Influence of Different Soil Tillage Systems on Potato Yield, Fuel Consumption and Working Time

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Summary

The paper presents the results of a two-year trial with two different tillage systems in potato cultivation in Croatia. The tillage systems compared were the conventional system (ploughing, disc harrowing, and seedbed preparation) and the conservation system (including tillage with chisel plough and rototiller). The aim of this study was to determine the effects of tillage systems on the yield of four different potato cultivars (Arizona, Masai, Prada and Red Lady) as well as the fuel and working time required for tillage. Both trial potato growing seasons were characterized by drought and high temperatures, which led to significantly lower yields compared to the Croatian average. In these unfavourable conditions, the application of the conservation tillage system resulted in significantly higher potato yields in both experimental seasons ($P < 0.05$), except for the cultivar Masai in 2021, with an average yield increase of 4.57% in 2021 and 6.42% in 2022 compared to the conventional system. The use of a chisel plough instead of a mouldboard plough in primary tillage contributed to fuel savings of 16.36% in 2021 and 22.33% in 2022. The conservation tillage system required around 30% less working time in comparison to conventional tillage system. These results indicate the advantages of the conservation tillage system, both in energy requirement and in the working time, with higher yields in both researched years.

Key words

conservation tillage, potato, yield, fuel consumption, working time

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Introduction

The potato (*Solanum tuberosum* L.), one of the most important cultivated plants in the world, is grown in 140 countries between 65°N and 50°S with altitudes varying from sea level to 4.000 m, indicating the plant's tolerance to a wide range of environmental conditions (Birch et al., 2012). Soil preparation is crucial in potato production because potato has a fine, branched root system that will be damaged in compacted soils (Barakat et al., 2020). Proper soil preparation ensures that the soil is loose and friable so that the potato roots can easily penetrate the soil and absorb nutrients and water. A compacted or hard soil can restrict root development, which can lead to stunted growth and lower yields. Tillage is the main component of soil preparation, which must ensure good soil conditions for successful potato growth. Although there isn't a set tillage method for potato crops, most potato growers believe that deep plowing is essential before seedbed preparation and ridging in order to guarantee a sufficient amount of loose-structured soil, which is necessary for the best possible tuber production and quality. But in order to control crop residues, provide a good seedbed, and improve the physical characteristics of the soil for germination and crop production, conventional tillage technologies are thought to be required (Drakopoulos et al., 2016). Although there is no set tillage method for potato crops, most potato growers believe that deep plowing prior to seedbed preparation and ridging is essential to ensure a sufficient amount of loose soil, which is necessary for the best possible tuber production and quality. But in order to control crop residues, provide a good seedbed, and improve the physical characteristics of the soil for germination and crop production, conventional tillage technologies are thought to be required. (Ivany et al., 2007).

However, conventional tillage practices, particularly plowing, can adversely affect the environment and soil health because of significant changes in soil structure and function (Mancinelli et al., 2020). Reducing soil disturbance through alternative tillage practices such as subsoiling and spading could offer a solution, improving soil moisture retention, promoting biological activity, and reducing GHG emissions (Kraut-Cohen et al., 2020).

In arable crop cultivation, soil tillage is a significant consumer of energy and labor, necessitating the evaluation of suitable tillage methods based on their energy efficiency and environmental pollution mitigation (Jug et al., 2015). According to Ahmad et al. (2023), the conventional tillage systems cosume more than 50% of fuel for arable farming. Lowering the intensity of tillage lowers fuel consumption, raises the energy ratio, manages soil erosion, and cuts down on the time and effort needed to prepare the seedbed (Tabatabaeefar et al., 2009). Due to excessive soil disturbance, potato production is recognized as a primary source of soil erosion and the deterioration of soil water quality (Rees et al., 2011) and the use of conservation tillage in potatoes for system sustainability is the general trend (Djaman et al., 2022). The main goals of conservation tillage are to lower production costs, preserve soil moisture, and shield soils from erosion and compaction (Holland, 2004). Systems for conservation tillage have a lot of promise to lower costs and energy input (Ozgoz et al., 2017). Application of conservation tillage in potato crop rotations aims to reduce energy consumption, prevent soil structure degradation, improve soil biological properties, and protect soil from erosion (Kisić et al., 2017).

This experiment aims to investigate the possibility of applying conservation tillage in potato production and its comparison with conventional tillage, as well as the impact on energy consumption and potato yield in the area of Bjelovar-Bilogora County.

