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LONG-TERM TILLAGE AND NITROGEN FERTILIZATION FOR SOYBEAN ON GLEY SOIL

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ABSTRACT

During three years (2007, 2008 and 2009), multidisciplinary stationary research of reduced soil tillage and nitrogen fertilization was conducted for soybean [*Glycine max* (L.) Merr.], on Gley soil type of Croatian Baranya region. Research was carried out with four soil tillage treatments and three nitrogen fertilization level, set up as split-plot design in four repetitions. Tillage treatments (TT) were: CT- conventional tillage (autumn plowing 30 cm), DT- multiple disk-harrowing (autumn disk-harrowing 10-12 cm), LT- chiselling and disk-harrowing (autumn soil loosening 30 cm), NT- no-tillage. Nitrogen fertilization treatment (NF) for soybean was NF-1 = 35, NF-2 = 70, NF-3 = 110 kg N/ha. Weather conditions during the study were adverse with considerable aberrations, respectively significantly different from long-term mean. Thus, 2007 was extremely dry, 2008 was moderately humid and 2009 dry. Significant differences of soil water content (SWC) were identified in all years of research: NT had higher SWC in 2007 and 2008, while DT had hogher SWC in 2009 compared to CT. The yield was negatively statistically significant correlated with bulk density (BD), i.e. with increase of compaction yield decreased. Significant differences among years were recorded regarding soybean grain yield, whereas soil tillage systems showed following decreasing order, on average: CT (2.59 t/ha) > LT (2.46 t/ha) > NT (2.46 t/ha) > DT (2.41 t/ha). Nitrogen fertilization on average did not influence soybean yield. On average, compared to CT, only DT had significantly lower soybean grain yield. The study showed a very successful application of reduced soil tillage systems in soybean production with the optimal nitrogen fertilization.

Keywords: *Glycine max* (L.) Merr., tillage systems, nitrogen, soil type, climate change.

INTRODUCTION

Plant production in the world, as well as in Croatia, will face changes in temperature, concentration of CO_2 and precipitation in the next 30-years (Muñoz et al., 2011; Hatfield et al., 2011; Vistoso et al., 2012), and adaptation to new climate conditions will be a challenge to farmers. In the future period (2011-2040), Croatian farmers will confront with the increase of average temperatures in winter for 0.6°C and in summer for 1.0°C (Branković et al., 2012). According to the report of MEPPPC (2010), in Croatia total precipitation will decrease in spring, summer and autumn (cca 45 mm in season), while only in winter there will be a slight precipitation increase. Kirtman et al. (2013) emphasized the fact that, for the near-term period 2016-2035, the predicted anomaly is 0.47°C to 1.00°C (range 5-95%) at the global level. One of the possible ways to overcome the future negative climatic conditions is Conservation Agriculture (CA), whose principles are widely adopted and there are opportunities for further collaboration, synergy and complementarities (Giller et al., 2015). It is undoubted that the CA concept is a "basket" of agricultural practices (Giller et al., 2009) that result in soil and water conservation and furthermore can be used for combating desertification, increasing biodiversity and reducing the impact of climate change (Tittonell et al., 2012; FAO, 2018). Soybean is an important crop in crop rotations, but its importance is reflected in ability of symbiosis with nitrogen-fixing bacteria, *Bradyrhizobium japonicum,* through which it can improve soil physical and biological properties (Cheţan et al., 2016). Soybean production is based on conventional tillage (CT) with ploughing as the main intervention into the soil, disk-harrowing, seedbed preparation and sowing. Such

