Soil Compaction under Different Tillage System on Stagnic Luvisols

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Summary

Soil compaction issue is a growing limiting factor for agricultural production. Progress in technology and agriculture, launched a long-term trend of soil destruction as a result of compaction. The experiment placed on Stagnic Luvisols will try to provide an assessment of the impact of tillage system on soil compaction. The aim of this study was to determine the optimal tillage system due to the compaction of individual horizons. For that reason field experiment with six soil tillage systems was set up in Central Croatia. Tillage systems differed in tools that were used, depth and direction of tillage. During 2012 information of soil resistance, bulk density and soil porosity was collected. Statistical data evaluation showed significant differences in bulk density and porosity in most of the soil layers between all tillage systems. Bulk density values at all depths of all tillage systems varied in ranges of 1.47-1.69 g cm^{-3}. Soil porosity showed significant difference between all tillage systems in surface and deepest soil layer. Values ranged between 38.18 and 47.19%. Soil resistance showed significant differences in most of the soil layers between all tillage systems. There were no significant differences in soil resistance between soil layers during dry (August) and wet (December) periods in layers up to 30 cm. It can be concluded that different tillage practice significantly affected soil resistance in most of the soil layers during the year, except in periods of the highest precipitation surplus and deficit.

Key words

tillage, soil resistance, bulk density, soil porosity

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Introduction

Tillage is in the final consequence artificial and contrived procedure (Butorac et al., 2007), and has the task to repair the structure, suppress weeds, bringing fertilizer to the soil and conserve moisture. The importance of tillage depends on the acreage of the cropped land, the necessary amount of energy and production costs and its effects on the crop itself (Birkás et al., 1989). Development of tillage generated negative side, primarily associated with excessive plowing, such as anthropogenic soil compacting, deterioration of structure, occurrence of the erosion and permanent loss of soil organic matter in soil. One of the main problems facing modern agriculture is the compaction and destruction of soil structure (Hamza and Anderson, 2005). Researchers around the World reported on the millions hectares of degraded land by compaction. Global scale compacted soil is estimated at 68 million hectares of land only from the use of machinery (Flovers and Lal, 1998). Other authors (Akker and Canarache, 2001; Carder and Grasby, 1986) estimate the degradation of land area of 33 million hectares in Europe and about 4 million hectares of wheat belt in Western Australia. The nature and consequences of soil degradation are recognized worldwide.

To assure normal plant growth, the soil must be in such conditions that roots can have enough air, water and nutrients. Compaction pressed larger pores in the soil and reduces the amount of air. In general, root tips are unable to penetrate pores narrower than their diameter (Taylor, 1983; Campbell and Henshall, 1991). Most crop species can exert maximal vertical pressure from 0.7-2.5 MPa (Gregory, 1994). By reduced porosity of the soil, and thus the transfer of water through the soil and the exchange of gases between the atmosphere and root crops decreased. Also, biological soil phase have difficult living conditions due to reduced aeration and heat in the soil (Bašić and Herceg, 2010), which results in a change of mineralization rate of organic carbon and nitrogen (Neve and Hofman, 2000), and the concentration of carbon dioxide in the soil (Conlin and Driessche, 2000) as a result of slow gas exchange in compacted soils. Final result of compacted soil reflected on a decreased earthworm activity (Birkás et al., 2004), reduced yield and higher level of weeds (Birkás et al., 2002).

Many authors favor certain factors to determine the soils compaction. Some researchers prefer bulk density (Hakansson i Lipiec, 2000) or soil resistance (Taylor, 1971; Mason et al., 1988; Panayiotopoulos et al., 1994; Hamza and Anderson, 2001, 2003), while others explore the water infiltration rate (Hamza and Anderson, 2002, 2003), which is directly influenced by soil porosity and soil water and air capacity. For instance, Carter and Ball (1993) stated that bulk density is inversely related to total porosity. The most common variables used to assess soil strength in tillage studies were bulk density and penetrometer resistance. They are interrelated and the use of only one of these variables may lead to misleading results (Campbell and Henshall, 1991).