Materials and methods

The trial was conducted in the 2021 and 2022 potato growing seasons on the experimental field in Bjelovar-Bilogora County in northwestern Croatia (45° 65' N, 17° 08' E, 129 m a.s.l.) on Stagnosol (IUSS 2022). Soil texture throughout the profile is a homogeneous sandy loam (Table 1). According to the basic chemical properties, this soil is moderately acidic with pH 6.21 (measured in M KCl), well supplied with phosphorus and potassium (determined using the AL method), and slightly weaker with nitrogen (determined using the Micro-Kjeldahl method). With an organic matter content of 1.4% (determined using the Bichromath-Tjurin method), it belongs to the group of slightly humic soils.

The experimental field of 1.62 ha was divided into two equal parts dimensions 450 x 18 m with different soil tillage practices, conventional and conservation tillage. Each of these two parts was then divided into four plots dimension 220 x 8 m with a distance of 1 m between plots on which different potato cultivars were planted. The trial started with the same working circumstances for both tillage systems in terms of soil moisture content, soil compaction, and post-harvest residues.

The conservation tillage system included ploughing with a three-furrow plough, two passes of disc harrow with 28 discs, and two passes of combined implement for final soil preparation. The conservation tillage system included primary tillage with a chisel plough with 11 shovels and secondary tillage with a rototiller with a built-in packer roller. A four-wheel drive tractor with a weight of 4.300 kg and an engine output of 78 kW was used for all tillage work. The implements had following working width: mouldboard plough - 105 cm, disc harrow - 250 cm, combined implement - 360 cm, chiesel plough - 200 cm and rototiller - 300 cm.

Due to extremely poor weather conditions and excess soil moisture during November and December 2020 and 2021, primary and secondary tillage in both experimental years 2021 and 2022 were carried out at the end of February. Before potato planting, fertilization was carried out on the whole experimental field with mineral fertilizers. Potato planting in both experimental years was carried out in early March with two-row automatic planters and four different potato cultivars (Arizona, Masai, Prada and Red Lady) were planted. Potato planting was carried out earlier because this allows the plants to take advantage of more favorable humidity conditions and avoid the summer heat that slows down development, which is a consequence of changed climate conditions. Before potato emergence weed protection was carried out. During the growing season, potatoes were fed twice with foliar fertilizers. The most important pest of potatoes is certainly the potato beetle (Leptinotarsa decemlineata), which is favored by warm weather, so two treatments were needed, and no difference was observed regarding the attack of the potato blight about the soil tillage system.

Table 1. Soil texture of Stagnosol evaluated on experimental plots

Depth (cm)	Particle size distribution (%)				Texture class
	Coarse sand (2-0.2 mm)	Fine sand (0.2-0.02mm)	Silt (0.02-0.002mm)	Clay (< 0.002 mm)	
0 – 22	1.8 ± 0.47	58.6 ± 3.7	24.2 ± 3.5	15.4 ± 2.5	Sandy loam
22 – 39	2.1 ± 0.55	57.1 ± 5.9	26.0 ± 5.4	14.8 ± 4.4	Sandy loam
39 – 90	0.5 ± 0.23	54.5 ± 6.9	25.4 ± 3.2	19.6 ± 4.0	Sandy loam

Note: data expressed as average of all treatments, four replications ± standard deviation

Since there were several potato cultivars, including early cultivars, the harvesting started already in July and was completed at the beginning of September 2021. The harvesting was carried out with a single-row pulled combine harvester.

The weather conditions in Veliki Zdenci during the experimental years 2021 and 2022 and their comparison with 30-year averages (1991.-2020.) are shown in Figs. 2 & 3. The both potato growing seasons are characterized by unfavorable precipitation distribution and low temperatures in potato germination time (Fig. 2), drought and extremely high temperatures in months that condition the growth of potatoes (Fig. 3).

Fuel consumption was determined for each tillage system and implement using the volumetric method. This method, also known as the tank filling method, is a simple and commonly used approach to determine fuel consumption. It involves refilling the fuel tank to its original full level after each tillage operation and measuring the volume of fuel added. The energy need was determined using a net heating value of 42 MJ kg^{-1} (35.07 MJ L^{-1}) of diesel fuel according to ASTM D240 standard test method (ASTM International, 1997), which had a specific density of 0.835 kg dm^{-3}. Weighing the potato tubers from each harvested patch allowed us to calculate the yields.

SAS software was used to conduct the statistical analysis (SAS, 2000). The effects of the treatments on the yield, energy requirement, and working time were assessed using analysis of variance (ANOVA). At the 0.05 level, means were differentiated using the least significant differences method (LSD).