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production system, is expensive if compared to CA (Sharma et al., 2011), energetically more demanding (Barut et al., 2011; Moreno Lucas et al., 2011), and ecologically questionable (Busari et al., 2015). In Croatia 25-35% of overall agricultural area is degraded by human related factors (Kisić et al., 2004). The production system should aim at high yields with sustainable use of resources and stop the soil degradation as the interaction of the soil, human, climate relief and vegetation (Ravi et al., 2010). Reduced tillage systems, such as disking, soil loosening or ultimately no-till have advantages in economic, ecological and organizational aspects (Derpsch et al., 2010; Barut et al., 2011; Delate et al., 2012; Llewellyn et al. 2012; Souza et al., 2013.). The conventional tillage systems obtained higher yields (Căpăţână and Ciocian, 2016; Cociu, 2019) than reduced systems, whilst anthropogenic soil degradation and impoverishment occurs consequently (Keller et al., 2013.). Changes in soil physical properties, such as bulk density, soil compaction, hydraulic conductivity, compacted soil layers are amongst those that are under significant impact of soil tillage (Cholaky et al., 2008; Jabro et al, 2009; Sharma et al., 2011; Savci 2012; Ungureanu et al 2015). This work includes research results for soybean in conventional soil tillage systems (CT) and reduced soil tillage systems, considering negative climate projections that will occur in future.

MATERIAL AND METHODS

Site description

A multidisciplinary field trial was managed at Darda, Baranya region, in north-eastern Croatia (45°37′N and 18°42′E, 83 m elevation). The experiment was carried out over 3-year period (2007, 2008 and 2009) with soybean, as a stationary two-factorial experiment using a split plot design in four replications. The main factor was soil tillage (TT) consisting of 4 variants, while the subfactor was N fertilization (NF) divided in 3 levels. Basic tillage plot size was 585 m^2, whereas basic N plot size was 165 m^2. The soil pit was determined according to FAO IUSS Working Group WRB (2006) and Gley soil type was determined. Soil properties were defined according to procedures and standards, as follows: $pH_{(H2O)}$ = 5.61; $pH_{(KCl)}$ = 4.52 (ISO 10390); 86 mg/kg P_2O_5 and 242 mg/kg K_2O (Egner - Riehm - Domingo, 1960) and 2.2% humus (ISO 14235).

Experimental methods

Soybean [*Glycine max* (L.) Merr.] cultivar Podravka 95 was sown at a rate of 120 kg/ha on 10^{th}, 26^{th}, and 9^{th} April 2007, 2008 and 2009 respectively. Conventional tillage was applied prior to the start of the trial. Potassium and phosphorus fertilization as well as the plant protection from weeds, pests and diseases were uniform for all investigated tillage and fertilization variants. Applied tillage treatments (TT) were: 1) Conventional tillage (CT) based on autumn ploughing (30 cm); 2) Autumn disk-harrowing (2 x 10-12 cm) (DT); 3) Autumn soil loosening (30 cm) with chisel (LT); 4) No-tillage (NT). Seedbed preparation consisted of disk-harrowing and seedbed preparation for all systems, except for No-tillage. Nitrogen fertilization (NF) was subfactor and consisted of three rates: 1) 35, 2) 70 and 3) 110 kg N/ha. NF 30 was done during seedbed preparation, while NF 70 and 110 through other two side dressings.

Soil sampling and analysis

Some parameters were determined: soybean plant number at flowering (counted in 4 frames with dimension 0.25 m^2, at growing stage V4 by Feekes), thousand kernel weight, hectolitre mass, grain yield in kg/ha (measured on Schrran portable wheel scale, calculated on 9% grain moisture content). Each year during the harvest, four passes of the harvester were done to determine the crop grain yields. Afterwards, seeds were cleaned and weighed and the obtained values were corrected to a 9% grain moisture content. Metal cylinders were used for soil sampling for gravimetrical determination of soil bulk density (BD) 2009, from three different soil layers (0-10, 10-20 and 20-30 cm) (ISO 11272). Undisturbed soil samples were taken in 3 repetitions (3 cylinders per layer) on each tillage plot. Bulk density samples were taken to determine soil water content 2007, 2008 and 2009 in April before sowing. Soil water content (SWC) data are presented in mm by multiplying the water content by soil depth and corresponding bulk density. Effect of different soil tillage treatments (TT) and nitrogen fertilization (NF) on soybean yield components was examined by ANOVA. Statistical analysis was performed by SAS 9.3 software package (SAS Institute Inc., NC, USA) and Microsoft Office Excel 2016.

Results

Rainfall patern and soil water content

Weather conditions during the investigated years (Table 1) were unfavourable in terms of temperature and rainfall regime (Figure 1).

