doi: 10.17221/156/2015-PSE

Effects of tillage systems on soil water content and yield in maize and winter wheat production

K. Copec, D. Filipovic, S. Husnjak, I. Kovacev, S. Kosutic

Faculty of Agriculture, University of Zagreb, Zagreb, Croatia

ABSTRACT

The four-year trial was conducted in north-western Slavonia (main arable crop producing region in Croatia) to evaluate the effects of different tillage systems on the water content of silty loam soil (Albic Luvisol) and yields of maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.). The tillage systems compared were: conventional tillage; reduced conventional tillage; conservation tillage I; conservation tillage II (CM); no-tillage (NT). During the study period, there were one dry, two wet and one average season. Soil water content (SWC) was measured at 0–5, 15–20 and 30–35 cm depths on a monthly basis. Tillage systems had significant ($P < 0.05$) effects on SWC and yields. The highest average SWC in all seasons was measured under the NT system, followed by the CM system. In the second season, the highest yield was measured under the NT system while in all other seasons, it was under the CM system.

Keywords: soil tillage; dry farming; rainfall; grain yield; weather conditions

Maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) are the most important arable crops in Croatia and Croatian farmers traditionally use the conventional tillage system in their production (Jug et al. 2001), although the European Community's agricultural policy has strongly encouraged soil conserving tillage practices (European Union 2000). Production of these crops in Croatia is also characterized by the dry farming system without irrigation and soil is only watered by precipitation. Efficient arable crop production is highly influenced by water availability during the growing season and it is very important to apply a tillage system that helps maintain a favorable soil water regime for optimal crop growth and development. Conservation tillage systems attempt to disturb the soil as little as possible in order to conserve its natural structure (Weise and Bourarach 1999) and are defined as any tillage or planting system that leaves ≥ 30% of crop residues on the soil surface after planting (Uri et al. 1999). Depending on the degree of disturbance by tillage systems, changes can be observed in soil water content, aeration and soil temperature, which influence the decomposition rate of residues left in the soil (Ma et al. 1999).

The effect of conservation tillage on water use efficiency and grain yield depends on the soil type, crop requirements, rainfall probability and soil water-storage capacity (Hemmat and Eskandari 2004). According to Lampurlanés et al. (2001), conservation tillage increases stored soil water by increasing infiltration and reducing evaporation, but depending on the soil type and climatic conditions, this leads to higher, equal or even lower yields than conventional tillage systems. For example, McMaster et al. (2002) reported that grain yields were always equal or higher in no-tillage than on moldboard plowed plots, while Unger (1994) found that tillage system had no effect on yield in long-term trials. Guzha (2004) found that no-till grain yields were lower than those of conventional tillage and Taa et al. (2004) observed that wheat yields from minimum and zero tillage were lower than those of conventional tillage.

The aim of this investigation was to determine the influence of five tillage systems on soil water content (SWC) as well as their influence on crop yield within the common crop rotation on a silty loam soil covering a significant area in north-western Slavonia.

doi: 10.17221/156/2015-PSE

MATERIAL AND METHODS

The trial was conducted during the period 2003–2006 on a site near the Suhopolje village (45°49'19''N, 17°29'54''E), 150 km north-east of Zagreb, the capital of Croatia. The climate is semihumid with average annual precipitation of 813.1 mm and average annual temperature of 10.9°C. The different tillage systems were applied on Albic Luvisol (FAO 1998), a silty loam soil by texture. Major soil physical properties, given in Table 1, were determined as follows: Particle size distribution according to ISO 11277: 2009, consistency limits according to standard test methods for liquid limit, plastic limit and plasticity index of soils (ASTM D4318-10) and specific density according to ISO 11508: 1998.

According to the basic chemical properties, this soil is acidic due to pH 5.6 (measured in water) and pH 4.9 (measured in 1 mol/L KCl), moderately rich in available nutrients, phosphorus and potassium (determined by Al-method). The organic matter level of 2.7% (assessed by bichromate Tjurin method) ranks this soil as one with a good level of organic matter.

