Impact of Conservation Tillage on Grain Yield and Yield Components of Maize in North-West Croatia

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Summary

Finding optimal tillage system in ever-changing agroecosystem with quality and stable grain yield is challenging but essential to the farmer. At the Experiment Station Šašinovec (NW Croatia), the trial was conducted to evaluate the effects of different tillage systems and straw on yield and its components of maize (*Zea mays* L.) on silty clay loam soil (Fluvisol). The tillage systems compared were conventional tillage, minimal tillage and reduced tillage. Under each treatment, there were subplots with and without straw. Tillage systems had significant ($P < 0.05$) effects on 1000-seed weight, protein, harvest index and yield. The use of cover was significant only on yield, while the interaction of factors (tillage x cover) significantly affected all yield components. In our short-term experiment, deeper soil tillage provided significantly higher values on some yield components (harvest index and protein content) than conventional tillage, thus showing our farmers possible sustainable solutions for their production under agroecological conditions of the north-west of Croatia.

Key words

soil tillage, grain yield, yield components, maize, NW Croatia

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Introduction

Croatia is often considered "maize country", as confirmed by the National Bureau of Statistics (2018), with production around 6,3 t ha^{-1} on 247 119 ha. This is no surprise, as maize has an acceptable market value, it is vital for its nutritional value, and as an energy crop for biofuel (Zrakić et al., 2017). Nowadays, when the climate changes accelerate, farmers are searching for a sustainable agro technical practices to ensure stable yields. Olesen et al. (2011) confirm that climate change is unfavorable for crop yield in Pannonia. In the past decade, different soil tillage systems, containing fertilization, were tried in Europe (Neudert and Smutný, 2018). As the most energy-consuming part of the production, tillage can present a chance for altering its usual methods. Tillage systems are regionally and even locally specific, they should be compatible with soil and climate conditions (Butorac, 1999; Husnjak et al., 2011; Servadio et al., 2014). To uphold crop demand for water, preservation of soil moisture and water retention with conservation tillage systems is increasing on croplands worldwide (Birkás et al., 2008). Mulching or permanent soil cover and sustainable tillage with wide crop rotation offer possible solution (Jug et al., 2015). These principles are intertwined in conservation agriculture, with an application on over 125 million hectares globally (Friedrich et al., 2012). Conservation tillage (CA) is encouraged by the European Common Agricultural Policy (European Union, 2000), and is applicable to all agroecological zones (Ceglar et al., 2018). CA improves soil quality and boosts crop productivity (Jug et al., 2018). Reducing evaporation and increasing infiltration CA can store more soil water, thus increasing yield (Nyakatawa et al., 2000; He et al., 2011). Lampurlanés et al. (2001) point out the influence of soil type and climatic conditions on possible yield under CA. Straw mulching has shown that soil quality improves (Bogunović et al., 2018a), but leads to the reduction (Dihma et al., 2009) or increase (Noor et al. 2021) of grain yield. Amount of straw mulch, time of application, and tillage management greatly affect the efficiency of mulch on increasing crop yield (Wang et al., 2019). Yields of maize vary under CA worldwide. Extensive European meta-analysis by Van den Putte et al. (2010) concludes that reduced tillage lowers yields by 4.5 %. Several authors have found that CA responds with a greater yield than conventional tillage under arid and semi-arid conditions (Romaneckas et al., 2020; Madarász et al., 2016). In humid or semi-humid conditions, plowing has achieved higher or similar maize yields compared to other reduced tillage methods (Berhe et al., 2013; Li et al., 2019). Experiments with the effect of alternative tillage method on protein content in maize are limited. Hence, this yield parameter should also be investigated. According to Špoljar et al. (2009), crop rotation helps with the growth of protein levels in maize, and with higher nitrogen rates. Deep tillage is recommended for protein build up in grain (Wasaya et al., 2017).

In Croatia, particularly in its north-western (NW) part, Mihalić and Butorac (1969) were pioneers with reduced-tillage methods in the middle of the 20th century with experiments on Stagnosol. Since then, to our knowledge, there have been no papers regarding different tillage methods with effect on yield and yield components of maize in similar agro-ecological conditions and even more, on Fluvisol. Finally, as is commonly known, finding optimal tillage method is a complex task, which consists of understanding several factors as soil type, climate, fertilization and other agroecological conditions. This paper aims to evaluate different conservation methods compared to conventional tillage on the several yield parameters of maize in agroecological conditions of NW Croatia.