Table 1. Climatic conditions (IV-X), Darda, 2007 to 2009 and long-term mean (1965-1995)

Rainfall, mm								
	Apr	May	Jun	Jul	Aug	Sep	Oct	
2007	0	45	42	27	61	45	82	**302**
2008	53	55	73	73	39	67	34	**394**
2009	13	44	118	17	35	12	50	**289**
1965-1995	51	59	89	68	56	55	51	**429**
Temperature, °C								
2007	13.8	18.5	22.9	24.0	23.0	14.8	10.6	**18.2**
2008	12.7	18.4	21.9	22.2	22.4	15.8	13.0	**18.1**
2009	14.7	18.9	19.7	23.2	22.9	19.1	11.3	**18.6**
1965-1995	11.1	16.5	19.7	21.2	20.9	16.4	11.3	**16.7**

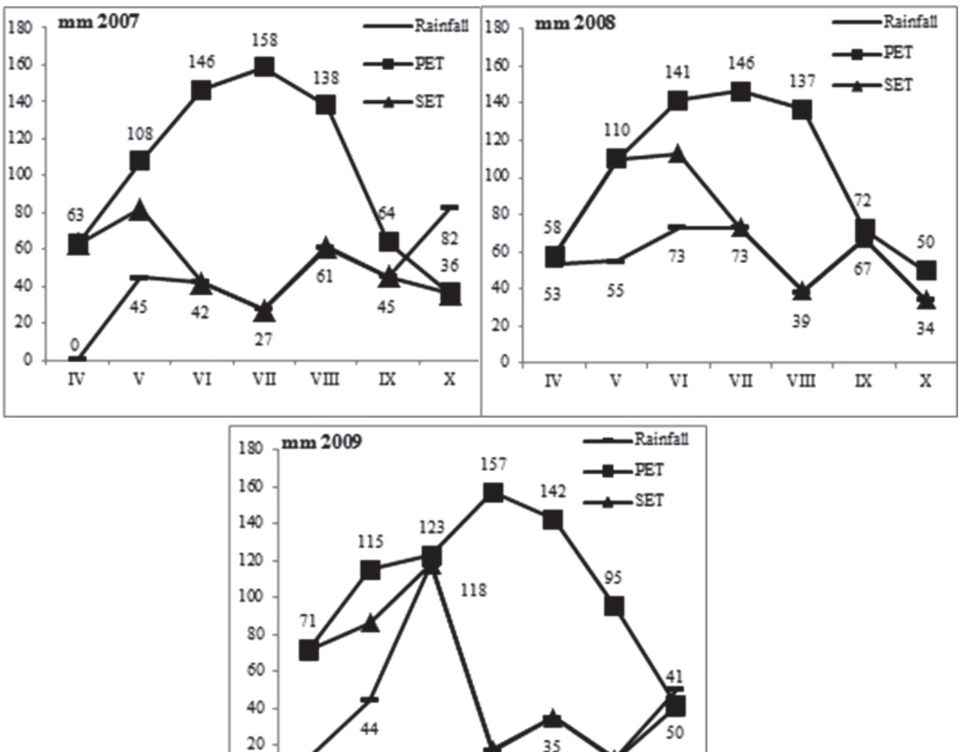

Figure 1. Weather conditions between April and October, 2007 to 2009, Darda
(Rainfall - mm; PET - potential corrected evapotranspiration; SET - real evapotranspiration)

Weather conditions of 2007, 2008 and 2009 were significantly different compared to long-term mean 1965-1995, having a strong impact on soybean yield components and grain yield. The first year of research was extremely dry, second was favourable, respectively moderately humid and third was dry.

During vegetation (April - October) 2007, 302 mm of rainfall were registered, i.e. less for 127 mm compared to 30 years average. Also, in 2008 394 mm were recorded, respectively lack of 35 mm, as well as 2009 when deficit was 140 mm as compared with 30 years mean. The low level of rainfall during July, in all three years, had negative effect on soybean productivity, because soybean was in reproductive period (phases R3 - R5). Average temperatures during the season (April - October) were higher in 2007 by 2.0 to 3.2°C than long-term mean. In 2008 temperatures were higher by 1.0 to 2.2°C, except September. In season 2009 temperatures were much higher, by 2.0 to 3.6°C, except June and September which were equal with 30 years average. Significant differences of SWC were identified in all three years (Figure 2).