At the present time in Croatia the conventional tillage system dominates, which usually consists of two or more actions, the first of which involves plowing and others finer treatments for the seedbed preparation. Under the influence of anthropogenic disturbance in the soil, discussion about the different tillage systems and their effects on the conditions in soil gaining importance. Also, interest in no-tillage is growing, due to increasing periods of drought in the last decade (Jolankai and Birkas, 2007), and due to the effective reduction in time and costs which this practice allows.

Studies comparing no-tillage with different conventional tillage systems have given different results for soil bulk density. In most of them, soil bulk density was greater in no-till in first 5-10 cm soil depth (Osunbitan et al., 2005; Pelegrin et al., 1988; Hill, 1990; Unger and Jones, 1998; Wander and Bollero, 1999). In others, no differences in bulk density were found between tillage systems (Arshad et al., 1999; Jabro et al., 2008; Logsdon et al., 1999). Also being carried out studies about the different ways of tillage in conventional tillage systems, so as to be determined most suitable tillage treatment for current climate characteristics of an region.

One of the goals of tillage is to reduce bulk density by increasing soil porosity. Kovac and Zak (1990) found that changes in soil physical properties were induced by different tillage treatments, but the changes were small and insignificant. Jabro et al. (2008) concluded that long-term frequency of tillage reduced compaction in the soil surface (0 to 10 cm), but increased in the subsurface soil (>10 cm) due to the traffic intensity induced by tillage system. Their paper also shows that tillage intensity effectively altered soil penetration resistance, and minimally affected soil bulk density. Some authors pointed out that the tillage treatments affected the soil physical properties, especially when similar tillage system has been practised for a longer period (Birkás et al., 2002, 2004; Jordhal and Karlen, 1993; Mielke and Wilhelm, 1998).

There are several factors that have influence on soil resistance during penetration: soil water content, bulk density, texture, soil organic matter, particle surface roughness and structure (Cassel, 1982; Bratford, 1986; Campbell and O'Sullivan, 1991). Tillage system simultaneously affects several factors - penetration resistance, soil water content, bulk density and soil porosity, and they should not be observed separately. Also, climatic conditions should be taken into consideration. According to Buschiazzo et al. (1998), the influence of tillage system on the soil physical properties was greater in the humid climate area and on loamy soils in comparison to the arid climate and sandy soils. In general, the timing, frequency, depth and extent of soil mixing and aggregate disruption determine the degree to which a tillage technique influences soil properties (Unger and Cassel, 1991).

There is no recorded data or experiences on the influence of different tillage systems on the soil physical properties in agroclimatic conditions of Moslavina region in Central Croatia. According to Kisic (2004), 25-35% of total agricultural land is affected by human-induced degradation in Croatia. Therefore, the main objective of this study was to examine the impact of tillage management and frequency on soil penetration resistance, bulk density and soil porosity of a Stagnic Luvisols (according to FAO classification 1990) in semi humid to humid conditions in Central Croatia, and to determine the optimal tillage system due to the compaction of individual horizons.

Materials and methods

Long term tillage and crop management practices trial was established in 1994 at the site located approximately 15 km southwest of Daruvar (45°33' N, 17°02' W) in Moslavina region,

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Table 1. Particle size distribution on Stagnic Luvisols

Soil depth (cm)	Soil horizon	Coarse sand (2-0.2 μm)	Texture (g kg⁻¹)			Texture class
			Fine sand (0.2-0.02 μm)	Silt (0.02-0.002 μm)	Clay (<0.002 μm)	
0-24	Ap+Eg	18	586	242	154	Sandy loam
24-35	Eg+Btg	21	571	260	148	Sandy loam
35-95	Btg	5	545	254	196	Sandy loam

Central Croatia. The soil is mapped as Stagnic Luvisols with a slope of 9%. The experimental design consists of six plots each 1.87 m wide × 22.1 m long. By its texture the soil belongs to sandy loam (Table 1). Climate is semihumid to humid with annual precipitation of 878 mm and average annual temperature of 10.6^{0}C (Meteorological and Hydrological Institute of Croatia).

