Tillage and Soil Amendments Effect on Soil Physical Properties and Yield of Oats (*Avena sativa* L.) in Organic Farm in Mediterranean Croatia

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Summary

Organic agriculture represents sustainable and environmentally friendly soil management. Nevertheless, this kind of management requests high level of knowledge due to limitations in use of agrochemicals. Proper agro-technical measures are especially important on organic farms on degraded saline-sodic soils in Mediterranean. In this paper, we study the impact of two tillage managements (disc-harrow – DH and disc-harrow with ripping – DH+RIP) and three selected treatments on soil physical properties in saline-sodic soils of River Raša valley, Croatia. Treatments were: control, G_6+OM (6 t ha^{-1} gypsum + 40 t ha^{-1} farmyard manure) and G_6S_2 (6 t ha^{-1} gypsum + 2 t ha^{-1} sulphur). Results show that DH+RIP treatment recorded lower bulk density, penetration resistance and higher air filled porosity compared to DH treatment. Soil amendments also show implications on soil physical properties. Lowest compaction was noted at G_6+OM, while control treatment recorded the highest. Yields of oat were generally low due weed infestation. DH+RIP treatments showed 15% higher yields compared to DH treatments. Amendments also recorded different response on oat yield. G_6+OM treatment recorded 34% higher yields of oats compared to control, while G_6S_2 treatment recorded 82% of grain yields compared to control. This can be justified by the period between sulphur application into this treatment and sowing date, which was too short. Research should be continued with expanded monitoring of soil hydraulic properties, carbon dynamics, soil structure and aggregate stability in order to find most appropriate and sustainable soil management on saline-sodic soils under organic production in Mediterranean.

Key words

saline soils, sodic soils, Istria, bulk density, penetration resistance, oat yield

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Introduction

Soil degradation resulting from soil salinity and/or sodicity is recognized as a major problem of soil productivity and quality under arid and semiarid climates (Rasouli et al., 2014; Choudhury et al., 2014; Singh et al., 2016). In Croatia, the information on the order of Halomorphic soils is very limited, with different assumption according to numerous soil scientists. Real extent and distribution of saline and/or sodic soils in Croatia is unknown and is not accurately mapped due to generally small percentage of land under agroecosystem and their spotty and clustered distribution. Tomić et al. (2008) stated that order of Halomorphic soils is represented over an area of 410.5 ha, while Adam (1981) assumes about 1500 ha in Slavonia and Baranja. Usually, they can be found around Tovarnik and Bizovac (Škorić et al., 1977; Bogunović et al., 1983), locations Poljic and Marijanci (Racz, 1981), Neretva valley (Romić et al., 2008), rivers Mirna and Raša in Istria (Bašić, 2013; Bogunovic et al., 2017a). Nowadays, climate change accelerates the penetration of seawater into river valley, which endangers the fertile land in Mediterranean part of Croatia. Excessive amounts of salts have implications on the soil physical and chemical properties, microbiological processes and on plant growth, thus causing a decline in soil productivity (Rietz and Haynes, 2003; Tejada et al., 2006; Rasouli et al., 2014; Luo et al., 2017). The major problem of excessive saline soils is recognized when Na^+ content increases above the level of Ca^{2+} cations at soil cation exchange capacity (Vukadinović et al., 2010). Structural deterioration by physical processes such as slaking, swelling and dispersion of clay is consequence of excessive Na^+ content. This processes leads to compaction, very poor water infiltration rate and hydraulic conductivity (Bethune and Batey, 2002; Qadir et al., 2003; Qadir et al., 2007; Choudhury et al., 2014) and occurrence of a hardpan in the subsoil (Rasmussen et al., 1972; Wong et al., 2010; Wang et al., 2014). Therefore, management of such soils is particularly challenging. Several approaches have been adopted for reclamation of saline and sodic soils like the application of agrochemicals, organic manures, electrolytes, leaching and development of forests and cropping (Qadir et al., 2000, 2001; Singh et al., 2016).

