

Winter wheat yield and yield components as affected by soil tillage systems

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Abstract: Eight different soil tillage systems (TS) for winter wheat after soybean crop production were compared at the chernozem soil type in Croatian Baranya region in a 4-year period (2001/2002, 2002/2003, 2003/2004, 2004/2005). Tillage systems were: CT) conventional tillage, based on autumn mouldboard ploughing; DH) autumn disc harrowing; CH) autumn disc harrowing + chiselling; NT) No-tillage; CSDW) DH for winter wheat, alternated with CT for previous crop soybean; CWDS) CT for wheat, DH for soybean; CsNw) NT for wheat, CT for soybean; and CwNs) CT for wheat, NT for soybean. The dry conditions experienced in 2002/2003 decreased at half winter wheat grain yield at treatments NT and CwNs. The most stable grain yields were obtained by CT, CH, and CSDW in the third of 4 experimental years. CsNw, DH and CWDS did not result in significant crop yield reduction when compared to CT. There was no striking regularity regarding applied TS at the grain yield components. The strongest effects on yield and yield components for winter wheat were due to the climate conditions. TS had a significant effect on the grain yield and crop population in the earing stage in all 4 experimental years. The biggest difference in stem height was determined between CWDS and CsNw. Mass of plant, number of grains per spike, and hectolitre mass were greater under CT than under other TS. Coefficient of tillering and mass of 1000 grains had approximate values for all applied TS. In conclusion, CH, CSDW, and CsNw produced similar or slightly better quality properties than CT and these systems could be presented as an even-handed replacement for soil tillage.

Key words: Grain yield component, reduced soil tillage, winter wheat

Introduction

Conventional tillage (CT) practices are one of the many emerging environmental agronomic-economic issues that are addressed in contemporary cropping systems. Farmers traditionally use intensive CT (i.e. mouldboard ploughing) for cereal production, but the European Community's Agricultural Policy has strongly encouraged soil conserving tillage practices (and in some instance the conversion of cropland into

set-aside land) in order to decrease soil loss (European Union 2000), although new demands of bio-fuel production will decrease set-aside land. Wheat production in eastern Croatia is based on CT, which includes mouldboard ploughing (25-30 cm) and standard seedbed preparation (disc harrowing, harrowing, seeding), and very rarely no-tillage (NT) (Jug et al. 2001). López-Bellido et al. (1996) argued that the decreased water evaporation from the soil due

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to the residual cover under NT could increase the soil water content in comparison with CT, especially in dry seasons, which could be the reason for the increased wheat yield. In general, NT systems have a greater positive effect on crop growth and yield when used on soil characterised by low organic matter levels and poor structure, rather than on well-structured soils high in organic matter (Kladivko et al. 1986). No-tillage production results with changes in soil physical properties, including increased content of organic matter in soil (Grant et al. 2002) and aggregating stability and macroporosity (Gyuricza et al. 2004). The changes may be detrimental, neutral, or beneficial for crop growth, yield, soil texture, and structure (Silva et al. 2000; Birkás et al. 2002; Birkás and Gyuricza 2004; Balogh et al. 2007) and climatic factors such as rainfall (Morrison et al. 2000) or drought (Birkás and Gyuricza 2004). The objective of this research was to determine the effect of 8 different soil tillage systems on grain yield component of winter wheat including grain yield, crop population in the tillering and earing stages, coefficient of tillering, stem height, mass of plant, number of grains per spike, mass of 1000 grains, and hectolitre mass.

