years the amounts and distribution of precipitation were more favorable for maize production. Four favorable years, both in terms of the amount and distribution of the precipitation, for the maize production were: 1999 with 531.1 mm, 2001 with 510.6 mm, 2004 with 427.6 mm and 2006 with 417.1 mm.

Table 1. Analysis of variance (ANOVA), degrees of freedom and significance levels for maize grain yield

Sources of variance	*df*	*F*
Blocks (*R*)	3	0.18
Year (*A*)	9	85.41**
Tillage (*B*)	2	496.09**
$A \times B$	18	11.00**
Fertilizers (*C*)	2	140.12**
$A \times C$	18	8.63**
$B \times C$	4	14.25**
$A \times B \times C$	36	3.96**

**statistically significant at $P = 0.01$

RESULTS AND DISCUSSION

The statistical analysis showed highly significant effects for all three factors, i.e., year, soil tillage and amount of fertilizers, on maize yield (Table 1). In addition, all interactions between the factors had a significant effect on the expression of maize yield.

Analyzing the results of the maize yields over the years, significant (*LSD* 0.01) variations were found in almost all years (Table 2 and Figure 2). Significant effects of the year on the yield and its components are observed very often in long-term field studies due to differences in precipitation and grow degree days (GDD) accumulation during the vegetative period of maize (Wilhelm and Wortmann 2004, Boomsma et al. 2010). In addition, the soil tillage systems had different effects on the preservation of the soil moisture contents,

Table 2. Maize grain yield over the years, tillage systems and levels of applied fertilizers

	A	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	$\bar{x}$
NT	F_0	5.03	1.98	3.99	8.28	5.42	8.81	5.90	5.49	5.72	2.25	5.29
	F_1	7.27	3.01	6.65	8.62	5.95	12.31	6.93	7.76	7.22	4.54	7.03
	F_2	6.89	3.90	7.33	8.48	6.66	13.28	13.91	10.67	6.22	5.01	8.23
	$\bar{x}$	6.40	2.96	5.99	8.46	6.01	11.47	8.92	7.97	6.39	3.94	6.85
RT	F_0	10.79	4.19	7.03	8.34	7.46	11.00	10.87	9.29	5.85	3.42	7.82
	F_1	11.20	4.93	8.66	8.80	7.76	13.90	12.35	10.85	8.57	8.37	9.54
	F_2	9.93	6.33	8.26	9.19	7.24	13.58	13.96	12.15	8.23	7.17	9.60
	$\bar{x}$	10.64	5.15	7.98	8.78	7.49	12.83	12.39	10.76	7.55	6.32	8.99
CT	F_0	10.70	8.44	8.85	9.58	8.69	14.54	13.13	10.08	6.48	9.64	10.01
	F_1	11.40	8.68	9.51	10.26	8.98	14.25	13.80	13.51	9.20	10.27	10.98
	F_2	12.09	9.27	8.60	10.24	8.85	14.09	14.70	12.72	9.10	8.79	10.84
	$\bar{x}$	11.39	8.79	8.99	10.03	8.84	14.29	13.87	12.10	8.26	9.57	10.61
$\bar{x}$	F_0	8.84	4.87	6.62	8.73	7.19	11.45	9.97	8.29	6.01	5.10	7.71
	F_1	9.96	5.54	8.27	9.22	7.56	13.48	11.03	10.70	8.33	7.73	9.18
	F_2	9.64	6.50	8.06	9.30	7.58	13.65	14.19	11.85	7.85	6.99	9.56
	$\bar{x}$	9.48	5.63	7.65	9.09	7.44	12.86	11.73	10.28	7.40	6.61	8.82
LSD					$A_{0.05} = 0.69$			$A_{0.01} = 0.91$				
					$B_{0.05} = 0.23$			$B_{0.01} = 0.30$				
					$C_{0.05} = 0.23$			$C_{0.01} = 0.31$				
					$AB_{0.05} = 0.83$			$AB_{0.01} = 1.16$				
					$AC_{0.05} = 0.81$			$AC_{0.01} = 1.13$				
					$BC_{0.05} = 0.41$			$BC_{0.01} = 0.54$				
					$ABC_{0.05} = 1.82$			$ABC_{0.01} = 3.02$				