Appropriate tillage is important factor for mitigation of negative effect of saline-sodic soils. Different tillage interventions affect the soil physical properties by changing conditions in the soil, and thus have a direct impact on the crop growth and the cost of yield production (Jabro et al., 2011). Here, anthropic interventions usually mean loosening procedures, which alleviate compacted soil state to the deeper layers (> 60 cm) (Blaskó, 2017). Nevertheless, numerous tillage practices performed on such soils have implications on soil structure, carbon sequestration, erosion control and yields (e.g. Sadiq et al., 2007; Singh et al., 2016; Matosic et al., 2018). Application of organic matter through various sources is another amelioration strategy for saline-sodic soils. This concept includes all the procedures that increase soil biological activity and source of organic material by applying green manure and/or microbial preparations thereby enhancing the physical, chemical and colloidal soil properties (Matosic et al., 2018). Organic matter has positive effects on the salt-affected soil amelioration trough increased binding of soil particles into aggregates and permeability. The structure improved by organic matter enhances Na^+ leaching, reducing surface evaporation, and inhibiting salt accumulation in the surface layers (Lax et al., 1994; Qadir et al., 2001; Bronick and Lal, 2005; Cha-um and Kirdmanee, 2011; Mahdy, 2011). Sulphur and gypsum are widely used agents in amelioration of salinity and sodicity. Source of Ca^{2+} from gypsum replaces the Na^+ from the colloidal surface, and Na^+ with SO_4 form Na_2SO_4, which is soluble in water and can be easily drain out from the field trough precipitation or during irrigation. In this context, reclamation also can be performed, especially if soils contain carbonates, with elemental S. S furnish Ca indirectly when S oxidized to sulfuric acid which reacts with the calcium carbonate to form gypsum.

Valley of Rasa River is one of the most typical areas in Istria peninsula, Mediterranean area of Croatia, with a long history in agriculture. Specific geographic location nearby and below the sea, in close surroundings by karst hills, with specific amelioration system and in combination with several decades of land abandonment has greatly affected the soil properties. Seawater intrusion raises the salinity and sodicity level to high extent at this area (Bogunovic et al., 2017a). Nowadays, land re-cultivation of this area offers new chance for organic crop production. In this paper we hypothesize that proper tillage and amendment application (e.g. farmyard manure, gypsum, sulphur) can help to improve soil properties and increase soil quality. According to our knowledge there is lack of organized investigations on national level of tillage and chemical amendments on restoration of saline-sodic soils in Croatian soils. Very few research of this topic (Adam, 1981; Galović, 1998) open dilemma and better understanding of mentioned problems could improve soil productivity, improve stability of organic crop yields and increase financial income to the farmers.

Materials and methods

Location, climate and soil

The study area was in Istrian peninsula (45°3' N; 14°2' E). Agricultural area is divided into several main parts by a river and channels (Figure 1). Agricultural areas are part of Rasa basin. Terrain is flat and ameliorated, bordered by canals, where water level is controlled by pumping stations. From north to south, the

Figure 1. Study area in Croatia with location of experiment

Table 1. Main characteristics of soils on study area

	Anthrosols		
	0 – 35	35 – 90	90 - 160
pH (H_2O)	7.7	8.2	8.0
pH (KCl)	7.2	7.4	7.4
$CaCO_3$ (%)	32.9	30.4	26.5
Organic matter (%)	1.9	–	–
Total N (%)	0.14	–	–
C/N	7.8	–	–
ECe (dS m^{-1})	8.03	–	–
CEC (cmol(+) kg^{-1})	25.67	–	–
ESP	22.16	–	–
Sand (%)	8.74	3.62	1.69
Silt (%)	56.57	50.55	40.26
Clay (%)	34.69	45.83	58.05
Texture	Silty Clay Loam	Silty Clay	Clay

elevation gradually decreases and areas near the sea have the lowest elevation. Great part of study area is below sea level (about 1.5 m) and this is the reason for pumping the water into drains. Dam covers south area and prevents the penetration of sea water into the valley. Embankments also cover river Rasa and several creeks from ameliorated fields. Land was abandoned at least two decades and covered with natural grasses and reeds, while re-cultivation begins in 2015.

The study area has a Mediterranean climate with 2-3 months of summer drought, usually during from late July to September. Mean annual temperature ranged from 12.2 °C and 15.2 °C, and the average annual precipitation varied from 476 mm to 1444 mm between 1978 and 2014 (Hydrological and meteorological institute of Croatia). Soils on larger part of study area are classified as silty clay loam Anthrosols (Table 1).

Experimental design, sampling and statistical analysis

Experiment was set up in spring of 2016. Design consists from six treatments in four repetitions, all laid out in randomized complete block design. The treatment differs in amount and combinations of soil amendments. For the purposes of this paper, three selected treatments were separated: 1) control treatment - no addition of any soil amendments; 2) G_6S_2 – six tons of gypsum ($CaSO_4$ x $2H_2O$) per ha with 2 tons of sulphur per ha; and 3) G_6+OM – six tons of gypsum in combination with 40 tons of farmyard manure per ha. Tillage was performed in spring (April 11th 2016) at approximately 80% of soil retention capacity. Tillage treatments were: 1) disc harrowing to 10 cm – DH; and 2) disc harrowing to 10 cm with ripping to 30 cm – DH+RIP. Each tillage treatment was performed on block of two repetitions of soil amendments.