Materials and Methods

The experiment was performed at Experiment Station Šašinovec, University of Zagreb, Faculty of Agriculture (45° 50' N, 16° 11' E) in the City of Zagreb. Zaninović et al. (2008), state that the City of Zagreb lies in the inland region of Croatia, which has a temperate continental climate. The experimental field consisted of nine plots with dimension length 100 m x width 10 m each, organized as randomized blocks with three replications. Different tillage treatments were as follows: 1. Conventional tillage – ploughing in autumn and disking and harrowing in early spring (CT) 2. Minimum tillage – multitiller in spring (MT) 3. Reduced tillage – subsoiling in autumn and multitiller in spring (RT). The summary of tillage operations in the experiment is presented in Table 1. On each plot, cover (straw or no straw) was used as subfactor (50 m x 10 m). Wheat straw (2.75 t ha^{-1}) was applied briefly after sowing. The soil is silty clay loam Fluvisol (Husnjak, 2014; IUSS Working Group WRB, 2015). According to the basic chemical property data this soil is neutral with pH 7 (in H_2O), well supplied in phosphorus (249 mg/kg) and potassium (214 mg kg^{-1}), and medium in total nitrogen. Organic matter is low (2.1%).

Temperature and rainfall data (Table 2) were recorded daily at meteorological stations located in the experimental fields' vicinity. The analysis of climatic conditions for the trial involved total monthly precipitation and mean monthly air temperatures compared with the earlier studied period (1983.-2012.). The rain factor (Rfm) was calculated monthly for precipitation (mm) and mean air temperatures (°C), according to Gračanin (1950).

Before seedbed preparation, fertilization was broadcast: 400 kg ha^{-1} NPK 7:20:30 combined with 100 kg ha^{-1} of UREA (46% N).

Weed control was uniformly carried out on May 11 with 4 l/ha LUMAX (37.5 g L^{-1} + Mezotrion+375 g L^{-1} S-metolaklor+125 g L^{-1} Terbutilazin) and on June 12 with 0.3 L ha^{-1} LONTREL 300 (300 g L^{-1} Clopyralid).

Maize (FAO 460) was sown on May 6, 2020, at recommended planting density to achieve a stand of 65 000 plants per hectare at harvest. The preceding crop was soybean. Harvest was conducted at technological maturity (October 30, 2020) from an area of 10 m^2, leaving out maize plant at the edge of the area. No irrigation was applied. From each treatment 1 maize grain sample was collected, 18 in total. For biological yield ten plants were selected from each treatment, bundled and weighed. Data for both yields was converted to t/ha, prior to calculating HI.

Grain analyses were conducted at Križevci College of Agriculture (Agrochemical laboratory and Laboratory for testing the quality of agricultural reproduction material). Grain samples were weighted and dried at 105 °C until constant weight to determine moisture content. Hectolitre mass was conducted using Schopper scale (0,25 L). A 1000-seed weight was determined with Contador Seed Counter (Pfeuffer Gmbh, Germany). The maize yield, hectoliter weight and 1000-seed weight for each plot were calculated at 14% grain moisture. The amount of total nitrogen was determined by the Kjeldahl method, while the concentration of

Table 1. Tillage operations and equipment used in the experiment during 2020

Operation	Equipment	Treatment		
		CT	MT	RT
Subsoiling	Mandan MGW 5 3000; working depth 35-40 cm; working width 300 cm	-	-	18 December 2019
Ploughing	Kuhn Varimaster 151; working depth 18-20 cm; working width 150 cm	18 December 2019	-	-
Disc harrowing	OLT 36 Drava; working depth 10-14 cm; working width 395 cm	23 April 2020	-	-
Multitiller	Dexwal Grunt; working depth 10-15 cm; working width 300 cm	-	20 April 2020	20 April 2020
Seedbed preparation	Maschio ASI 2; working depth 1-4 cm; working width 185 cm	5 May 2020	5 May 2020	5 May 2020

Note: CT – conventional tillage – ploughing in autumn and disking and harrowing in early spring; MT – Minimum tillage – multitiller in spring; RT – Reduced tillage – subsoiling in autumn and multitiller in spring

Table 2. Percipitation, air temperature and rainn factor (Rfm) for 2020 in comparison to referent period (1983-2012)

Months	Precipitation (mm)		Temperature (°C)		Rfm		Climate classification	
	1983-2012	2020	1983-2012	2020	1983-2012	2020	1983-2012	2020
May	67.5	76.2	16.6	15.4	4.1	4.9	Sa	Sa
June	95.1	106.8	19.7	19.4	4.8	5.5	Sa	Sh
July	71.8	118	21.7	21.2	3.3	5.6	A	Sh
August	89.1	107.5	21.1	22.3	4.2	4.8	Sa	Sa
September	92.9	111.7	16.4	16.9	5.7	6.6	Sh	Sh
October	78.8	195.7	11.2	11.6	7	16.8	H	Ph

Note: A - arid (Rfm 1.7 – 3.3); Sa - semiarid (Rfm 3.4 – 5.0); Sh - semihumid (Rfm 5.1 – 6.6); H - humid (Rfm 6.7 – 13.3); Ph- perhumid (Rfm > 13.3)

total protein content was calculated from total nitrogen multiplied by a factor of 6.25. Harvest index (HI) was calculated according to Beadle (1987) ((HI = grain yield/biological yield) × 100, %).