Results and discussion

The average yields of four potato cultivars are presented in Fig. 1. The yields of potato achieved at both tillage systems are very low, but they are mostly due to the negative impact of drought and extremely high temperatures, especially in June and July (Fig. 2). The average yield of all potato cultivars (both years) and tillage systems (10 t·ha^{-1}) was 44.13% lower than average potato yield in Croatia in 2020 year, which was 17.9 t·ha^{-1} (Central Bureau of Statistics, 2021). The application of the conservation tillage system resulted in significantly higher potato yields in both experimental seasons ($P < 0.05$), except for the cultivar Masai in 2021, with an average yield increase of 4.57% in 2021 and 6.42% in 2022 compared to the conventional system. At that, the largest increase in potato yield of 7.69% was determined in the Arizona cultivar in the experimental year 2022.

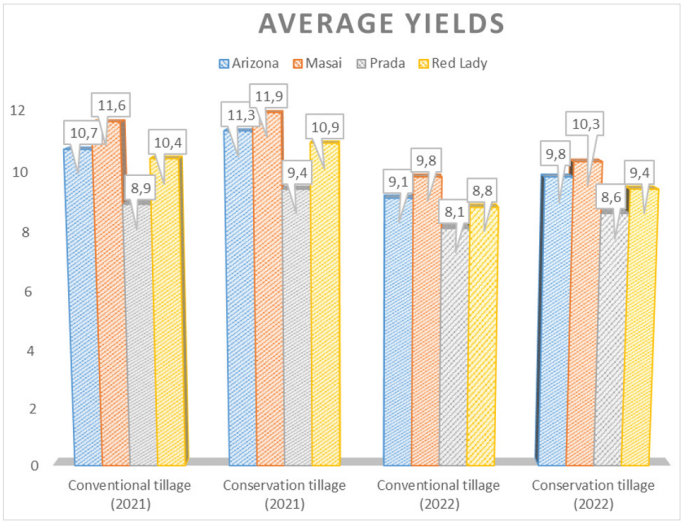

Figure 1. Average yields of different potato cultivars (t ha^{-1})

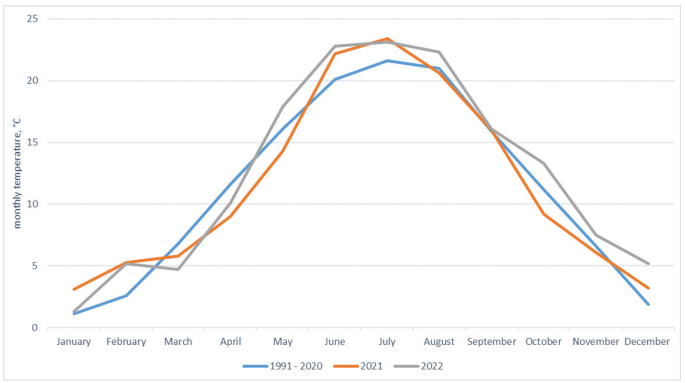

Figure 2. Monthly temperatures in Veliki Zdenci during period 1991.-2020. and experimental year 2021, 2022

Different tillage methods are frequently used to compare yields, and the majority of authors claim that conventional tillage produces a larger yield than other tillage systems (conservation, reduced, and no-till). Al-Hamed et al. (2016) observed a 12.87% higher potato yield during ploughing operation with a mouldboard plough than the tillage operation with a chisel plough. Ati et al. (2015) also reported significantly higher potato yield (5%) at tillage with a mouldboard plough than the tillage operation with a chisel plough. They noted that a significant difference between tillage treatment with mouldboard plough and chisel plough is

due to the process tillage generally leads to breaking compaction layer and then increasing the exploitation of plants to the water, as well as improved soil physical properties. Ivany et al. (2007) reported that a 7.5% higher potato yield was achieved with a conventional tillage system consisting of mouldboard ploughing and disc harrowing in comparison to spring zone tillage using a chisel plough which had coulters mounted in front of the chisel to cut the sod. According to Barakat et al. (2020), Because it creates the right conditions for root growth and nutrient absorption, which benefits shoot growth, and because it increases leaf area, which eventually produces large amounts of carbohydrates that are stored in potato tubers, moldboard plough treatment produced the highest productivity of potato tubers when compared to other tillage techniques.