Materials and methods

A field experiment was conducted at Kneževo site in the Baranya region situated in north-eastern Croatia (45°32'N and 18°44'E, 90 m elevation). The study was conducted over a 4-year period (2001/2002, 2002/2003, 2003/2004, and 2004/2005) as a monofactorial trial with randomised plots divided into blocks within 4 replications and with a basic plot area of 900 m² (18 × 50 m), as a stationary experiment on the dominant soil type of the Baranya region, chernosem (pH_(H₂O) = 8.14; pH_(KCl) = 7.58; 2.79% organic matter; 120.9 mg kg⁻¹ P and 131.8 mg kg⁻¹ K (determined by Egner-Reihem Domingo Al- method, Page 1982) and 2.55% CaCO₃). The study started in 2001/2002. The experiment was conducted in the same homogeneous field and at the same location for each experimental year. Prior to the start of the experiment, only conventional tillage was applied. In all 3 years the preceding crop was soybean. Winter wheat cultivar Demetra in 2001/2002 for all tillage systems was sown at a rate 300 kg ha⁻¹ on 30 October 2001, 22 November 2002, 29 October 2003, and 28

October 2004. In 2001/2002 wheat emerged on 10 February, in 2002/2003 on 29 February, in 2003/2004 on 22 November, and in 2004/2005 on November 12. Fertilisation was uniform for all tillage systems and each experimental year (40 kg ha⁻¹ N in basic dressing, 81 kg ha⁻¹ N top dressing, 130 kg P ha⁻¹, and 130 kg K ha⁻¹). Grain drills John Deer 750A was used for all TS variants at the depth of 5 cm. The following tillage systems were applied in continuation: 1) conventional tillage (CT), where plots were cultivated by autumn ploughing (30 cm deep), disc harrowing (DH) (15 cm) and disc harrowing to depth of 10 cm. 2) Autumn disc harrowing (DH) was applied (fine till) to a depth of 15 cm and 10 cm. 3) Autumn disc harrowing + soil loosening was performed by chisel (CH) to a depth of 20-30 cm, disc harrowing to a depth of 15 cm. 4) No-tillage (direct drilling). In all experimental years following discontinued tillage systems were applied: 5) Autumn disc harrowing to a depth 15 cm and 10 cm for a winter wheat, whereas the previous year had CT for soybean (CSDW). 6) Conventional tillage for wheat and previous year disc harrowing for soybean (CWDS). 7) No-tillage for wheat and previous year conventional tillage for soybean (CsNw). 8) Conventional tillage for wheat and previous year no-tillage for soybean (CwNs). The following wheat quality parameters were assessed: plant population density per sq m in tillering (counted in 4 frames with dimension of 0.25 m², during winter wheat growing stage 2 by Feekes), plant density per sq m in the earing (4 frames in stage 11 by Feekes), coefficient of tillering (plant density in earing divided by plant density in tillering), height of stem in cm (measured on 50 randomly collected whole winter wheat plants a few days before harvest), mass of plant in g (same 50 plants sample), number of grains per spike (same 50 plants), thousand-kernel weight in g (from 2 grains subsamples of 2 kg each, collected from the harvested grain mass in harvest, 4 times 500 kernels were counted and weighed), hectolitre mass in kg (from the same 2 grains subsamples, 2 readings of the hectolitre mass and grain moisture has been acquired by Dickey John GAC 2100 apparatus), and grain yield in t ha⁻¹ (the whole basic plot grain yield was harvested and measured on the Schrran portable wheel scale, and recalculated on standardised 14% grain moisture weight). The influence of different tillage systems (TS) on the yield component of wheat

was tested by ANOVA of the split-plot design, where Year was treated as the main factor, and TS as the sub-factor. The means were compared by F-test protected LSD values calculated for $P < 0.05$ and $P < 0.01$.

Results

The winter precipitation was 307 mm in 2004 and 343 mm in 2005 in comparison to the 30-year average of 290 mm. Conversely, the winter precipitation in 2002 and 2003 was only 171 mm and 222 mm. Total precipitations during the growing season was greater in 2 out of 4 years than the 30-year average of 360 mm and ranged from 387 in 2004 to 406 mm in 2005. In 2003 total precipitation during the growing season was lowest with 126 mm in comparison to the 30-year average of 360 mm. Average temperatures during season (March-July) were higher in 2002, 2004 and 2005 by 1-2 °C than the 30-year average, except in 2003. In general, 2002, 2004, and 2005 were wetter and cooler than the long-term mean. In contrast, with the exception of March and April, 2003 was drier than the mean during the growing season and slightly warmer than the mean, particularly in May and June.