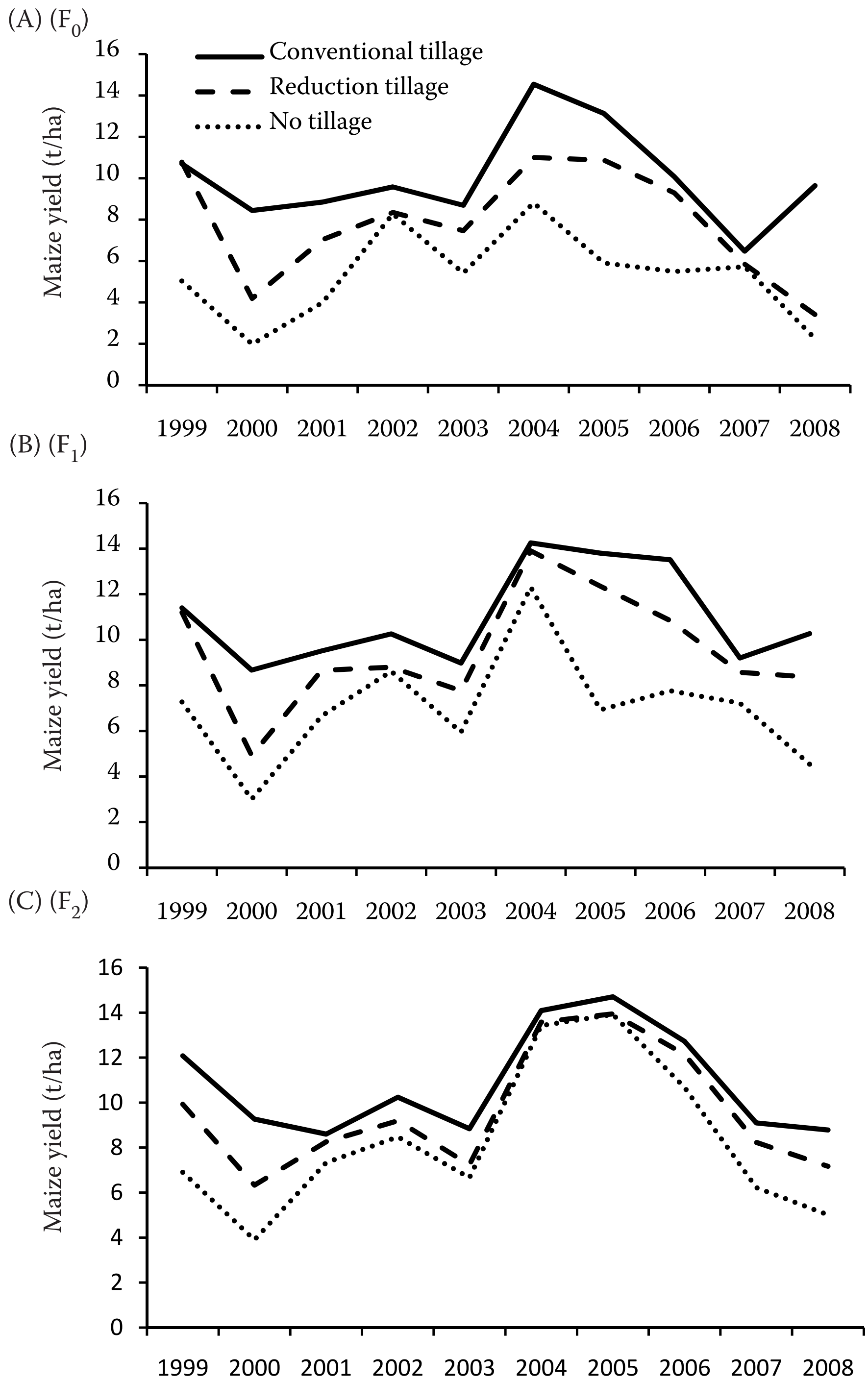

Figure 2. The influence of the soil tillage system on maize yield (t/ha) with (A) no fertilizers applied; (B) 258 kg/ha NPK applied and (C) 516 kg/ha NPK applied in the period from 1999–2008