In the season 2015/2016, crop was spring oat (*Avena sativa* L.) sowed immediately after tillage was performed. Soil samples were collected after sowing and harvesting from non-traffic zone. Sampling was carried out by sampling cylinders of 100 cm^3 volume by Kopecky method at soil layers 0-15 cm and 15-30 cm, in four repetitions. Soil bulk density (BD) was determined by Kopecky's cylinders. Total porosity (TP) was calculated from bulk density and particle density. Air filled porosity was calculated from water holding capacity and total porosity. During 2016 penetration resistance (PR) was measured with penetrometer Eijkelkamp Penetrologger to a depth of 40 cm. The conical point was 1 cm^2 in area and the point angle was 60°. The measurement range was 0 to 9 MPa. Each term has 6 repetitions per plot. Penetration resistance data were grouped in soil layers 0-10 cm, 10-20 cm, 20-30 cm, and 30-40 cm, respectively. During the harvest, the harvester was used to determine the crop grain yields. Seeds were cleaned and weighed after each plot. The obtained values were corrected to a 14% soil water content.

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

Results are presented in figures 2-8 and show tillage and soil amendments implications on soil properties and yields. Bulk density was highest on control treatment (1.45 g cm^{-3}) while the lowest was measured on G_6S_2 treatment (1.40 g cm^{-3}) (figure 2). Tillage also influence on bulk density (figure 3). At 0-15 cm depth DH+RIP treatment (1.21 g cm^{-3}) showed lower compaction compared to DH (1.33 g cm^{-3}). Similar findings were found at 15-30 cm depth.

Soil amendments showed significant ($F=42.1$, $p<0.01$) impact on penetration resistance. G_6+OM treatment (1.15 MPa) recorded significantly lower PR compared to control and G_6S_2 treatments (1.23 MPa) (figure 4). Although difference between treatments exists, vertical distribution of PR (figure 5) showed the gradual increase of PR at all treatments, but highest values are still below 2 MPa. Tillage also has significant influence on PR ($F=15.0$, $p<0.01$) and showed lower PR at DH+RIP (1.16 MPa) compared to DH treatment (1.29 MPa).