Plant density

The lowest plant density in tillering was achieved by CT (341 m^{-2}) and CWDS (340 m^{-2}), while the highest was by CSDW (376 m^{-2}) and DH (366 m^{-2}) with a multiyear average of ranging from 340 to 376 m^{-2} (Table 1). Beside CWDS treatment, all other TS showed a trend of higher plant density in the tillering (Table 1), which can lead to the presumption that soil condition, acquired by reduced soil tillage systems, was suitable for proper emergence and tillering. Different tillage systems applied in the research years did not have a significant influence on the plant density in the tillering ($F = 1.88$, variation coefficient, VC = 10.6%). In the 2002/2003 experimental year plant density in the tillering of winter wheat was significantly greater than that in other years ($P < 1\%$). Year influence, according to the F-test, was very significant ($F = 15.64^{**}$), with a variation coefficient of 19.8%.

The highest plant density in the earing was attained by CSDW and the lowest by CT, whereas the others resulted in approximately the same values. The analysis of variance and the F-test showed that TS had a significant influence on the plant density in the

earring ($F = 4.13^{**}$) with variation coefficient of 10.4%. The highest plant density in the earing on 4-year average was observed in first (2001/2002) and the lowest in second experimental year (2002/2003) (Table 1). According to the F-test year influence was very significant ($F = 122.71^{**}$), with variation coefficient of 25.4%. The interaction of TS \times Y was significant ($F = 2.03^*$) (Table 1).

Coefficient of tillering of winter wheat

The highest coefficient in the tillering on 4-year average was achieved in the first (2001/2002) and the lowest in the second experimental year (2002/2003) (Table 1). According to F-test year influence on the coefficient of tillering was very significant ($F = 30.70^{**}$) with a variation coefficient of 54.1%. On 4-year average, the highest coefficient in the tillering was attained by CSDW and the lowest by CH, whereas the other tillage systems did not result in approximately the same values. The TS did not have an influence on the coefficient of tillering ($F = 0.38$) (7%).

Height of stem

The biggest difference in stem height of winter wheat on 4-year average was determined between years (Table 1). The analysis of variance and F-test showed that year had a significant influence on the stem height of winter wheat ($F = 252.55^{**}$) with a variation coefficient of 102.9%. On average, highest values in stem height of winter wheat were attained by NT and by CsNw and the lowest by CWDS, whereas the other tillage systems resulted in approximately the same values. The different tillage systems did not have a significant influence on the stem height of winter wheat ($F = 1.35$).

Mass of plant

Mass of plant on 4-year average was 2.18 g. The lowest mass of plant was obtained in the second (2002/2003) and highest in the first (2001/2002) experimental year. The F-test showed that year had a significant influence on mass of plant ($F = 42.98^{**}$) with a variation coefficient of 60.5% (Table 1). On 4-year average the highest mass of plant was attained by CT, CH, CWDS, and CwNs; and lower by DH, NT, and CSDW; whereas the lowest was by CsNw. Different tillage types applied in the research years did not have a significant influence on mass of plant ($F = 1.02$) (Table 1).

Table 1. Analysis of variance and mean for grain yield and yield components of winter wheat as affected by different tillage systems (CT=conventional tillage, based on mouldboard ploughing; DH=diskharrowing; CH=chiselling + DH; NT=No-tillage; CSDW=CT for soybean, DH for w. wheat; CWDS=CT for w. wheat, DH for soybean; CsNw=CT for soybean, NT for w. wheat; CwNs=CT for w. wheat, NT for soybean), Kneževno site, from 2002 to 2005.