Tillage systems differed in tools that were used, depth and direction of tillage. Six tillage systems and implements, which were included in some system, are as follows: 1) Check treatment (CT) – ploughing and other operations up and down the slope, black fallow; 2) Conventional ploughing (25-30 cm) up and down the slope (CP) – other operations depending on the crop also up and down the slope; 3) No-tillage system – no-till planter (NT); 4) Ploughing across the slope (PA) – conventional ploughing (25-30 cm) across the slope, other operations depending on the crop also across the slope; 5) Deep ploughing (50 cm) across the slope (DP) – operation is repeated after termination of prolonged effect (every 3-4 years when crop rotation allows), other operations in conventional way depending on the crop; 6) Conventional ploughing across the slope (30 cm) with subsoiling to 60 cm (SUB) – subsoiling is repeated after termination of prolonged effect (every 3-4 years when crop rotation allows); other operations depend on the crop.

In the season 2012 cover crop was corn. Soil samples were collected after harvesting from non-traffic zone. Sampling was carried out by sampling cylinders of 100 cm³ volume by Kopecky method at soil layers 0-10 cm, 10-20 cm, 20-40 cm and 40-60 cm, respectively, in three replicates. Soil bulk density determined by Kopecky's cylinders. Total porosity was calculated from bulk density and particle density. During 2012 soil resistance was measured with penetrometer Eijkelkamp Penetrologger during eight terms to a depth of 80 cm. The conical point was 1 cm² in area and the point angle was 60^0. The measurement range was 0 to 9 MPa. Each term has 16 repetitions per variant. Soil resistance data were grouped in soil layers 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-60 cm, respectively. Data were analyzed using ANOVA (analysis of variance). A Duncan's test was used to compare the mean values when a significant variation was highlighted by ANOVA. The differences were accepted as significant if P<0.05.

Results and discussion

Bulk density and soil porosity

Soil bulk density is generally used as the most important parameter of soil physical condition. The average amount of bulk density by all depths per variants vary from 1.55 (CT) to 1.60 g cm⁻³ (PA and DP). The minimum values at different depths (Fig 1) were observed in SUB variations in the depth of 0-10 cm (1.47 g cm⁻³), and the largest in DP variants at a depth of 20-40 cm

(1.69 g cm⁻³). Statistically significant differences in bulk density of soil among different depths were found in all variants except the CP variant where no statistically significant difference was. By comparing the average values of tillage system at depths we found the highest density at a depth of 20-40 cm (1.63 g cm⁻³), which indicates the existence of impermeable layer at that depth. The lowest average values of soil bulk densities of all variants were at a depth 0-10 cm (1.54 g cm⁻³). By comparing different tillage systems at depths we determined significant differences in soil bulk density at all depths except at a depth of 10-20 cm. Husnjak et al. (2002) at a depth of 0-35 cm in Albic Luvisol in northwestern Slavonia conditions had the average density from 1.46 g cm⁻³ under conservation tillage to 1.53 g cm⁻³ under reduced tillage. Kovacevic et al. (2009) compared tillage with mole plow and subsoiler with conventional tillage on chernozem. Average density of arable layer (0-30 cm) varied from 1.26 g cm⁻³ under mole plow and subsoiler to 1.43 g cm⁻³ with conventional tillage. Jabro et al. (2008) compared the long-term no-till, spring till, fall and spring till on mixed Typic Argiborolls. Soil bulk density of the top 15 cm had minimum deviation (1.58-1.61 g cm⁻³) between different tillage systems. According to Lhotsky (1991), soil bulk density above 1.50 g cm⁻³ in the plough horizon on medium heavy soils has a negative effect on the growth and development of agricultural crops and is regarded as the threshold value of adverse soil compaction, which was also confirmed Butorac et al. (1992) in study where they compared soybean yield. For normal growth and development of most agricultural crops, the surface soil layer to the sowing depth should have a bulk density about 1.00 g cm⁻³, and the layer in which the seed is sown 1.30-1.45 g cm⁻³ (Miština and Kováč, 1993). However, such conditions were not recorded in our study. Results from several studies have shown an increase in soil bulk density with the conversion of CT to NT (Hill, 1990; Wu et al., 1992; Gregorich et al., 1993). However, in this study, the average values of NT variant are not greater than other variants. Similar results were recorded in other studies (Arshad et al., 1999; Jabro et al., 2008; Logsdon et al., 1999). No-tillage soils are not disturbed by tillage, and biopores created by soil organisms and root channels of preceding crops remain in place in such soils (Gantzer and Blake, 1978). It is, therefore, concluded that the biopores minimized effects of bulk density differences among different plots where NT was used and that the soils developed a 'rigid' structure independent of bulk density.