which significantly affected maize yield (Simić et al. 2009). According to the presented facts of the amounts and the distribution of the precipitation in the vegetative period (Figure 1), in the four years that had less than 300 mm precipitation, average yields were from 5.63 t/ha (2000) up to 7.44 t/ha (2003). The two years with precipitation between 300–400 mm had average yields of 9.09 t/ha (2002) and 11.73 t/ha (2005), and in four years with precipitation over 400 mm, average values were from 7.65 t/ha (2001) up to 12.86 t/ha (2004). However, there were evidently some drifts from this regularity, when the yield did not increase with increasing amount of precipitation. In the year 2005, the observed yield was 11.73 t/ha, which was the second highest yield of all the considered years while the actual year was ranked among the moderately favorable years. The highest yield, 12.86 t/ha (2004), was significantly different from all others. The average yields over all the treatments in that year were higher than in any other year in this 10-year experiment, primarily because of sufficient amount and good distribution of precipitation during the most important developmental maize stages (June–August), (Table 2, Figure 1).

The annual fluctuations of maize yields are highly expressed as a result of the impact of different weather conditions (Figure 2 and Table 2). Kovačević et al. (2008) found out that different levels of P and K fertilization had a significant impact on maize yield although yield differences among years were grater. Moreover, for the F_0 treatment, major differences between the soil tillage systems were observed. For the treatments F_1 and F_2, the differences were less expressed; hence, an appropriate application of fertilizers can reduce the differences appearing between the soil tillage systems.

Results indicated the advantage of the CT system for yield of maize (Tables 1 and 2). The highest average yield was observed with CT 10.61 t/ha (100.00%), while the yield was lower with RT 8.99 t/ha (84.37%) and NT 6.86 t/ha (64.65%). The yield with the NT system ranged from 2.96 t/ha (2000) up to 11.47 t/ha (2004). These two years also had extreme yields at the RT system, (5.15 and 12.83 t/ha). The lowest average yield with CT was recorded in 2007 (8.26 t/ha), while 2004 was the year with the highest yield (14.29 t/ha). The tendency of increasing yields with a higher level of applied soil tillage was observed in all years, and the differences between the yields were significant in almost all years. Lower maize yields in no-tillage or minimum tillage systems compared to conventional tillage systems are widely documented in other similar studies, both when crop rotation was applied, or with continuous maize production (Pederson and Lauer 2003, Boomsma et al. 2010). This is partly due to the fact that no-tillage environments are more likely to exhibit non-uniform germination, emergence and early growth and development (Vyn and Hooker 2002), which causes great plant-to-plant variability for multiple morpho-physiological traits, that are associated with yield reduction (Liu et al. 2004, Tokatlidis and Koutroubas 2004).

The experiments of different levels of fertilizers indicated that the lowest yield was achieved with F_0 treatment (7.71 t/ha – 100.00%), while the yields were higher after F_1 (9.18 t/ha or 119.07%) and F_2 treatments (9.56 t/ha or 124.00%). The effect of the interaction between the soil tillage and the level of the fertilizers was highly significant at the NT treatment for all levels of fertilizers. At the RT treatment a significant difference was observed between F_0 and F_1 and between F_0 and F_2, while there was no difference between F_1 and F_2. Moreover for CT, at F_1 treatment higher yield (10.98 t/ha) was achieved than on F_2 (10.84 t/ha). Application of plough may compact the soil below the tilled layer and rotavator may cause less compaction problem in the soil, which can impact the water conservation and fertilization efficiency as well. That suggested that the application of the double amounts of fertilizers is not justified when RT or CT tillage system are applied (Table 2).

Comparing the average yields with different fertilizer treatments (F_0, F_1, F_2) for NT, RT and CT, the statistical differences were significant. At the F_0 treatment, the average yield at NT was 5.29 t/ha, while at RT, the yield was 7.82 t/ha and at CT 10.01 t/ha, which is almost double than at NT. The difference between the two amounts of applied fertilizers (F_1 and F_2) for the different soil tillage systems was also significant but not as highly expressed as compared to the F_0 treatment. The average ten-year yield of the treatment F_1 at NT was 7.03 t/ha, at RT 9.54 t/ha and at CT 10.98 t/ha. When the highest amount of fertilizer was applied, the yields ranged from 8.23 t/ha at NT up to 10.84 t/ha at CT.

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Corresponding author:

Dr. Živorad Videnović, Maize Research Institute, Principal Research Fellow, Zemun Polje, Slobodana Bajića 1, 11080 Belgrade-Zemun, Serbia
phone: + 381 11 37 56 708, fax: + 381 11 37 56 707, e-mail: zvidenovic@mrizp.rs