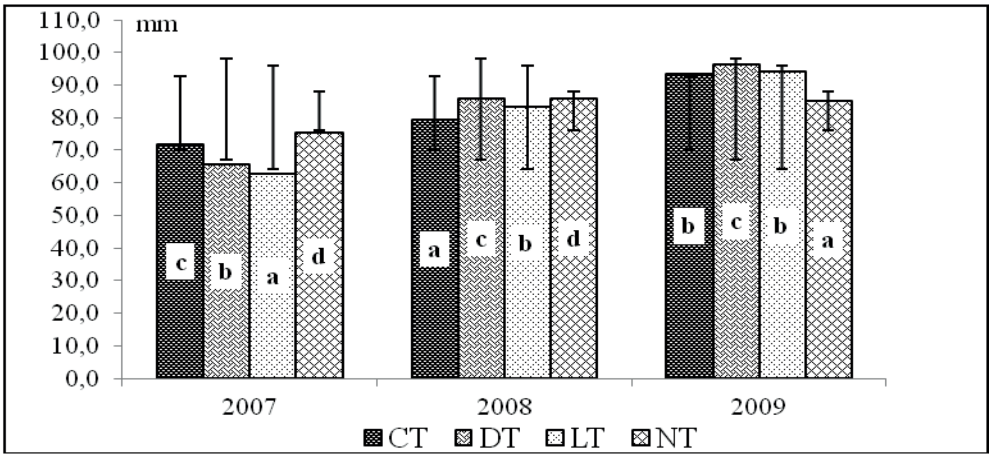

Figure 2. Impact of different soil tillages on soil water content (mm) at 0-40 cm depth between 2007 to 2009 (hanging bars represent the standard deviation; *values marked with the same letter are not different at 0.05 confidence level)

TT significantly influenced SWC in every year of investigation. The highest SWC in 2007 and 2008 was recorded on NT, while in 2009 it was DT. Compared to CT, all TT had significant lower or higher SWC in all years of investigation.

Soybean plant density at growing stage V4 by Feekes

In 2007 plant density was lower by 16% and in 2009 by 48% whilst only in 2008 optimal plant density was achieved (60 plants/m^2). Differences for number of plants between years were very significant (F = 252.25**; VC = 18.68%). No statistical differences were recorded on reduced tillage systems in comparison to CT during of 2007 (51 plants/m^2) and 2008 (CT = 60 plants/m^2). In 2009, significantly lower density was recorded only at NT (27 plants/m^2) in comparison to CT (34 plants/m^2). The impact of NF rates on plant density was absent in all investigated years.

Soybean thousand seeds weight

ANOVA for this parameter showed that the year had very significant influence (F = 708.91**, VC = 7.52%) and also the different TT (F = 4.98**), whilst influence of NF was absent. In 2007 significantly higher mass was achieved by NT (100.7 g) compared to CT (85.0 g), whilst in 2008 significantly lower mass was recorded on DT (130.5 g) and NT (128.2 g) in comparison to CT (136.8 g).

Differences in thousand seeds weight per TT in 2009 were non significant. Regarding to NF effect, in 2009 significantly higher mass was achieved by NF 110 (118.4 g) in comparison to NF 35 (114.3 g), whilst in other investigated years differences were non significant.

Soybean hectolitre mass

The differences between years were very significant (F = 84.52**; VC = 1.43%), while the influence of TT (F = 2.07) and NF (F = 0.60) was absent. In 2007 the impact of TT and NF on hectolitre mass was missing. In 2008 DT (71.4 kg) and NT (71.4 kg) resulted with significantly higher hectolitre mass compared to CT (71.0 kg), whilst impact of NF was absent. Regarding to the TT and NF effect in 2009 differences were non significant.