Higher bulk density reduced total porosity and changed the ratio of water holding capacity to air capacity in favour of water holding capacity. The average total porosity (P) for all variants and depths was 41.7%. Husnjak et al. (2002) found an average of total porosity 42.42% to a depth of 35 cm. Turšić and Mesić (2011) had 45.6% at depth 0-26 cm, 38.3% at depth 26-45 cm and 41.6% at depth 45-90 cm in soil under tobacco in Croatia.
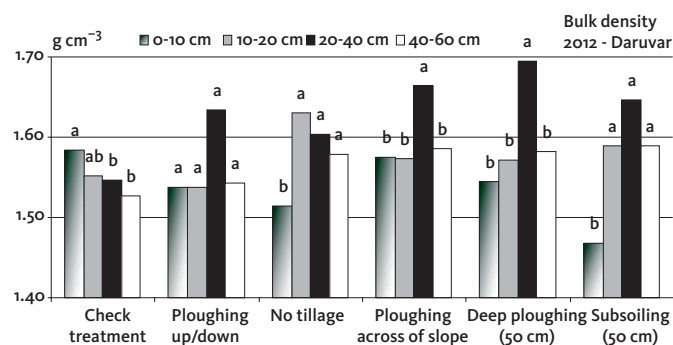
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Figure 1. Soil bulk density (g cm^{-3}) between tillage systems and different depths

Figure 2. Soil porosity (%) between tillage systems and different depths

Total average porosity for all depths per particular tillage systems varied from 39.5% (NT), 41.1% (CP), 41.5% (CT), 42.3% (PA), and 42.4% (DP) to 43.4% (SUB). Comparing the averages of all variants at different depths (Fig 2) we found the highest porosity at a depth of 0-10 cm (42.6%), while the lowest porosity was observed at a depth of 20-40 cm (40.1%). These results correspond to the values of the largest soil volume density at a depth of 20-40 cm. Total porosity below 45% on medium heavy soils had negative effect on plant growth (Lhotsky, 1991). Detailed
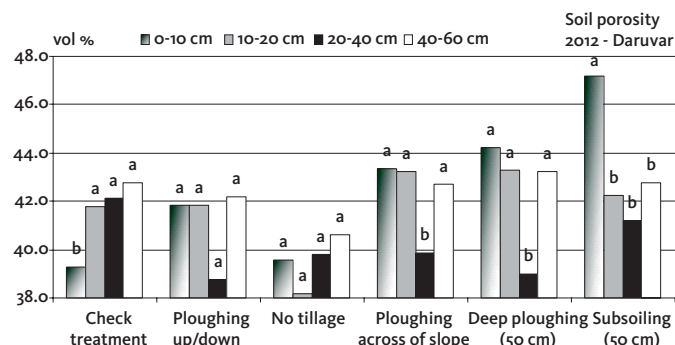
statistical differences of soil porosity between tillage systems are shown in Fig 2.

Soil resistance (penetration resistance)

Differences in soil resistance in the soil layer (0-60 cm) among layers and tillage treatments may be attributed to differences in soil water content at the time of sampling and the period since the primary tillage date. The lowest average soil resistance at depth 0-60 cm showed CT variant (1.90 MPa), while the highest showed CP variant (2.79 MPa). Soil resistance (Table 2) at depth