All collected data were analyzed with analysis of variance (ANOVA). When significant F-tests were observed, the mean separation was obtained using a Fisher's LSD test at the $P < 0.05$ probability level.

Results and Discussion

The long-term average of the mean monthly temperature during vegetation period (May-October) was 17.8 °C, while precipitation in the region was 495 mm (Table 2). Values of the mean monthly air temperatures in 2020, were similar in comparison to the long-term average, with ideal distribution during the vegetation period (Pucarić et al., 1997). According to Pospišil (2010), needed precipitation for stable yield during vegetation period is 400 mm. During 2020, the precipitation was 30% above the long-term average. Especially intense precipitation was in July and October (40% and 60% above the long-term average). The impact of this phenomenon was reflected in the yield and quality of maize.

The variances of the productivity averaged for the investigated period, revealed the statistical significance of the independent and combined interaction of the cover and soil tillage factors (Table 3). The interaction of factors (C x T) significantly affected all yield parameters while the use of cover only significantly affected grain yield and contrary tillage did not significantly affect only hectoliter mass.

Table 3. Results of ANOVA analysis for crop yield and yield components of maize

	Yield	1000-kernel weight	Harvest index	Protein	Hectoliter mass
Tillage (T)	*	*	*	*	n.s.
Cover (C)	*	n.s.	n.s.	n.s.	n.s.
T × C	*	*	*	*	*

Note: * - $P < 0.05$; n. s. – nonsignificant

According to Svečnjak et al. (2004), 1000-seed weight is the most stable yield component, with little or no effect from abiotic factors. It is also important to note that more extended maturity groups (>FAO 400) tend to produce heavier 1000-seed weight. Tillage practices significantly affected 1000-seed weight (CT (394.88 g)>RT (388.37 g)>MT (362.83 g)), while the use of cover did not affect significantly (Bare (382.53 g); Covered (381.49 g)). The significantly highest value was observed on straw covered plots with RT treatment, followed by CT (Table 4). Both of those treatments have autumn tillage which conserves more water. These results agree with those by Asenso et al. (2018). Moreover, deeper autumn ploughing followed by multi-tiller use in spring achieved the highest result on Stagnic Luvisol in arid conditions (Kvaternjak et al., 2015). Similar to our results, deeper tillage (22-25 cm) had significantly higher 1000-seed weight than shallow tillage (10 cm) (Romaneckas et al., 2020). Finally, under humid conditions, Jug et al. (2007) recommend conventional tillage for maize. Our study results showed only relative differences between straw covered and bare plots. According to Khurshid et al. (2006) application of straw significantly affected 1000 kernel weight only when it was applied with 4 or more tons per hectare. De and Bandyopadhyay (2013) found no significant difference between mulched and un-mulched treatments. Also, Noor et al. (2021) did not report significant differences with an application of 5 t ha^{-1} of wheat straw. However, in arid conditions, straw mulching increased kernel weight (Noor et al., 2021; Wang et al., 2011).

Hectoliter mass is considered the most important physical feature for grain quality assessment, storage, transport and milling (Bódi and Pepó, 2007). Tillage (CT (82.84 kg/hl)>MT (81.81 kg hL^{-1})>RT (81.32 kg hL^{-1})) and cover (Bare (80.66 kg hL^{-1}); Covered (80.66 kg hL^{-1})) as single factor did not impact significantly, but the interaction of tillage x cover significantly impacted the hectoliter mass. The interaction of factors probably resulted in forming favorable agroclimatic conditions during grain-filling period. The highest hectoliter mass was recorded on covered plots with CT followed by RT (Table 4). Similar values were obtained by Kvaternjak et al. (2015) during the second year of their experiment. Deep soil loosening and tillage do not provide significant differences in hectoliter mass, as stated by Cociu and Alionte (2011). Also, Kisić et al. (2002) found significantly higher hectoliter mass in ploughing treatments in comparison with no-tillage. On chernozem, Jug et al. (2007) reported significantly lower hectoliter mass with shallow tillage when compared with deep tillage.