Soybean grain yield

On average, the highest influence on soybean grain yields had the weather conditions (F = 821.91**; VC = 14.67%), then TT (F = 2.51**; VC = 13.70%) whilst NF impact was absent (Figure 3; Table 2). The highest average grain yield was registered in moderately humid 2008 (3.60 t/ha), lower was in dry 2009 (2.41 t/ha) and the lowest in extremely dry 2007 (1.47 t/ha). The differences amongst investigated years were significant. Regarding TT influence, ANOVA and F-test showed very significant effect in 2008 (F = 2.64*; VC = 5.51%) and 2009 (F = 3.61*; VC = 6.54%).

Compared to CT (3.78 t/ha), significantly lower yield was recorded only at NT (-410 kg/ha) in 2008, whilst in 2009 (CT = 2.53 t/ha) significantly lower yield was obtained at DT (-290 kg/ha).

Concerning the effect of NF (Table 2), in all investigated years the impact of NF on grain yield was absent, which is confirmed by F-test for this indicator (2007 F = 0.89; 2008 F = 1.42; 2009 F = 0.31).

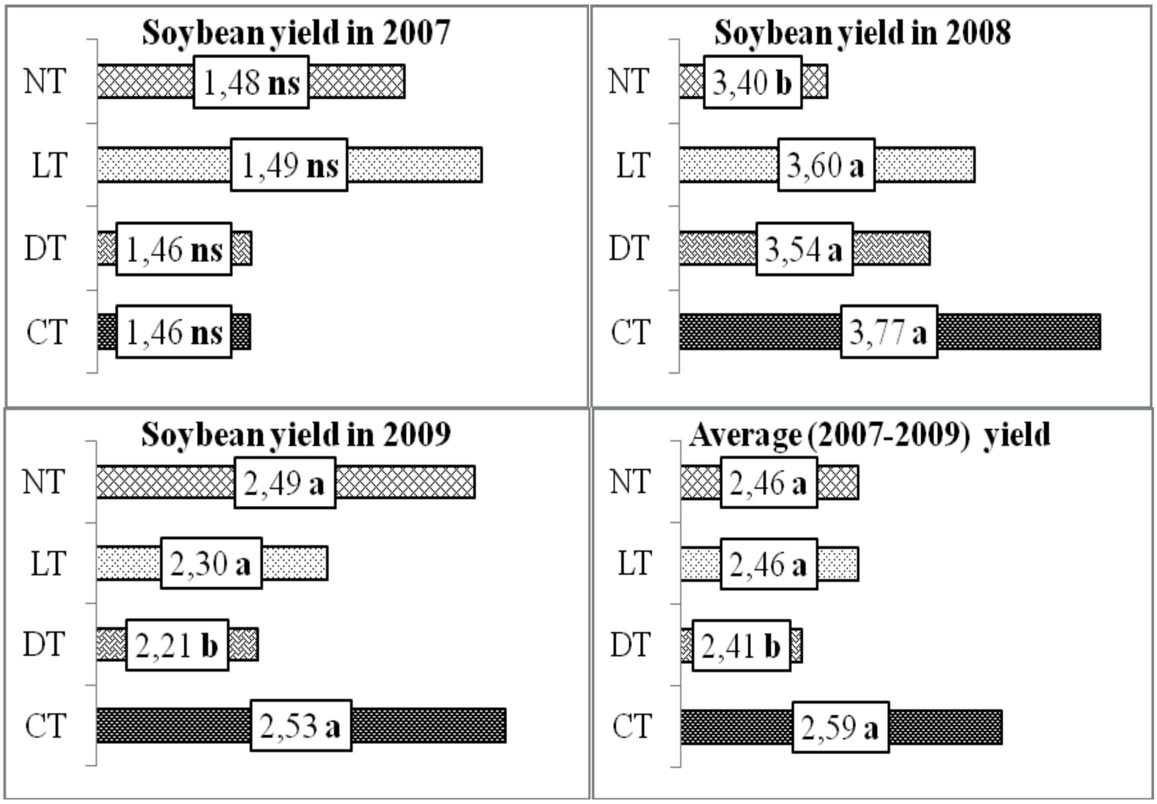

Figure 3. Soybean grain yield (t/ha) on different TT during the investigation from 2007 to 2009, at Darda (CT = ploughing; DT = disk-harrowing; LT = chiselling + disk-harrowing; NT = No-tillage; *values marked with the same letter are not different at 0.05 confidence level)