The trial field consisted of 9 plots of 100 m length and 28 m width each, organized as randomized blocks with three replications. The treatments were applied to the same plots each year. The trial included the following five tillage systems and the appertaining implements: (1) Conventional tillage – plough, disc harrow, seedbed implement (CT); (2) reduced conventional tillage – plough, seedbed implement (RCT); (3) conservation tillage I – chisel plough, power harrow (CP); (4) conservation tillage II – chisel plough, multitiller (CM), and (5) no-tillage – no-till planter (NT).

The trial commenced with ploughing and chisel ploughing on November 28, 2002. The preceding crop was winter barley under conventional tillage. Prior to primary tillage in November, precipitation was 53.4 mm or 34.4% lower than the 30-year average. Tillage treatments were performed under adequate SWC conditions in all trial years. Secondary tillage with a disc harrow, combined implement, power harrow and multitiller was done on April 15, 2003. Maize (*Zea mays* L.), cv. BC 592, was sown on April 28, 2003 and harvested on September 18, 2003. In the second year, primary tillage was done on October 06, 2003 and secondary tillage on October 10, 2003. Winter wheat (*Triticum aestivum* L.), cv. Manda, was sown on October 14, 2003 and harvested on July 19, 2004. The third year primary tillage was performed on September 30, 2004 and secondary tillage on May 02, 2005. Maize was sown on May 05, 2005 and harvested on October 14, 2005. The fourth year primary tillage for winter wheat was done on October 25, 2005 and secondary tillage on October 27, 2005. Winter wheat was sown on November 04, 2005 and harvested on July 02, 2006. Fertilizing and crop protection were uniform for the whole trial field. Postharvest residues of the preceding crop were chopped and distributed over the soil surface. A four-wheel drive tractor with front tyres 16.9 R 28 and rear tyres 20.8 R 38 was used in the trial.

SWC monitoring started in the spring of 2003 and continued until the summer of 2006. Sampling was carried out on a monthly basis; samples were taken from three soil layers (0–5, 15–20 and 30–35 cm) with three replicates for each layer. Volumetric soil water content was determined by the gravimetric method (drying method, w/w) according to ISO 11461: 2001.

Statistical data analysis was done with the SAS Version 9.1 (SAS Institute 2002) using analysis of variance and regression analysis. The significance of differences between the five tillage systems was assessed by the least significant difference (*LSD*) test at the level of probability $P < 0.05$.

RESULTS AND DISCUSSION

Table 2 presents the precipitation and air temperatures recorded at the local meteorological

Table 1. Basic soil physical properties

Soil property	Depth (cm)		
	10	30	50
Particle size distribution (%)			
Clay (< 0.002 mm)	21.7	22.8	23.4
Silt (0.06–0.002 mm)	69.1	66.8	67.1
Sand (2.0–0.06 mm)	9.2	10.4	9.5
Texture		Silty loam	
Consistency limits (%)			
Liquid limit	26.2	28.1	28.8
Plastic limit	18.9	21.1	21.6
Plasticity index	7.3	7.0	6.7
Specific density (t/m^3)	2.56	2.58	2.59

doi: 10.17221/156/2015-PSE

Table 2. Precipitation and air temperature during the study period (2003–2006) and thirty-year average (1977–2006)

Month	Precipitation (mm)					Air temperature (°C)				
	2003	2004	2005	2006	1977–2006	2003	2004	2005	2006	1977–2006
January	87.4	68.1	34.2	28.7	51.4	–1.4	–0.4	0.4	–2.0	0.0
February	22.4	62.0	78.3	31.1	44.4	–3.3	2.7	–2.1	1.3	1.7
March	5.9	75.7	61.6	59.6	54.1	6.8	5.5	4.6	5.3	6.6
April	23.9	146.0	70.2	75.0	63.5	11.1	11.8	11.4	12.6	10.9
May	27.8	58.7	89.3	95.6	70.1	19.6	15.1	16.6	16.1	16.3
June	81.2	113.6	59.4	72.7	88.6	23.9	19.4	19.7	20.2	19.5
July	47.6	42.4	165.2	26.7	73.1	22.8	21.3	21.3	23.3	21.2
August	23.9	40.4	177.7	146.7	74.2	24.4	21.0	18.9	19.2	20.7
September	85.7	94.8	88.3	25.8	79.2	15.6	15.6	16.7	17.5	16.1
October	131.3	97.7	3.9	27.2	66.5	9.3	13.1	11.1	12.9	11.2
November	84.9	69.2	39.9	58.5	81.4	7.9	6.4	4.5	8.6	5.3
December	31.4	71.4	119.7	31.1	66.6	1.6	1.8	1.4	3.4	1.5
Total/Average	653.4	940.0	987.7	678.7	813.1	11.5	11.1	10.4	11.5	10.9