Commonly, the harvest index (HI) represents the plant capacity to allocate biomass (assimilates) into the formed reproductive parts of the plant (Wnuk et al., 2013), and it is greatly influenced by soil tillage (Ion et al., 2015). HI was significantly influenced by tillage x cover interaction. On covered plot RT have the highest HI, while CT on the bare plot have the lowest HI (Table 4). Deeper tilled plots (RT) showed higher value of HI, which was contrary to Wasaya et al. (2017) but similar to Asenso et al. (2018) probably due to higher grain and biological yield. Although the cover's single effect was not significant on harvest index, the straw (28.31%) had the greatest effect compared to the bare plot (27.39%). Tillage had significant differences on HI (RT (29.68%)>MT (26.94%)>CT (26.90%)), which is in line with findings from Moriaque et al. (2019).

The protein content is deficient in maize, and typically its variability ranges from 8 to 11% (Watson et al., 1987). Interestingly, according to Dudley and Lambert (1992), grain yield and protein concentration have an inverse relationship. Their significant ($P < 0.001$) negative correlation (r = - 0.885) is reported in Cociu and Alionte (2012), and thoroughly explained in Mason and D'croz-Mason (2002). The mean maximum value of protein was observed on RT plots with cover, while the minimum was noted on CT plots with cover (Table 4). In our experiment, subsoiling significantly (RT (8.34%)>CT (7.47%) >MT (7.42%)) provided the best results regarding protein content. The use of cover (Bare 7.77%; Covered 7.61%) as a single factor did not have a significant effect. Benefits from the combination of deeper tillage and straw mulch on protein content are in line with Zamir et al. (2013). It is possibly because deep tillage broke the compacted layer, allowing better nitrogen and water uptake from deeper soil layers (Kessel and Hartley, 2000). On the other hand, literature provides conflicting results, Špoljar et al. (2009, 2010) and De Vita et al. (2007) recommend conventional tillage while Houx et al. (2016) and Sessiz et al. (2010) find no significant effect from tillage systems. Furthermore, according to Cociu and Alionte (2012), conservation tillage significantly lowers protein content.

Yield is an essential factor in agriculture production. Tillage, cover, and T x C interactions significantly affect maize grain yield. Bare plots (12.6 t ha^{-1}) note a higher yield than straw plots (10.9 t ha^{-1}) (Fig. 1). RT yield 13.3 t/ha while MT and CT achieves lower yields by 24% and 13 % (Fig. 1). Tillage × cover interaction (Fig. 2) reveals the negative impact of straw on MT and RT treatments, resulting in 23% and 9% lower yields than bare plots probably, caused by intense precipitation during the vegetation period

Table 4. Values of yield components of maize

Tillage	1000-kernel (g)		Hectolitar mass (kg hl^{-1})		Harvest index (%)		Protein (%)		N (%)	
	Bare	Straw	Bare	Straw	Bare	Straw	Bare	Straw	Bare	Straw
CT	394.39 aA	395.28 aA	82.34 aA	83.34 aA	25.58 bA	28.26 aB	7.60 aA	7.33aA	1.21	1.17
MT	365.07 bA	360.59 bA	79.21 aB	84.2 aA	27.08 bA	26.80 aA	7.54 aA	6.98 aA	1.20	1.12
RT	388.14 aA	388.60 aA	80.43 aA	82.19 aA	29.51 aA	29.85 aA	8.17 aA	8.52bA	1.31	1.36

Different letters represent significant differences at a $P < 0.05$ between tillage (lowercase-column) and cover (uppercase-rows) treatments; CT – conventional tillage – ploughing in autumn and disking and harrowing in early spring; MT – Minimum tillage – multitiller in spring; RT – Reduced tillage – subsoiling in autumn and multitiller in spring

(Alvarez and Steinbach, 2009). The effect of subsoiling caused better soil physical condition (e.g., Bogunović et al., 2018b), and mineralization of nutrients and root growth (Chalise et al., 2020), which reflected on a higher yield. When comparing different tillage systems in similar environments of Croatia, the following systems produce less maize: reduced tillage produces 20-25% (Kisić et al., 2002; 2010), disk harrowing 13 %, no-tillage 36 % (Jug et al., 2006), avoiding autumn ploughing 30 % (Kvaternjak et al., 2015) when compared with conventional plough tillage. With the use of straw, intense rainfall causes significant differences, which is contrary to Shan et al. (2018), as an effect of mulching takes longer to manifest significantly on grain yield. Accordingly, covered plots note lower yields, but if tilled deeper, satisfactory yield is attained.