Variable	Plant density in the tillering	Plant density in the earing	Coefficient of tillering	Height of stem (cm)	Mass of plant (g)	Number of grains per spike	Mass of 1000 grains (g)	Hectolitre mass (kg)	Yield of grain (t ha ⁻¹)
Year									
2001/2002	333	543	1.68	65.7	2.52	35.5	36.9	78.4	6.64
2002/2003	399	433	1.09	41.6	1.57	29.7	29.4	81.4	2.59
2003/2004	349	529	1.53	84.4	2.26	30.2	27.9	81.8	6.84
2004/2005	343	522	1.54	56.4	2.39	39.8	37.4	75.8	6.19
Average (Y)	356	507	1.46	62.0	2.18	33.8	32.9	79.4	5.56
Tillage									
CT	341	482	1.45	62.1	2.25	36.1	32.8	79.4	5.62
DH	366	521	1.44	62.1	2.19	33.6	33.5	79.4	5.59
CH	362	501	1.42	61.1	2.24	34.7	33.0	79.5	5.76
NT	353	516	1.48	63.5	2.15	32.2	33.3	79.3	5.40
CSDW	376	532	1.45	62.0	2.15	33.2	32.8	79.6	5.68
CWDS	340	487	1.52	60.4	2.24	34.0	33.2	78.8	5.50
CsNw	358	521	1.49	63.9	2.04	32.1	32.1	79.5	5.62
CwNs	350	495	1.43	61.0	2.21	34.7	32.3	79.3	5.36
Average (TS)	356	507	1.46	62.0	2.18	33.8	32.9	79.4	5.56
LSD values									
Year	34**	21**	0.21**	5.2**	0.30**	4.8**	4.7**	1.1**	0.20**
Tillage systems	NS	32**	NS	NS	NS	NS	NS	NS	0.21**
Y × TS	NS	61*	NS	NS	NS	NS	NS	NS	0.52**

NS: not significant; * P < 0.05 and ** P < 0.01

Number of grains per spike

On 4-year average the highest number of grains per spike was achieved by CT and the lowest by NT and CsNw, whereas the other tillage systems resulted in a significant reduction when compared to CT. According to the F-test different TS did not have a significant influence on number of grains per spike ($F = 1.50$). The biggest difference in number of grains per spike was determined between research years (Table 1). The analysis of variance and F-test showed that year had significant influence on the number of grains per spike ($F = 20.74^{**}$), with a variation coefficient of 34%.

Mass of 1000 grains

Thousand-kernel weight was on 4-year average 32.9 g. The lowest weight was obtained by CsNw (32.1 g) and the highest by DH and NT, reaching 33.5 and 33.3 g. Moreover, the other applied tillage systems did not have a significant influence to 1000 grains mass reduction when compared to CT (Table 1). Different tillage types applied in the research years did not have a significant influence on the mass of 1000 grains ($F = 1.20$) (4.4%), although some of them had higher mass of 1000 grains than CT (DH, NT, CWDS, and CH). The biggest difference in mass of 1000 grains was determined between years. Differences in mass of 1000 grains between years were very significant ($F = 23.24^{**}$), with a variation coefficient of 34.1%.

Hectolitre mass

On 4-year average, hectolitre mass for all applied tillage systems resulted in approximately the same values. Different tillage types applied in our research did not have a significant influence on the hectolitre mass ($F = 1.46$) (Table 1). The biggest difference in hectolitre mass was determined between research years. Differences for hectolitre mass between years were very significant ($F = 127.61^{**}$), with a variation coefficient of 7.9%.

Grain yield

The lowest grain yield was obtained by CwNs (5.36 t ha^{-1}) and NT (5.40 t ha^{-1}) and the highest by CH, reaching 5.76 t ha^{-1} , whereas the other tillage system resulted in approximately the same values. There was a significant grain yield decrease with CwNs and NT in comparison with CT. Grain yield in 2002/2003 was on average 2.59 t ha^{-1} , and was lower than in the other years (Table 1). The analysis of variance and the F-test showed that year had a very significant influence on the grain yield ($F = 2014.21^{**}$), with a variation coefficient of 164.1%. Moreover, TS was very significant on grain yield ($F = 6.01^{**}$), with a variation coefficient of 7.5%. A year \times tillage system interaction was significant and possibly could also explain why higher wheat yields were recorded in 2004 in all tillage systems than in other years in the present study (Table 1).