station during the study period. The maize growing season of 2003 was rather dry with 35.3% lower precipitation, the growing seasons of winter wheat 2003/2004 and maize 2005 were wet with 15.1% and 29.2% higher precipitation, and the winter wheat growing season of 2005/2006 was average with 0.4% higher precipitation than the thirty-year average. Monitoring of air temperature during the study period showed less deviation in comparison with the thirty-year average.

In the first trial year (2003), SWC decreased gradually during the maize growing season in all tillage systems and at all depths. The highest SWC was recorded in April and the lowest level in September (Figure 1). This is explained by the fact that precipitation in all months from maize

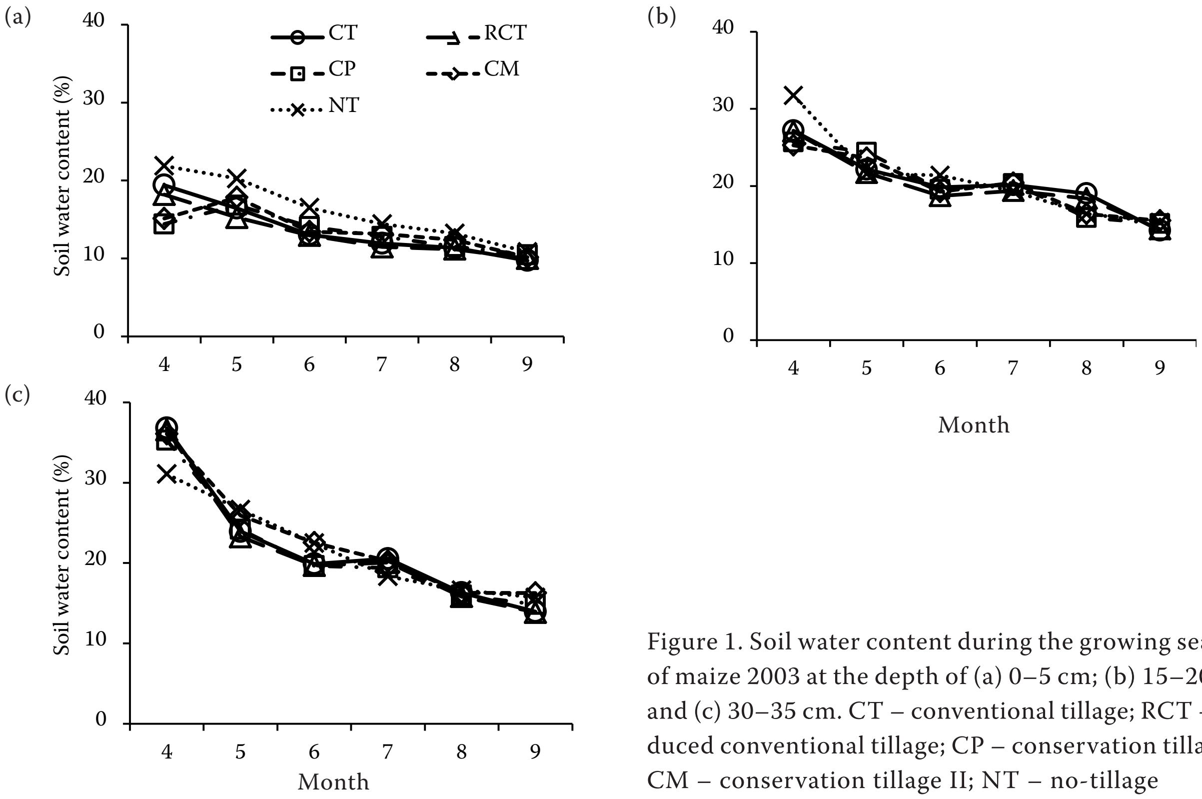

Figure 1. Soil water content during the growing season of maize 2003 at the depth of (a) 0–5 cm; (b) 15–20 cm and (c) 30–35 cm. CT – conventional tillage; RCT – reduced conventional tillage; CP – conservation tillage I; CM – conservation tillage II; NT – no-tillage