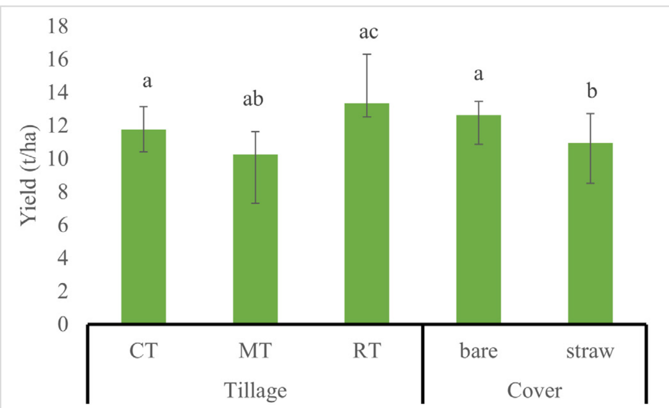

Figure 1. Effect of single factor tillage and cover on grain yield (t ha^{-1})
Note: Different letters represent significant differences at a $P < 0.05$

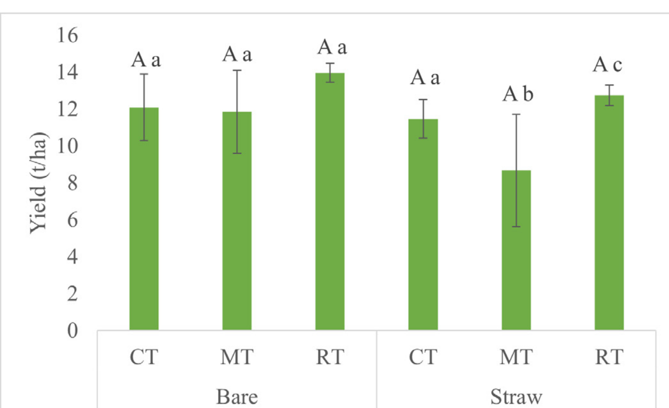

Figure 2. Effect of factor interaction (cover and tillage) on yield (t ha^{-1})
Note: Different letters represent significant differences at a $P < 0.05$ between tillage (lowercase) and cover (uppercase) treatments

Conclusion

This experiment was established to estimate the short-term effects of tillage and straw at Experiment Station Šašinovec on maize yield and yield components. Reduced tillage method with subsoiling achieved higher yields when compared to conventional tillage. Also, as expected, tillage had a significant effect on most of the maize yield components. The use of straw under extensive rainfall did not provide higher yields nor significantly affect most other yield components. For this experiment, we can conclude that non-inverted deeper tillage contributes to higher yields and soil potential by disrupting "plough pan" caused by intensive traditional tillage. There is a viable need to modify our tillage methods, so establishing long-term experiment for further observation is needed. Forming specific tillage systems for agriculture production in temperate climates provides new insights for farmers to experiment with new ideas at the local level, to increase tillage diversity, usage and quantity of straw (mulch) and most importantly to contribute to the sustainability of the local agroecological system.

References

Alvarez R., Steinbach H. S. (2009). A Review of the Effects of Tillage Systems on Some Soil Physical Properties, Water Content, Nitrate Availability and Crops Yield in the Argentine Pampas. Soil Tillage Res. 104: 1-15. doi: 10.1016/j.still.2009.02.005

Asenso E., Li J., Hu L., Issaka F., Tian K., Zhang L., Zhang L., Chen H. (2018). Tillage Effects on Soil Biochemical Properties and Maize Grown in Latosolic Red Soil of Southern China. Appl Environ Soil Sci. 1: 1-10. doi: 10.1155/2018/8426736

Beadle C. L. (1987). Plant Growth Analysis. In: Techniques in Bioproductivity and Photosynthesis. 2nd ed. J. (Coombs J., Hall D.O., Long S.P., Sacrlock J.M.O., eds), Pregamon Press, Oxford: New York, USA, pp. 21-23

Berhe F. T., Fanta A., Alamirew T., Melesse A. M. (2013). The Effect of Tillage Practices on Grain Yield and Water Use Efficiency. Catena 100: 128-138. doi: 10.1016/j.catena.2012.08.001

Birkás M., Szemők A., Antos G., Neményi M. (2008). Environmentally-Sound Adaptable Tillage. Akadémiai Kiadó, Budapest, Hungary, pp. 50-80

Bódi Z., Pepó P. (2007). Determining Factors of Test Weight in Maize (*Zea mays* L.). Acta Agrar Debr. 27: 40-42. doi: 10.34101/actaagrar/27/3099

Bogunović I., Kisić I., Mesić M., Zgorelec Ž., Šestak I., Perčin A., Bilandžija D. (2018a). Održive mjere gospodarenja tlom u ekološkoj poljoprivredi za klimatske uvjete mediteranske Hrvatske. University of Zagreb, Faculty of Agriculture, Zagreb, Croatia, pp. 31-47

Bogunović I., Pereira P., Kisic I., Sajko K., Sraka M. (2018b). Tillage Management Impacts on Soil Compaction, Erosion and Crop Yield in Stagnosols (Croatia). Catena 160: 376-384