Discussion

The increased drought stress in 2003 was probably responsible for the lower grain yields observed in 2003 (Table 1), which exacerbated the negative effects of NT and CwNs on grain yield of winter wheat when compared to CT. Moisture deficits that frequently occur from March through July (2003) reduced the yield of wheat cultivar used in this study, which is in accordance with many authors who emphasised the importance of climatic conditions during the growing season for grain yield (Sabo et al. 2006). The influence of climate conditions, tillage systems, and interaction $Y \times TS$ on the plant density in the earing was significant in the second experimental year (2002/2003) for all tillage systems (Table 1). There was a significant grain yield decrease of 61% of yield in the first year (2001/2002). This indicates that

establishment of wheat is reduced when cold and wet conditions occur at seeding time under NT compared with CT systems, while establishment is enhanced when relatively dry conditions and mild or warm temperatures occur. In 2002/2003 year wheat was planted on 22 November 2002 and it emerged on 10 February 2003. This resulted in a significant decrease in grain yield, plant density during the tillering, coefficient of tillering, and height of stem when compared the other research years (Table 1). The best TS was CSDW, with the yield of only 2.86 t ha^{-1} , followed by CH, CT, CsNw, CWDS, and DH (2.77 , 2.73 , 2.73 , 2.66 , and 2.64 t ha^{-1} , respectively), all of them significantly higher than NT and CwNs (2.20 and 2.14 t ha^{-1} , respectively). The weather condition was so deteriorative for winter wheat development that plants developed only 1.09 spikes (regardless of applied TS), instead of 1.53-1.68 spikes, as in more favourable years. Year 2003/2004 was wetter and cooler than the long-term mean with a greater multiyear average (Table 1). In contrast, with the exception of April and June, 2004 had more precipitation than the mean during the growing season (Table 1). The highest grain yields, height of stem, and hectolitre mass were achieved in the 2003/2004 experimental year (Table 1). On 4-year average grain yield of wheat was determined under CT 5.62 t ha^{-1} and it was not significantly lower than any other applied tillage systems (Table 1). Grain yield variation in 4-year average (except 2002/2003) by CT was lower (0.5 t ha^{-1} , 9.1%), pointing to high stability in CT applying for winter wheat cultivation. The most stable grain yields were obtained by CT, CH, and CSDW in 3 out of the 4 experimental years (data not shown). These TS could, therefore, be considered as the most favourable for wheat growing. Moreover, CsNw, DH, and CWDS did not result in significant crop yield reductions when compared to CT. Some authors state that CT is significantly better for wheat than the disc harrowing (Košutić et al. 2005). However, the longer time between tilling and seeding by CT can reflect upon a decrease in plant density in the tillering (Fisher et al. 2002; Stipešević et al. 2005). In the present study the plant density in the tillering was significantly lower under CT and CWDS than the others that applied TS. According to Sabo et al. (2006), contrasts were found between DH and CH where equal or slightly better wheat quality properties were