Table 2. Soybean grain yield (t/ha) on different NF levels during the investigation from 2007 to 2009, at Darda site (NF 1 = 35 kg N/ha, NF 2 = 70 kg N/ha, NF 3 = 110 kg N/ha)

Nitrogen fertilization (NF)		Year (Y)			Mean (NF)
		2007	2008	2009	2006-2009
1.	NF_{35}	1.45	3.66	2.41	2.51
2.	NF_{70}	1.50	3.57	2.42	2.50
3.	NF_{110}	1.45	3.57	2.43	2.51
Mean (Y)		1.47**A**	3.60**C**	2.41**B**	2.49
$LSD_{(NF)}$	0.05	ns	ns	ns	ns
$LSD_{(Y)}$	0.05	0.10			

*values marked with same letter are are not different at 0.05 confidence level.

Correlation between bulk density (BD) and average soybean yield

The results from our study showed a highly negative correlation between BD and soybean yield, backed up by the correlation coefficient r = -0.891 (Figure 4). The regression equation and correlation coefficient showed an inverse correlation between soybean yield and BD, i.e. with the increase of BD grain yield decreased.

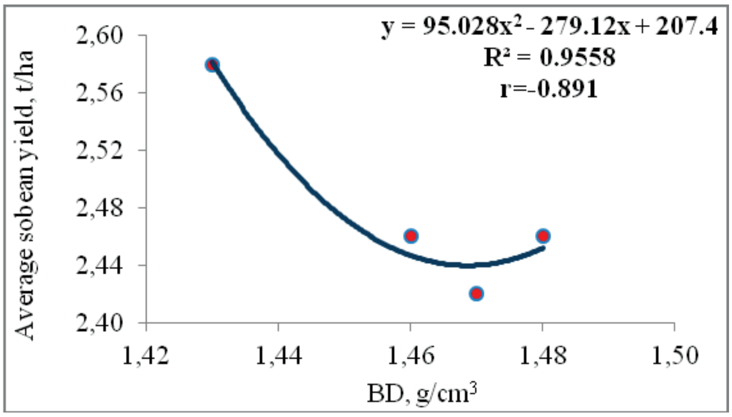

Figure 4. Correlation between BD (g/cm^3) and average soybean yield (t/ha)

RESULTS AND DISCUSSION

There is tremendous literature and researches, which indicate strong impact of weather/climatic conditions on agricultural production (Kovačević et al., 2013; Smith et al., 2014; Jug et al., 2018). Climate extremes, such as temperature changes, water deficit or water excess, heat waves, increased UV-B radiation, etc. detect sensitiveness of agroecosystems and its relation to climate change (IPCC, 2014). Soil water content (SWC) was strongly influenced by TT in all years. NT retained more water than other TT in 2007 and 2008, whilst in 2009 it was DT, which retained more water. Similar results were reported by Alvarez and Steinbach (2009) in dry conditions. Bogunović et al. (2018) stated that NT had higher SWC than CT, due to higher infiltration and diminished evaporation because of crop residues (Stelli et al., 2018). Bogunović and Kisić (2014) noticed that NT stored more SWC in 0-40 layer than other tillage systems.