doi: 10.17221/156/2015-PSE

sowing to harvest was lower than the thirty-year average and water extraction by plants increased with growing. More precipitation fell just after maize harvesting in that season. At the 0–5 cm depth, SWC was extremely low under all tillage systems while it was significantly higher under the NT system than in other systems in all measurements. At the depth of 15–20 cm, SWC varied under different tillage systems and the average SWC was highest under the NT system, but the differences were smaller. The lowest SWC of most measurements was recorded under the RCT system at all depths. Strong correlation (r = 0.73**) between SWC and tillage system was found in that season.

In the second season, after winter wheat was sown in the second part of October 2003, a large amount of precipitation fell, almost twice the average for that month, and the highest SWC under all tillage systems was recorded in November (Figure 2). In the first half of 2004, all months except May had above-average precipitation and the mean SWC was 37.6% higher than mean SWC in the first season. In that wet season, SWC was highest under the NT system at all depths, while the lowest SWC was recorded under the CT system. Very strong correlation (r = 0.97**) was found between SWC and tillage system in that season.

The third season was also characterized by significantly higher precipitation than the average for this region and average SWC for all depths and tillage systems was 27.6%, the highest in the trial. The highest SWC during the maize growing season was recorded in August as a result of more than twice the average amount of precipitation during July and August 2005 (Figure 3). In that season, SWC was also highest under the NT system at all depths, while the lowest SWC was under the CT system. Differences between these systems were even higher, with a very strong correlation (r = 0.97**).

In the fourth season, in December 2005, precipitation was almost twice higher than the average and in that month the highest SWC was recorded for all tillage systems and depths (Figure 4). After that, there was a period with slightly higher or lower precipitation than average and total precipitation was almost the same as the thirty-year average. As water extraction by plants increased with growing, SWC decreased until winter wheat harvest and the average SWC of all depths and tillage systems was 24.03%. In that season, SWC was also the highest under the NT system at all depths, while the lowest SWC was under the CT system. Very strong correlation (r = 0.99**) between SWC and tillage system was also found.