Table 2. Soil resistance (MPa) in soil layers per month and average values

Depth (cm)	Variant	Average	January	March	April	June	August	September	October	December
0-10	CT	1.134	0.040c	0.292b	0.682c	1.132ab	2.286a	2.266d	1.776a	0.599a
	CP	1.288	0.062bc	0.345b	1.280b	1.361a	1.683a	2.857c	1.967a	0.746a
	NT	1.334	0.152a	0.512a	2.009a	0.648c	2.153a	3.260b	0.967b	0.974a
	PA	1.297	0.065bc	0.343b	0.857bc	1.111ab	2.540a	3.759a	0.996b	0.702a
	DP	1.178	0.065bc	0.329b	1.003bc	1.140ab	2.106a	3.299b	0.961b	0.520a
	SUB	1.123	0.090b	0.347b	0.837c	1.015b	1.926a	3.080bc	1.001b	0.691a
	Average	1.23	0.08	0.36	1.11	1.07	2.12	3.09	1.28	0.71
10-20	CT	1.510	0.060c	0.369c	0.860c	1.569a	2.956a	2.929d	2.343a	0.991a
	CP	1.833	0.120bc	0.681b	1.808b	1.754a	2.486a	3.603c	2.744a	1.465a
	NT	2.029	0.323a	1.174a	3.170a	1.145a	3.193a	4.014b	1.594b	1.616a
	PA	1.785	0.105bc	0.734b	1.249bc	1.643a	3.190a	4.821a	1.331b	1.205a
	DP	1.714	0.133bc	0.465bc	1.298bc	1.426a	3.360a	4.590a	1.378b	1.060a
	SUB	1.695	0.180b	0.730b	1.594b	1.392a	3.063a	4.080b	1.380b	1.143a
	Average	1.761	0.154	0.692	1.663	1.488	3.041	4.006	1.795	1.247
20-30	CT	1.942	0.143c	0.777c	1.266c	2.198a	3.013a	3.618c	2.866b	1.653a
	CP	2.756	0.275b	1.378ab	2.448b	2.222a	3.301a	6.043a	4.165a	2.212a
	NT	2.544	0.417a	1.561a	3.122a	1.587b	3.895a	5.601a	2.148bc	2.018a
	PA	2.696	0.373ab	1.705a	2.717ab	2.281a	4.720a	5.739a	2.023bc	2.008a
	DP	2.064	0.256bc	1.023bc	1.503c	1.676b	3.490a	4.962b	1.913c	1.691a
	SUB	2.425	0.340ab	1.611a	2.131b	1.896ab	4.193a	5.506ab	2.099bc	1.620a
	Average	2.404	0.301	1.343	2.198	1.977	3.769	5.245	2.536	1.867
30-40	CT	2.268	0.250c	1.248c	2.213c	2.320bc	2.8433d	3.858d	3.136bc	2.273a
	CP	3.828	0.533ab	2.398a	3.106ab	2.753b	7.186a	7.000a	4.868a	2.780a
	NT	3.162	0.497b	1.818b	3.007ab	2.115c	6.050ab	6.563abc	2.752c	2.494a
	PA	3.659	0.624a	2.778a	3.516a	3.369a	5.833ab	6.855ab	3.131bc	3.166a
	DP	2.982	0.572ab	2.251ab	2.581bc	2.642b	3.022cd	6.427bc	3.375bc	2.989a
	SUB	3.229	0.520ab	2.605a	3.131ab	2.379b	4.736bc	6.102c	3.664b	2.694a
	Average	3.188	0.499	2.183	2.926	2.596	4.945	6.134	3.488	2.733
40-60	CT	2.625	0.414b	2.082b	2.552b	2.249c	4.263e	3.628b	3.318c	2.490c
	CP	4.233	0.684a	2.801a	2.983a	2.823ab	7.590a	7.000a	6.405a	3.574a
	NT	3.700	0.730a	2.283b	3.066a	2.687b	6.430bc	7.000a	4.470b	2.930bc
	PA	4.010	0.826a	2.950a	3.234a	3.219a	6.886ab	7.000a	4.697b	3.270ab
	DP	3.838	0.805a	2.975a	3.329a	3.011ab	5.266de	6.996a	4.767b	3.555a
	SUB	3.795	0.787a	3.013a	3.224a	2.973ab	5.416cd	6.799a	4.856b	3.288ab
	Average	3.700	0.708	2.684	3.065	2.827	5.975	6.404	4.752	3.185