According to Carter et al. (2005), there was no discernible treatment effect on the overall potato yield when comparing the effects of conventional autumn moldboard plowing followed by spring secondary tillage, spring moldboard plowing followed by secondary tillage, autumn chisel plowing followed by spring secondary tillage, and spring conservation tillage. This suggests that conservation tillage can preserve potato productivity and quality while also having the added advantage of being less expensive than conventional autumn moldboard plowing.

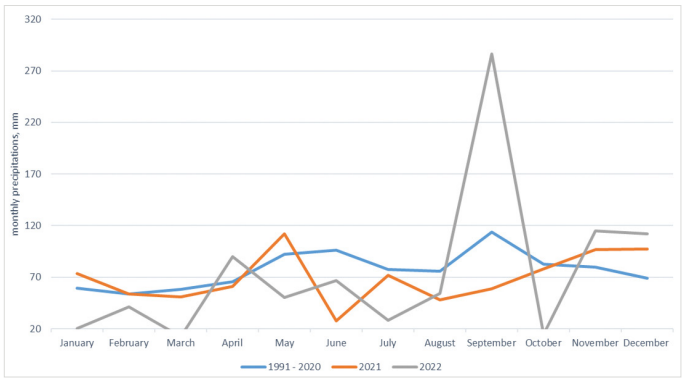

Figure 3. Monthly precipitations in Veliki Zdenci during period 1991-2020 and experimental year 2021, 2022

However, some authors reported that higher potato yields were achieved using non-conventional tillage systems. Mohammadi and Shamabadi (2012) reported significant (5%) potato yield differences among tillage methods and the maximum yield per hectare was related to spring chisel ploughing. Crop yield difference among potato cultivars wasn't significant. Ozgoz et al. (2017) also observed higher potato yield with chisel ploughing than with mouldboard ploughing of two potato cultivars. When Drakopoulos et al. (2016) compared reduced tillage to conventional tillage, they discovered that the average tuber size was smaller, which resulted in a 13.4% loss in tuber production. Stošić et al. (2021) also note that conventional tillage systems lead to higher fuel consumption and, as a result, increased greenhouse gas (GHG) emissions when compared to non-ploughing tillage systems. Heidari et al. (2022) conducted a meta-analysis of the effect of conservation tillage on potato yield and and concluded that conservation tillage method with chisel ploughing compared to conventional tillage method with moldboard ploughing caused a slight increase in potato yield.

The average fuel consumption, energy requirement, and working time of two different soil tillage systems are shown in Table 2. Conventional tillage systems involve inverting the entire soil profile with a mouldboard plough, followed by seedbed preparation with two passes of disc harrow and combination harrow. This tillage system is effective at burying harvesting residues and creating a fine seedbed, but intensive cultivation with many tractors passes result with high energy requirement. The total amount of fuel consumed for soil preparation for potato planting of the conventional tillage system was 55.56 $L \cdot ha^{-1}$ or 1948.49 $MJ \cdot ha^{-1}$ in 2021, and 65.52 $L \cdot ha^{-1}$ or 2298.14 $MJ \cdot ha^{-1}$ in 2022. Applying a conservation tillage system reduces the intensity of tillage and the number of tillage operations, and thus the number of trips of tractor with tillage machines over the field, which enables significant savings in fuel, labour and machine costs (Lithourgidis et al., 2009).

The use of a chisel plough instead of a mouldboard plough in primary tillage contributed to fuel savings of 16.36% in year 2021 and 22.33% in year 2022. The chisel plough is less energy-intensive than mouldboard plough because they do not invert the soil profile while the mouldboard plough inverts soil by cutting and moving soil perpendicular to the tillage direction (Ottl et al., 2022). Ati et al. (2015) also reported significantly higher fuel consumption of 29% of mouldboard plough in comparison to chisel plough with an explanation that the mouldboard plough for cut and inversion soil over needs more energy compared with chisel plough this is swallowtail without turn the soil. Ozgoz et al. (2017) also reported that conventional tillage system with mouldboard plough requires significantly more energy than conservation tillage system with chisel plough.

For the final soil preparation for potato planting with the conventional tillage system, two passes with the disc harrow and two passes with the combined tool were required, while with the conservation tillage system only one pass with the rototiller was needed, which achieved additional fuel savings so that the conservation system required 25.25% less fuel in comparison to the conventional system. When compared to conventional systems, the use of reduced tillage and sowing techniques can reduce costs by 5 to 50%, with lower fuel usage being the primary driver of this reduction (Sarauskis et al., 2012). According to Cooper et al. (2020), conservation tillage yielded net profit margins 13% higher than conventional ploughing after five years of practice due to a combination of operational efficiency savings and improved yields.