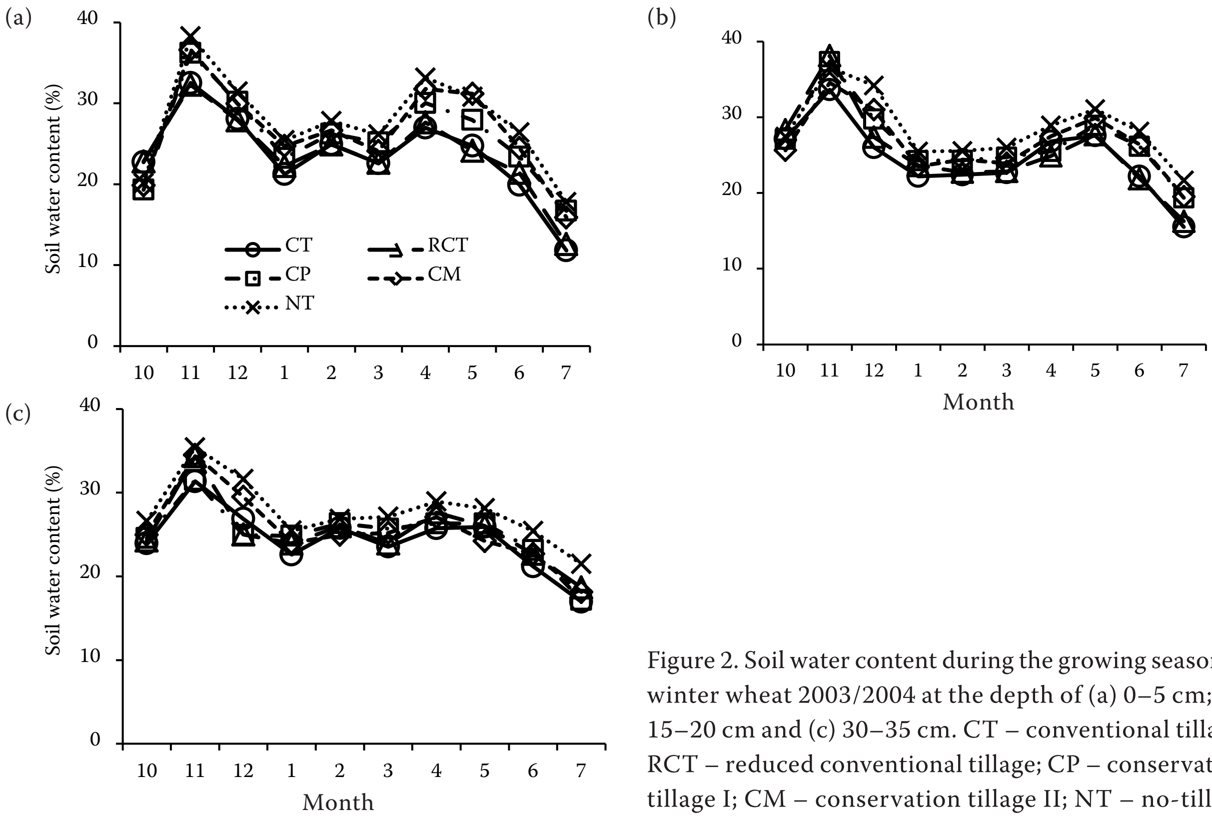

Figure 2. Soil water content during the growing season of winter wheat 2003/2004 at the depth of (a) 0–5 cm; (b) 15–20 cm and (c) 30–35 cm. CT – conventional tillage; RCT – reduced conventional tillage; CP – conservation tillage I; CM – conservation tillage II; NT – no-tillage