Butorac A. (1999). Opća Agronomija. Školska knjiga, Zagreb, Croatia, pp. 157-250

Ceglar A., Croitoru A. E., Cuxart J., Djurdjevic V., Güttler I., Ivančan-Picek B., Jug D., Lakatos M., Weidinger T. (2018). PannEx: the Pannonian Basin Experiment. Clim Serv. 11: 78-85. doi: 10.1016/j.cliser.2018.05.002

Chalise D., Kumar L., Sharma R., Kristiansen P. (2020). Assessing the Impacts of Tillage and Mulch on Soil Erosion and Corn Yield. Agronomy 10 (1): 63. doi:10.3390/agronomy10010063

Cociu A. I., Alionte E. (2011). Yield and Some Quality Traits of Winter Wheat, Maize and Soybean, Grown in Different Tillage and Deep Loosening Systems Aimed to Soil Conservation. Rom Agric Res. 28 (1): 109-120

Croatian Bureau of Statistics. (2018). Statistical Yearbook of the Republic of Croatia. Zagreb, Croatia. Available at: https://www.dzs.hr/Hrv_Eng/ljetopis/2018/sljh2018.pdf [Accessed: 20 08. 2020].

De B., Bandyopadhyay S. (2013). Influence of Soil Conservation Techniques on Growth and Yield of Maize (*Zea mays* L.) in Terai Region of West Bengal. SAARC J Agric. 11 (1): 133-147 doi: 10.3329/sja.v11i1.18390

De Vita P., Di Paolo E., Fecondo G., Di Fonzo N., Pisante M. (2007). No-Tillage and Conventional Tillage Effects on Durum Wheat Yield, Grain Quality and Soil Moisture Content in Southern Italy. Soil Till Res. 92 (1-2): 69-78. doi: 10.1016/j.still.2006.01.012

Dihma R. V., Vasilakoglou I. B., Gatsis Th. D., Panou-Philotheou E., Eleftherohorinus I. G. (2009). Effects of Aromatics Plants Incorporated as Green Manure on Weed and Maize Development. Field Crops Res. 110 (3): 235-241. doi: 10.1016/j.fcr.2008.09.005

Dudley J. W., Lambert R. J. (1992). Ninety Generations of Selection for Oil and Protein in Maize. Maydica 37: 81-89

European Union (2000). Special Report 14/2000 on Greening the CAP together with the Commission's Replies. Official Journal C353/2000. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32000Y1208%2801%29 [Accessed: 21 05. 2020].

Friedrich T., Derpsch R., Kassam A. (2012). Overview of the Global Spread of Conservation Agriculture. Available at: http://factsreports.revues.org/1941 [Accessed: 14 10. 2020].

Gračanin M. (1950). Mjesečni kišni faktori i njihovo značenje u pedološkim istraživanjima. Agric Conspec Sci. 12: 51-67

He J., Li H., Rabi G. R., Wang Q., Cai G., Su Y., Qiao X., Liu L. (2011). Soil properties and Crop Yields after 11 Years of No Tillage Farming in Wheat–Maize Cropping System in the North China Plain. Soil Till Res. 113: 48-54. doi: 10.1016/j.still.2011.01.005

Husnjak S., Romić M., Poljak M., Pernar N. (2011). Recommendations for Soil Management in Croatia. Agric Conspec Sci. 76 (1): 1-8

Husnjak S. (2014). Sistematika tala Hrvatske. Hrvatska sveučilišna naknada, Zagreb, Croatia, pp. 241-250

Houx III J. H., Wiebold W. J., Fritschi F. B. (2016). Long Term Tillage Treatment Effects on Corn Grain Nutrient Composition and Yield. Field Crops Res. 191: 33-40. doi: 10.1016/j.fcr.2016.04.002

Ion V., Dicu G., Dumbravă M., Temocico G., Alecu I.N., Băşa A.G., State D. (2015). Harvest Index at Maize in Different Growing Conditions. Rom Biotechnol Lett 20 (6): 10951-10960

IUSS Working Group WRB (2015). World Reference Base for Soil Resources 2014, update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps. World Soil Resources Reports Nr. 106. FAO, Rome, Italy.