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Table 3. Water balance (mm) according to Thornthwaite for Blagorodovac (2012)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	SUM
PET, k.	3.7	0.0	29.8	52.5	87.5	131.1	150.0	132.3	79.6	39.3	25.7	1.1	732.5
SET	3.7	0.0	29.8	52.5	87.5	131.1	117.9	4.5	79.6	39.3	25.7	1.1	572.6
M	0.0	0.0	0.0	0.0	0.0	0.0	32.1	127.8	0.0	0.0	0.0	0.0	159.9
V	28.4	48.2	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	17.0	118.4	216.4

PET, k. - potential corrected evapotranspiration; SET – real evapotranspiration; M – lack of water; V – surplus of water

of 0-10 cm varied from 0.04 to 3.76 MPa at depth of 10-20 cm from 0.06 to 4.82 MPa, at depth of 20-30 cm from 0.14 to 6.04, at depth of 30-40 cm from 0.25 to 7.18 MPa, and at depth of 40-60 cm from 0.41 to 7.59 MPa depending on the period of different soil water content.

Average of all variants at all depths showed that the minimum measured values were in January and the highest in September, which coincides with a lack of soil moisture obtained by Thornthwait method (Table 3). As soil became drier, soil resistance increased in all treatments, exceeding 4 MPa at almost all depths.

Soil resistance showed significant differences in most of the soil layers between all tillage systems. There were no significant differences in soil resistance between soil layers during dry (August) and wet (December) period in layers up to 30 cm. In this study, due to the range of soil resistance values found over the experimental period, we chose 2.5 MPa as the most suitable reference value for comparison purposes. At depths of 0-30 cm almost all values do not exceed a set limit compaction, except in August and September. The soil at depths of 30-60 cm showed soil resistance value up to 4 MPa, while some up to 5 MPa. Individual measurements in dry months (August, September) showed the results up to 7 MPa, which indicates some limitations of these soils for crop production. Even variants with prolonged effect of deeper tillage (DP and SUB) have not showed better results than others conventionally tilled variants. After deep tillage (deep ploughing and subsoiling) the loosening effect of tillage disappeared in both DP and SUB treatments. Karlen et al. (1991) also reported PR averages of 4.7 MPa and 6.5 MPa in a disked and non-disked soil respectively, at small soil water content. Turšić and Mesić (2011) reported soil resistance up to 9.05 MPa at the highest bulk density of soil for tobacco production in Croatia, while at mean bulk density soil resistance was 5.1 MPa. Differences between tilled and NT variants are visible in almost all measurements at depths up to 20 cm. NT variant showed the average maximum value of soil resistance between tillage systems. It is attributable to the tillage operation on the soil structure, while at greater depths that difference between NT and tilled variant is lost. In several studies comparing tilled and NT soils, greather penetration resistance was found under NT, especially in the upper 10 cm (Pelegrin et al., 1990; Hill, 1990; Lopez et al., 1996; Ferreras et al., 2000).

Conclusion

Significant differences showed in bulk density and soil porosity in most of the soil layers between all tillage systems. Minimum average amount of bulk density by variants showed CT while maximum had PA and DP variant. Comparing the av-

erage values of tillage system at depths the highest density at a depth of 20-40 cm indicates the existence of impermeable layer as consequence of shallow soil tillage in same depth. Soil bulk density of these soils indicates a negative effect on the growth and development of agricultural crops. Conversion from conventionally tilled systems to NT had no increase in soil bulk density and average values are not greater than other tilled variants. Soil porosity showed significant difference between all tillage systems in surface and deepest soil layer. Lowest average porosity recorded NT, while the highest recorded SUB. The lowest average soil resistance at depth of 0-60 cm showed CT variant, while the highest showed CP variant. Soil resistance showed significant differences in most of the soil layers between all tillage systems. There were no significant differences in soil resistance between soil layers during dry (August) and wet (December) periods. It can be concluded that different tillage practice significantly affected soil resistance in most of the soil layers during the year, except at highest periods precipitation surplus and deficit in layers up to 30 cm. Average values of all variants at all depths showed that the minimum measured values were in January and the highest in September, which coincides with a lack of soil moisture. As soil became drier, soil resistance increased in all treatments, exceeding 4 MPa at almost all depths.

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