The data of the working time presented in Table 2 showed that the conventional tillage system is also a higher time consumer, and the greatest part of working time was consumed by ploughing. The conservation tillage system required around 30% less working time in comparison to conventional tillage system. Although the mouldboard plough as a primary tool of conventional tillage has some advantages, it is considered as slow and costly due to its perceived inherent high draught force incurred by the way it is used (Ucgul and Saunders, 2020). Additionally, Sarauskis et al. (2012) noted that the use of traditional tillage and sowing technologies consumes the most working time. Applying reduced tillage techniques can save 0.4 to 1.3 hours of labor per hectare when compared to traditional systems.

Table 2. The average energy and time requirement of two different soil tillage systems

Year	Tillage system	Fuel consumption ($L \cdot ha^{-1}$)	Energy requirement ($MJ \cdot ha^{-1}$)	Work rate ($ha \cdot h^{-1}$)	Working time ($ha \cdot h^{-1}$)
		Conventional tillage			
2021	Plough	24.69	865.88	0.81	1.23
2022		27.59	967.58	0.69	1.44
2021	Disc harrow 2x	18.52	649.50	1.08	0.93
2022		20.69	725.60	0.87	1.15
2021	Comb. harrow 2x	12.35	433.11	1.61	0.62
2022		17.24	604.96	1.16	0.86
2021	Total	55.56[a]	1948.49[a]	-	2.78[a]
2022		65.52[a]	2298.14[a]	-	3.45[a]
		Conservation tillage			
2021	Chisel plough	20.65	724.20	1.39	0.72
2022		21.43	751.55	0.93	1.07
2021	Rototiller	23.71	831.51	0.88	1.13
2022		25.01	877.10	0.76	1.31
2021	Total	44.36[b]	1555.71[b]	-	1.85[b]
2022		46.44[b]	1628.65[b]	-	2.38[b]

Note: b - significantly different at $P < 0.01$

It is particularly crucial when there are relatively limited working hours for certain technological processes in the plant cultivation technological chain. In this study 0.93-1.07 $h \cdot ha^{-1}$ was saved with conservation tillage system depending on the year. Ozgoz et al. (2017) also reported that conventional tillage system with mouldboard plough requires significantly more human labour than conservation tillage system with chisel plough.

The climate, soil characteristics, plant species, fleet of tillage equipment, and other elements all have a significant role in choosing the right tillage strategy (Sarauskis et al., 2012). The advantages of using conservation tillage vary depending on the site, including cropping patterns, local climate, soil properties, and other aspects of the entire farming operation (Anikwe and Ubochi, 2007). Voltr et al. (2021) highlighted that conservation and reduced tillage systems are effective practices to control soil erosion and conserve water, contributes to the C sequestration and reduce monetary and energy costs. Similarly, Larkin et al. (2021) emphasized that incorporation of soil and crop management practices that promote soil health, such as crop rotations, cover crops and green manures, organic amendments, and conservation tillage, into improved cropping systems may help maintain and/or improve soil health and enhance productivity, sustainability, economic vitality, and environmental quality. This experiment with different soil tillage systems showed possibility of energy and working time-saving in potato production in the Bjelovar-Bilogora County. The conservation tillage system achieved a significantly higher yield of all tested potato cultivars than the conventional tillage system, and due to significantly lower energy and working time requirements could be of economic importance due to production costs reduction.

Conclusions

The results of this experiment indicate some advantages of the conservation tillage system in potato cultivation, especially under challenging climatic conditions. The application of the conservation tillage system led to a significant increase ($P < 0.05$) in potato yields for all cultivars, except for the cultivar Masai in 2021, showing an average yield increase of about 500 $kg \cdot ha^{-1}$ compared to the conventional tillage system. This indicates that the conservation tillage system is better suited to mitigate the negative effects of adverse weather conditions in potato production. Moreover, the conservation tillage system has shown additional benefits with a remarkable 20-30% reduction in fuel consumption, but also in terms of operational efficiency with around 30% reduction in working hours. The reduction in fuel consumption and working time could help farmers in this region to decrease production costs in potato production.

CRediT authorship contribution statement

Dubravko Filipović: Conceived the project and supervised the work, analyzed the data and drafted the manuscript. **Dalibor Jurina:** Investigation, performed most of the experiments. **Ivica Kisić:** Conceptualization, Investigation. **Mateja Grubor:** contributed to writing and the editing of the manuscript, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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