Jug D., Stipešević B., Jug I., Stošić M., Kopas G. (2006). Prinos kukuruza (*Zea mays* L.) na različitim varijantama obrade tla. Poljoprivreda 12 (2): 5-10

Jug D., Stipešević B., Jug I., Samota D., Vukadinović V. (2007). Influence of Different Soil Tillage Systems on Yield of Maize. Cereal Res Commun. 35 (2): 557-560. doi: 10.1556/CRC.35.2007.2.98

Jug D., Birkás M., Kisić I. (2015). Obrada tla u agroekološkim okvirima. HDPOT, Osijek, Croatia, pp. 56-84

Jug D., Jug I., Brozović B., Vukadinović V., Stipešević B., Đurđević B. (2018). The Role of Conservation Agriculture in Mitigation and Adaptation to Climate Change. Poljoprivreda 24 (1): 35-44. doi:10.18047/poljo.24.1.5

van Kessel C., Hartley C. (2000). Agricultural Management of Grain Legumes: Has It Led to an Increase in Nitrogen Fixation? Field Crops Res. 65 (2-3): 165-181. doi: 10.1016/S0378-4290(99)00085-4

Khurshid K., Iqbal M., Arif M. S., Nawaz A. (2006). Effect of Tillage and Mulch on Soil Physical Properties and Growth of Maize. Int J Agric Biol. 8 (5): 593-596

Kisić I., Bašić F., Birkas M., Jurišić A., Bićanić V. (2010). Crop Yield and Plant Density under Different Tillage Systems. Agric Conspec Sci. 75 (1): 1-7

Kisić I., Bašić F., Mesić M., Butorac A., Sabolic M. (2002). Influence of Different Tillage Methods on Yield of Maize on Stagnic Luvisols of Central Croatia. Agric Conspec Sci. 67 (2): 81-88

Kvaternjak I., Kisić I., Birkás M., Špoljar A., Marenčić D. (2015). Yields and Yield Components of Maize (*Zea Mays* L.) and Soybean (Glycine Max) as Affected by Different Tillage Methods. Ekológia (Bratislava) 34 (4): 371-379. doi:10.1515/eko-2015-0033

Lampurlanés J., Angás P., Cantero-Martí nez C. (2001). Root Growth, Soil Water Content and Yield of Barley under Different Tillage Systems on Two Soils in Semiarid Conditions. Field Crops Res. 69: 27-40. doi: 10.1016/S0378-4290(00)00130-1

Li Y., Li Z., Cui S., Jagadamma S., Zhang Q. (2019). Residue Retention and Minimum Tillage Improve Physical Environment of the Soil in Croplands: A Global Meta-Analysis. Soil Till Res. 194: 104292. doi: 10.1016/j.still.2019.06.009

Madarász B., Juhos K., Ruszkiczay-Rüdiger Z., Benke S., Jakab G., Szalai Z. (2016). Conservation Tillage vs. Conventional Tillage: Long-Term Effects on Yields in Continental, Sub-Humid Central Europe, Hungary. Int J Agric Sustain. 14 (4): 408-427. doi: 10.1080/14735903.2016.1150022

Mason S. C., D'croz-Mason N. E. (2002). Agronomic Practices Influence Maize Grain Quality. J Crop Prod. 5 (1-2): 75-91. doi: 10.1300/J144v05n01_04

Mihalić V., Butorac A. (1969). Utjecaj različite dubine oranja i različitih količina mineralnih gnojiva na prinos kukuruza. Agronomski glasnik 10/12: 663-674

Moriaque A. T., Felix K. A., Anastase A. H., Pascal H., Moncef B., Naivo R., Lionel M. (2019). Effect of Tillage and Mulching on Agronomics Performances of Maize and Soil Chemical Properties in Linsinlin Watershed of Centre of Benin. Afr J Agric Res. 14 (31): 1421-1431. doi: 10.5897/AJAR2019.13952

Neudert L., Smutný V. (2018). The Impact of Various Soil Tillage Methods on Soil Physical Properties in Grain Maize Stands. Agric Conspec Sci. 83 (1): 99-104

Noor M. A., Nawaz M. M., Ma W., Zhao M. (2021). Wheat Straw Mulch Improves Summer Maize Productivity and Soil Properties. Ital J Agron. 16: 1623. doi: 10.4081/ija.2020.1623

Nyakatawa E. Z., Reddy K. C., Mays D. A. (2000). Tillage, Cover Cropping, and Poultry Litter Effects on Cotton: II. Growth and Yield Parameters. Agron J. 92 (5): 1000-1007. doi: 10.2134/agronj2000.9251000x

Olesen J. E., Trnka M., Kersebaum K. C., Skjelvag O. A., Seguin B., Peltonen-Sainio P., Rossi F., Kozyra J., Micale F. (2011). Impact and Adaptation of European Crop Production Systems to Climate Change. Eur J Agron. 34 (2): 96-112. doi: 10.1016/j.eja.2010.11.003.