produced in comparison with CT; thus these could be presented as fair replacements for the conventional tillage. In this experiment, in the 4-year average the highest plant density in the tillering was by CSDW, DH, and CH (Table 1). According to Birkás et al. (2002), CH applying dominates in gaining high grain yield of wheat compared to other applied TS. Researched components on wheat grain yield by CH in this research were not dominant, and were ever poorer than other TS treatments (Table 1). The highest variation in grain yields was achieved by NT and CwNs in the experimental years, in comparison with CT and the other tillage systems (Table 1). Higher coefficients of tillering, hectolitre mass, and height of stem were achieved by CsNw in comparison to the other applied TS in this study. Coefficient of tillering was greater for CWDS than for other tillage systems. Moreover, on 4-year average in present study plant density in the tillering and earing, coefficient of tillering, height of stem, and mass of 1000 grains under NT were greater in comparison with CT (Table 1). Plant density in the tillering and in the earing was greater under CSDW than under the other tillage systems. On 4-year average declining in tiller production in the tillering and in the earing under CT, CWDS and CwNs systems were found, but they were increased under DH, CH, NT, CSDW, and CwNs (Table 1). Results in this study extend the observation that plant spacing in the tillering and in the earing production increased in growing wheat as reduction of the tillage intensity increased. The biggest differences in stem height were found between NT, CsNw, and the other applied tillage systems. Mass of plant was unaffected by tillage systems in our study. Moreover, year had a significant influence on the mass of plant ($F = 42.98^{**}$). The number of kernels per spike declined in the 4-year study as reduced tillage increased, which is in accordance with research conducted by Tanaka (1989). The negative effect of tillage on kernel number per spike was attributed to early season stress in tilled treatments compared with CT systems. No relationship between visual symptoms of early-season stress and tillage treatments was observed in the present study. Moreover, year had a significant influence on the number of grains per spike ($F = 20.74^{**}$). Different tillage systems applied in this 4-year research did not have a significant influence on the thousand-kernel weight ($F = 1.20$).

Mass of 1000 kernels had approximately the same values for all tillage systems in the present study. Kernel weight increased for soft white spring wheat as tillage declined in a continuous small-grain system at 2 out of 3 locations in the Pacific Northwest (Ciha, 1982). This researcher attributed the increase in kernel weight to the moisture conservation benefits that resulted from maintaining crop residue on the surface under reduced tillage and NT compared with CT systems. More available water occurred during the grain filling due to cooler soil temperatures in RT and NT systems. The biggest differences of hectolitre mass were determined between experimental years. According to the F-test, there was a very significant influence of year on the hectolitre mass ($F = 127.61^{**}$). The choice of TS did not have a significant influence on hectolitre mass, whereas there were statistically justified differences in 2002/2003 and 2003/2004. Climate conditions' influence on the components of yield was significant for all tillage systems. DH, CH, CSDW, and CsNw produced the same or slightly better properties than CT (Table 1). The reduction in tillage generally had a small effect on grain yield when HRWS was harvested mechanically in a wheat-fallow monoculture in the Great Plains (Carr et al. 2003), although soil water content usually increased (McConkey et al. 1994). Apparently, the advantages of soil water conservation by reductions in tillage are offset by plant stresses associated with RT and NT that are less severe or nonexistent under CT.

Conclusion

This research has proved a highly significant influence of reduced soil tillage on the grain yield at the given climatic and site conditions. However, tillage effect on the assessed grain yield components indicated a low statistically significant difference. Climate conditions had a statistically significant influence on the grain yield for all research components of yield in all experimental years. Grain yields ranged from 5.76 t ha^{-1} (CH) to 5.36 t ha^{-1} (CwNs), in the following order of descending yields: Chiselling (CH) > Diskharrowing for wheat, in alternation with conventional tillage for soybean (CSDW) > Conventional tillage, based on moldboard ploughing (CT) = No-tillage for wheat, in alternation

with conventional tillage for soybean (CsNw) > Diskharrowing (DH) > Conventional tillage for wheat, in alternation with diskharrowing for soybean (CWDS) > No-tillage (NT) > Conventional tillage for wheat, in alternation with no-tillage for soybean CwNs. Chiselling and disc harrowing (CH),

conventional tillage (CT) and disc harrowing DH, (CSDW) and (CsNw) produced equal grain quality properties. Positive results of the reduced tillage variants may call attention to replacement of the conventional tillage (CT) in the related wheat production agri-ecological conditions.

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