The impact of TT on number of plants, on 3-year average, was not significant, only in 2009 NT had significantly lower number than CT. Similar results were obtained by Gawęda et al. (2014) who recorded higher soybean plant density under ploughing in comparison to direct seeding, whilst Lanca Rodrígues et al. (2009) noted that there were no significant differences between TT for this indicator. Our results showed that extremely dry conditions that dominated in 2009 (April - 6 rainy days; lack of cca 35 mm rainfall) strongly influenced the number of plants, although Martínez et al. (2011) stated that soils under minimum tillage had increased water content, and increased available water for plants, due to increased storage pores (0.5 to 50 μm). Similar conclusions were highlighted by Birkas et al. (2004), which underline the fact that minimized soil interference enhance soil quality, which can reduce impact of climatic extremes on soil and plant. Impact of TT on thousand seeds weight was detected in the weather conditions of 2007 (mean 86.6 g) and 2009 (mean 116.4 g), which drastically affected the values. On 3-year average LT (107.3 g) had significantly lower values than CT (112.8 g). This indicator proved sensibility to tillage, which is in contrast with the findings of Gawęda et al., (2014) and Căpăţână and Ciocan (2016) who noted no significant differences between tillage systems. On the other hand Lanca Rodrígues et al. (2009) reported significantly lower thousand seeds on chiselling, but not on NT, in comparison to CT. We found positive significant correlation between thousands seeds weight and yield (r = 0.4958; n = 32). Results for hectolitre mass observed in this study were of the same order of magnitude like those reported by Topa et al. (2013), but at odds with the findings of Jug et al. (2010). Only in moderately humid 2008 significantly higher hectolitre mass was achieved on DT (71.4 kg) and NT (71.4 kg) compared to CT (71.0 kg), whilst in dry years 2007 and 2009 impact was absent. Tuzzin de Moares et al. (2017) emphasized the importance of correlation between the increase of soybean yield and increase of yield components, such as thousands seeds weight and hectolitre mass. This is important especially in dry periods or years, respectively in water deficit periods (Kobraei et al., 2011). In our study we determined negative significant correlation between hectolitre mass and yield (r = -0.5848; n = 32) and highly negative significant correlation between plant density and hectolitre mass (r = -0.9015; n = 32). Also, crop reaction is directly affected by soil physical factors, such as soil water and aeration, temperature and mechanical resistance, bulk density, etc. (Letey, 1985). Regarding the impact of TT on soybean yields, it is evident that only TT with higher tillage reduction gave significantly lower yields. The reason is probably drought stress and increased air temperatures in April - October period, which is confirmed by Cociu (2019), as CT can store higher amount of rainfall than reduced tillage. Popović et al. (2016) observed highly negative correlation between soybean yield and air temperatures. Also, according to Husnjak et al., (2002) favourable soil physical properties are very important for achieving high grain yields, especially bulk density and total porosity (Lozano et al., 2016). They stated that bulk density and total porosity significantly affected crop yield, respecting a strong reciprocal dependence between crop yield and bulk density, while amongst total porosity and crop yield there was a strong direct dependence. In our study on 3-year average, only DT (-180 kg/ha) had significantly lower yield in comparison to CT (2590 kg/ha), as well as in very dry 2009. In extremely dry 2007 yields were very low without significant differences between TT, whilst in moderately humid year, yield at NT (-370 kg/ha) was significantly lower compared to CT (3770 kg/ha). Results for this parameter were similar to those of Gawęda et al. (2014) who stated that differences between TT were small and inconsistent. Cociu (2019) pointed that yields under CT and NT were insignificantly higher. Similar results were obtained by Pedersen and Lauer (2003) who noted that tillage did not affect yield, but they recorded significant year effects for all tillage systems. Dorneles et al. (2015) pointed out that soybean yields are higher on CT than NT, probably because of physical or chemical limitation which compensate the positive effect of NT. This is contrast with the findings of DeFelice et al. (2006). Concerning NF, the results showed the weakest impact of NF on investigated parameters. Only the third year of investigation (2009) a significantly higher thousand kernel weight was recorded on NF_{110} (118.4 g) compared to NF_{35} (114.3 g). Number of plants, hectolitre mass and soybean yield did not react to NF fertilization. Soybean nitrogen fertilization is complex because of symbiotic nitrogen fixation. According to Harper (1974), 25-60% N in dry matter comes from symbiotic fixation and rest from soil. Also, soybean has two peaks when N is essential: (i) during seedling, (ii) during pod fill as a period of N consumption peak. High demands for N occur during R3 to R6 stage, which comes from N-fixation. In this study different N rates did not affect yield components and grain yield of soybean.

CONCLUSIONS

The results of 3-year study on Gley soil showed that DT achieved significantly lower average soybean yield compared to CT. Ssignificant differences were determined in SWC in all 3-year period and in all TT. We found out highly negative correlation between BD and soybean yield. Undeniably, TT with ploughing showed some advantages, but the carried research offered some other solutions for soybean production, emphasing that some TT can be more or less risky depending on climatic conditions.

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