Pospišil A. (2010). Ratarstvo I. dio. Zrinski, Čakovec, Croatia, pp. 85-115

Pucarić A., Ostojić Z., Čuljat M. (1997). Proizvodnja kukuruza. Hrvatski zadružni savez, Zagreb, Croatia, pp. 52-63

Romaneckas K., Avizienyte D., Adamaviciene A., Buragiene S., Kriauciuniene Z., Sarauskis E. (2020). The Impact of Five Long-Term Contrasting Tillage Systems on Maize Productivity Parameters. Agric Food Sci. 29 (1): 6-17. doi: 10.23986/afsci.83737

Servadio P., Bergonzoli S., Toderi M. (2014). Soil Mapping to Assess Workability in Central Italy as Climate Change Adaptation Technique. Glob Nest Journal 16: 229-239 doi: 10.30955/gnj.001299

Sessiz A., Alp A., Gursoy S. (2010). Conservation and Conventional Tillage Methods on Selected Soil Physical Properties and Corn (*Zea mays* L.) Yield and Quality under Cropping System in Turkey. Bulg J Agric Sci. 16 (5): 597-608

Shan Y. H., Johnson-Beebout S. E., Buresh R. J. (2008). Crop Residue Management for Lowland Rice-Based Cropping Systems in Asia. Adv Agron. 98: 117-199. doi: 10.1016/S0065-2113(08)00203-4

Svečnjak Z., Varga B., Pospišil A., Jukić Ž., Leto J. (2004). Maize Hybrid Performance as Affected by Production Systems in Croatia. Bodenkultur 55: 37-44

Špoljar A., Kisić I., Birkas M., Kvaternjak I., Marenčić D., Orehovački V. (2009). Influence of Tillage upon Soil Properties, Yield and Protein Content in Maize and Soybean Grain. J Environ Prot Ecol. 10 (4): 1013-1031

Špoljar A., Kvaternjak I., Kisić I., Marenčić D., Orehovački V. (2010). Utjecaj obrade na tlo, prinose, sadržaj ukupnih masti i bjelančevina u zrnu kukuruza. Agronomski glasnik 72 (2-3): 91-110

Van den Putte A., Govers G., Diels J., Gillijns K., Demuzere M. (2010). Assessing the Effect of Soil Tillage on Crop Growth. A Meta-Regression Analysis on European Crop Yields under Conservation Agriculture. Eur J Agron. 33 (3): 231-241. doi: 10.1016/j.eja.2010.05.008

Wang X., Dai K., Zhang D., Zhang X., Wang Y., Zhao Q., Cai D., Hoogmoed W. B., Oenema O. (2011). Dryland Maize Yields and Water Use Efficiency in Response to tTllage/Crop Stubble and Nutrient Management Practices in China. Field Crops Res. 120 (1): 47-57. doi: 10.1016/j.fcr.2010.08.010

Wang X., Fan J., Xing Y., Xu G., Wang H., Deng J., Wang Y., Zhang F., Li P., Li Z. (2019). The Effects of Mulch and Nitrogen Fertilizer on the Soil Environment of Crop Plants. Adv Agron. 153: 121-173. doi: 10.1016/bs.agron.2018.08.003

Wasaya A., Tahir M., Ali H., Hussain M., Yasir T. A., Sher A., Ijaz M. (2017). Influence of Varying Tillage Systems and Nitrogen Application on Crop Allometry, Chlorophyll Contents, Biomass Production and Net Returns of Maize (*Zea mays* L.). Soil Till Res. 170: 18-26. doi: 10.1016/j.still.2017.02.006

Watson S. A., Ramstad P. E. (1987). Corn: Chemistry and Technology. American Association of Cereal Chemists, St. Paul: Montana, USA, pp. 350-405

Wnuk A., Górny A.G., Bocianowski J., Kozak M. (2013). Visualizing Harvest Index in Crops. CBCS 8 (2): 48-59

Zamir M. S. I., Javeed H. M. R., Ahmed W., Ahmed A. U. H., Sarwar N., Shehzad M., Sarwar M. A., Iqbal S. (2013). Effect of Tillage and Organic Mulches on Growth, Yield and Quality of Autumn Planted Maize (*Zea mays* L.) and Soil Physical Properties. Cercet Agron Mold 46 (2): 17-26. doi: 10.2478/v10298-012-0080-z

Zaninović K., Gajić-Čapka M., Perčec Tadić M., Vučetić M., Milković J., Bajić A., Cindrić K., Cvitan L., Katušin Z., Kaučić D., Likso T., Lončar E., Lončar Ž., Mihajlović D., Pandžić K., Patarčić M., Srnec L., Vučetić V. (2008). Climate Atlas of Croatia 1961-1990., 1971-2000. Croatian Meteorological and Hydrological Service, Zagreb, Croatia. pp. 50-80

Zrakić M., Hadelan L., Prišenk J., Levak V., Grgić I. (2017). Tendencije proizvodnje kukuruza u svijetu, Hrvatskoj i Sloveniji. Glasnik zaštite bilja 40 (6): 78-85

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