doi: 10.17221/156/2015-PSE

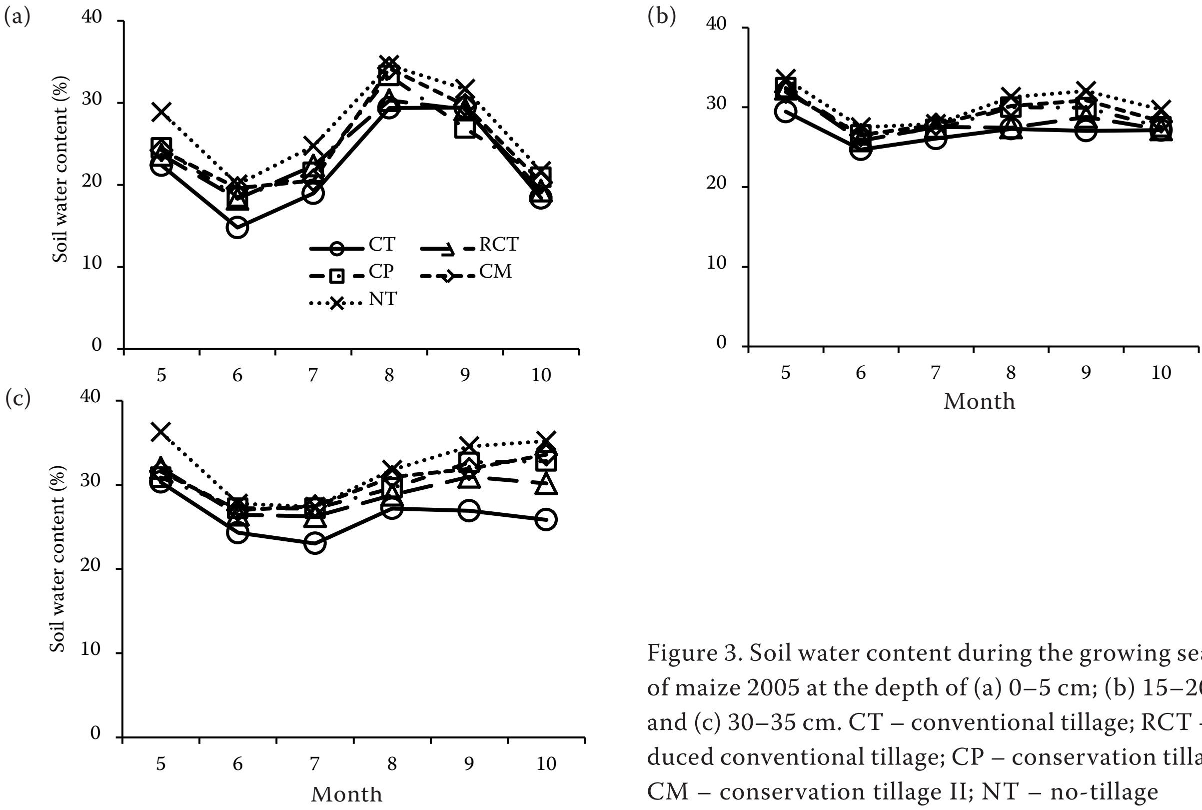

Figure 3. Soil water content during the growing season of maize 2005 at the depth of (a) 0–5 cm; (b) 15–20 cm and (c) 30–35 cm. CT – conventional tillage; RCT – reduced conventional tillage; CP – conservation tillage I; CM – conservation tillage II; NT – no-tillage

The results show that the no-tillage system conserves more soil water in the profile than other tillage systems, especially the conventional system. This can be partly explained by the fact that in these systems crop residues are maintained on the surface, producing less evaporation and greater

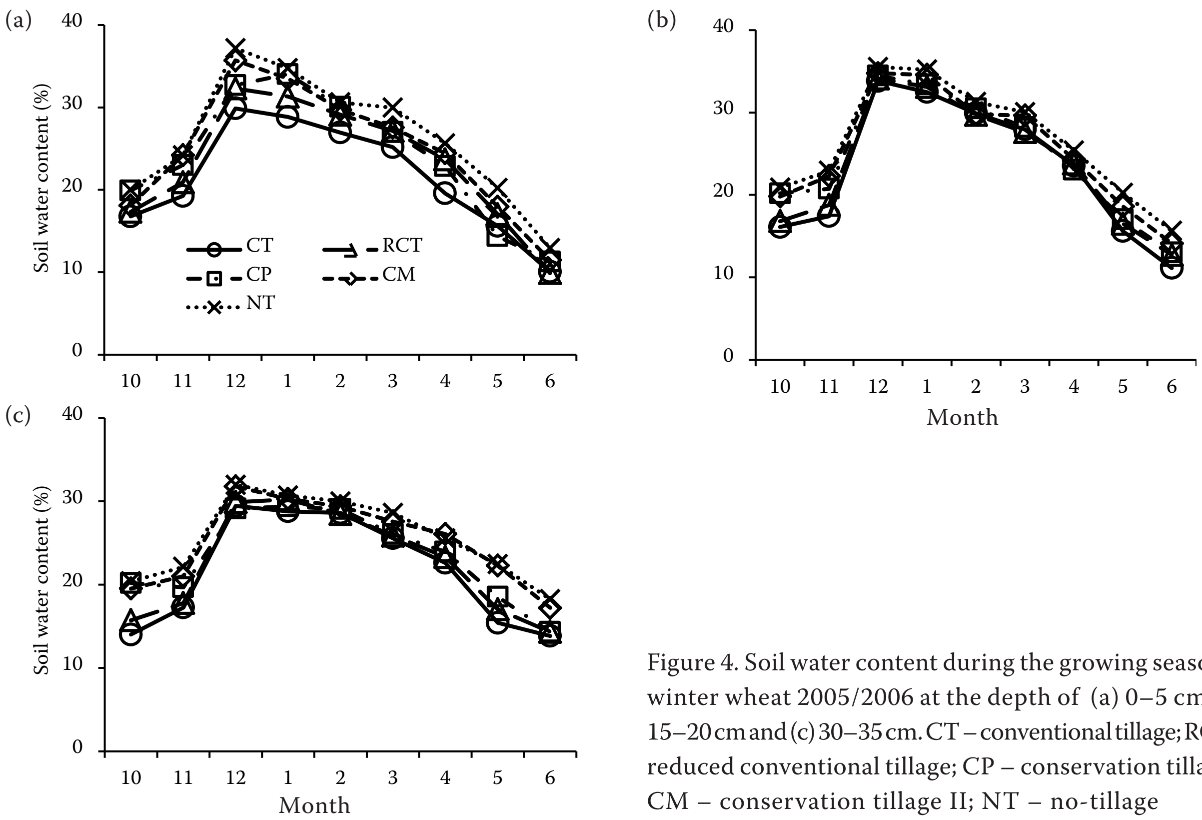

Figure 4. Soil water content during the growing season of winter wheat 2005/2006 at the depth of (a) 0–5 cm; (b) 15–20 cm and (c) 30–35 cm. CT – conventional tillage; RCT – reduced conventional tillage; CP – conservation tillage I; CM – conservation tillage II; NT – no-tillage

doi: 10.17221/156/2015-PSE

infiltration (Lampurlanés et al. 2001). Moreno et al. (1997) and Lamm et al. (2009) also reported higher soil water content under no-tillage or zero tillage than under conventional tillage. On the other hand, Hussain et al. (1999) found non-significant differences of the soil water content on silty loam (Albic Luvisol) between the conventional tillage, conservation tillage and no-till systems.

In the first trial season maize yields were very low under all tillage systems compared to the ten-year average (1997–2006) yield of Croatian enterprises 6.67 t/ha (Central Bureau of Statistics of the Republic of Croatia 2007). Lack of precipitation and low SWC caused a significant decrease in yield and under such conditions the highest maize yield was achieved with the CM tillage system, under which the highest SWC was measured at the 30–35 cm depth. Although the highest SWC at 0–5 cm and 15–20 cm depths was measured under the NT system, the yield was significantly lower compared to the CM system. The lowest yield was achieved under the RCT system, under which the lowest SWC in that season was measured at all depths (Table 3). No significant correlation was found between yield and tillage system in that season.

In the second season, winter wheat yields under all tillage systems were higher than the ten-year (1997–2006) average yield of Croatian enterprises 4.90 t/ha (Central Bureau of Statistics of the Republic of Croatia 2007). The highest winter wheat yield was achieved under the NT system, under which the highest SWC was measured at all depths in that season. The two lowest yields were achieved under the CT and RCT systems, under which the lowest SWC was also measured at all depths. Very strong correlation (r = 0.83**) was found between yield and tillage system.

Table 3. Yield of maize and winter wheat (t/ha) under different tillage systems in period 2003–2006

	Soil tillage system				
	CT	RCT	CP	CM	NT
Maize 2003	5.07^b	3.88^d	5.25^{ab}	5.42^a	4.48^c
Winter wheat 2003/04	5.49^c	5.40^c	5.52^c	5.68^b	5.88^a
Maize 2005	8.79^c	9.07^b	9.11^b	9.41^a	9.15^b
Winter wheat 2005/06	5.58^b	5.76^{ab}	5.85^a	5.92^a	5.81^a

Values followed by a different letter within rows are significantly different at $P < 0.05$. CT – conventional tillage; RCT – reduced conventional tillage; CP – conservation tillage I; CM – conservation tillage II; NT – no-tillage

In the third season, maize yields under all tillage systems were significantly higher than yields in the first trial season and the average of Croatian enterprises. The two highest yields were achieved under CM and NT systems, under which the highest SWC was measured, while the two lowest yields were achieved under CT and RCT systems, under which the lowest SWC was also measured at all depths in that season. Strong correlation (r = 0.72**) was found between yield and tillage system.

In the fourth season, yields of winter wheat under all tillage systems were higher than yields in the second season and the average of Croatian enterprises. The highest yield in that season was achieved under the CM system, under which the second ranking of SWC was measured, while the lowest yield was achieved with the CT system, under which the lowest SWC was measured at all depths. In that season, a strong correlation (r = 0.62*) was also found between yield and tillage system.

Yields are often compared through different tillage systems and authors have reported different results. According to Hemmat and Eskandari (2004), the cereal grain yield response to the conservation tillage practice is variable but higher yields are usually attributed to increased water conservation or utilization by the crop. Borin and Sartori (1995) reported that among conventional tillage, minimum tillage and no-tillage in maize production, the highest yield was obtained with conventional tillage. Jug et al. (2011) found that replacement of conventional tillage with reduced tillage can bring positive results in wheat production in Croatia. In a long term trial, Lal (1997) found that no-till treatments produced higher maize yields than plough-based treatments.

No significant correlation between SWC and yield was found in the first season, but there was a very strong correlation (r = 0.87**) in the second season. Correlation between SWC and yield in the third (r = 0.67**) and fourth (r = 0.62*) seasons was strong. The effect of SWC on yields confirmed the fact that SWC is one of the most important factors in efficient plant production.

REFERENCES

Borin M., Sartori L. (1995): Barley, soybean and maize production using ridge tillage, no-tillage and conventional tillage in north-

doi: 10.17221/156/2015-PSE

east Italy. Journal of Agricultural Engineering Research, 62: 229–236.

Croatian Bureau of Statistics (2007): Statistical Yearbook of the Republic of Croatia 2007. Zagreb, Croatian Bureau of Statistics.

European Union (2000): Special Report No. 14/2000 on Greening the Community Agricultural Policy together with the Commission's replies. Official Journal of the European Communities, C 353/1, Luxembourg, Publications Office of the European Union, 1–56.

FAO (1998): World Reference Base for Soil Resources. Rome, FAO.

Guzha A.C. (2004): Effects of tillage on soil microrelief, surface depression storage and soil water storage. Soil and Tillage Research, 76: 105–114.

Hemmat A., Eskandari I. (2004): Conservation tillage practices for winter wheat-fallow farming in the temperate continental climate of northwestern Iran. Field Crops Research, 89: 123–133.

Hussain I., Olson K.R., Ebelhar S.A. (1999): Impacts of tillage and no-till on production of maize and soybean on an eroded Illinois silt loam soil. Soil and Tillage Research, 52: 37–49.

Jug D., Zugec I., Kelava I., Eljuga L., Knezevic M., Marek G. (2001): Influence of reduced soil tillage on the yield of winter wheat, maize and soybean in an extremely dry year. In: Proceedings of the 37th Croatian Symposium on Agriculture with an International Participation, Opatija, 46–50.

Jug I., Jug D., Sabo M., Stipeševic B., Stošic M. (2011): Winter wheat yield and yield components as affected by soil tillage systems. Turkish Journal of Agriculture and Forestry, 35: 1–7.

Lal R. (1997): Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria. I. Crop yield and soil physical properties. Soil and Tillage Research, 42: 145–160.

Lamm F.R., Aiken R.M., Abou Kheira A.A. (2009): Corn yield and water use characteristics as affected by tillage, plant density, and irrigation. Transactions of the ASABE, 52: 133–143.

Lampurlanés J., Angás P., Cantero-Martínez C. (2001): Root growth, soil water content and yield of barley under different tillage systems on two soils in semiarid conditions. Field Crops Research, 69: 27–40.

Ma L., Ahuja L.R., Shaffer M.J., Rojas K.W., Peterson G.A., Sherrod L. (1999): Decomposition of surface crop residues in long-term studies of dryland agroecosystems. Agronomy Journal, 91: 401–409.

McMaster G.S., Palic D.B., Dunn G.H. (2002): Soil management alters seedling emergence and subsequent autumn growth and yield in dryland winter wheat-fallow systems in the Central Great Plains on a clay loam soil. Soil and Tillage Research, 65: 193–206.

Moreno F., Pelegrín F., Fernández J.E., Murillo J.M. (1997): Soil physical properties, water depletion and crop development under traditional and conservation tillage in southern Spain. Soil and Tillage Research, 41: 25–42.

SAS Institute (2002): SAS/STAT User's Guide. Version 9.1. Cary, SAS Institute.

Taa A., Tanner D., Bennie A.T.P. (2004): Effects of stubble management, tillage and cropping sequence on wheat production in the south-eastern highlands of Ethiopia. Soil and Tillage Research, 76: 69–82.

Unger P.W. (1994): Tillage effects on dryland wheat and sorghum production in the southern Great Plains. Agronomy Journal, 86: 310–314.

Uri N.D., Atwood J.D., Sanabria J. (1999): The environmental benefits and costs of conservation tillage. Environmental Geology, 216: 13–32.

Weise G., Bourarach E.H. (1999): Tillage machinery. In: Stout B.A. (ed.): CIGR Handbook of Agricultural Engineering. Vol. III. Plant Production Engineering. St. Joseph, ASAE, 184–217.

Received on March 6, 2015
Accepted on April 22, 2015

Corresponding author:

Prof. Dubravko Filipovic, University of Zagreb, Faculty of Agriculture, Svetosimunska 25, 100 00 Zagreb, Croatia
e-mail: dfilipovic@agr.hr