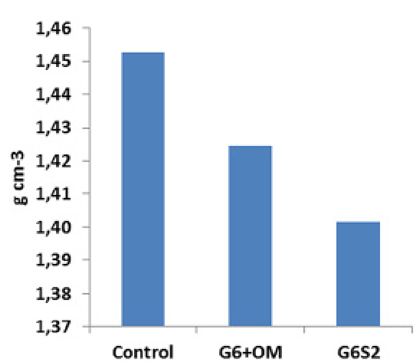

Figure 2. Amendment effect on bulk density

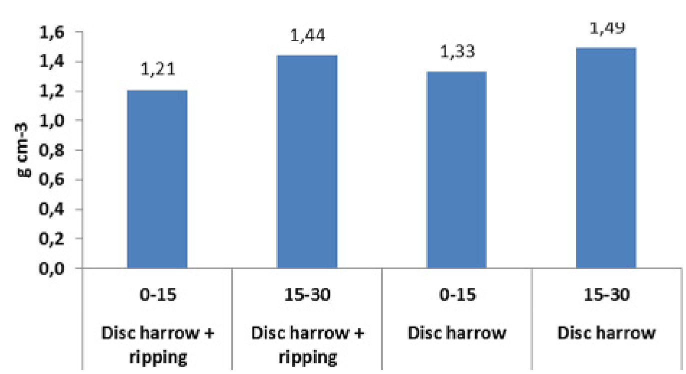

Figure 3. Tillage effect on bulk density on 0-15 cm and 15-30 cm depths

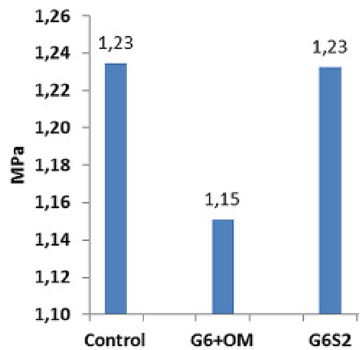

Figure 4. Amendment effect on penetration resistance

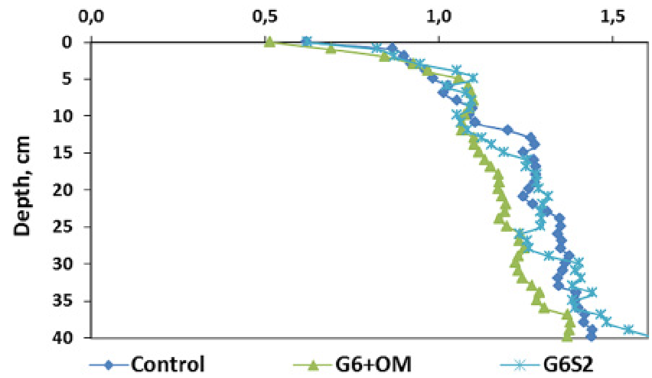

Figure 5. Vertical distribution of penetration resistance treatments

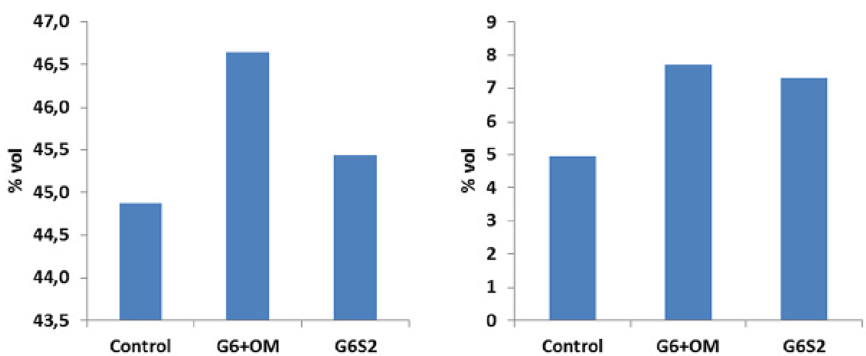

Figure 6. Water holding capacity (left) and air filled porosity (right) on each treatments

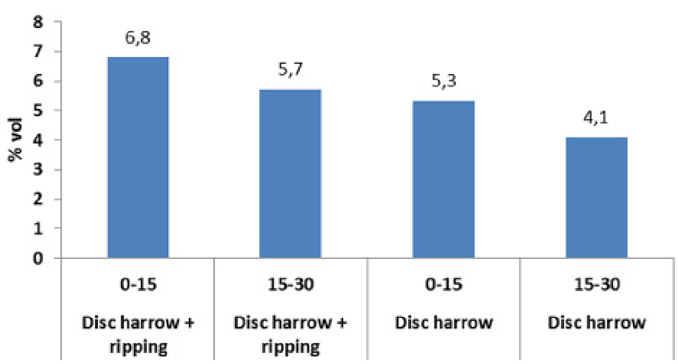

Figure 7. Tillage effect on air filled capacity on 0-15 cm and 15-30 cm depths

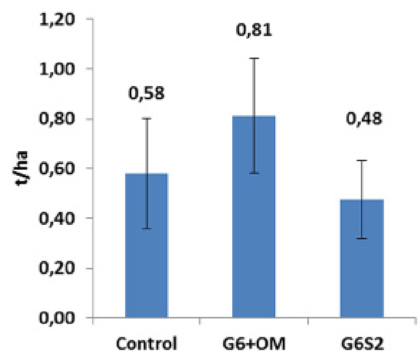

Figure 8. Amendment effect on oat yields

Treatment G_6+OM showed the highest possibilities to hold water with soil inner forces (46.65 %), while the control treatment showed the lowest (44.87 %) (figure 6). Similar relationships were measured on air filled porosity (figure 6). From figure 7, tillage induced impact on air filled porosity can be seen, where DH+RIP treatment resulted with higher percentage of large macropores, compared to DH treatments at 0-15 cm and 15-30 cm depths.

Yields of oats are in range from 0.48 t ha^{-1} to 0.81 t ha^{-1} (figure 8). G_6+OM showed 34% higher yields of oat grain compared to control, while the G_6S_2 treatment record 82% of yields compared to control. Tillage also shows influence on oat yield. The DH+RIP treatment resulted with 15% higher yields compared to DH treatment.

Discussion

Presented results indicate that soil management had implications on soil physical properties. Our results show that BD was higher in DH treatment than in DH+RIP treatment at 0-15 cm and 15-30 cm depth. Previous studies also showed that shallow tillage have a higher BD than ripped tilled soils (e.g. Lampurlanés and Cantero-Martinez, 2003; Hajabbasi, 2010), while others do not record any significant differences between treatments (eg. Veiga et al., 2008; Jabro et al., 2016). de Moraes (2016) found that soil BD was greater in treatment with disc tillage compared with chisel treatments on heavy clay soil. Similar results were reported by previous studies on silty soil in USA (Sharratt et al., 2006) and sandy loam soil in

India (Laddha and Totawat, 1997), although the significant justification between treatments is often missing (e.g. Hammad and Dawelbeit, 2001; Sharratt et al., 2006) due to low sensitivity of BD properties to tillage treatments. Our results were consistent with previous studies that reported higher BD under DH then under DH+RIP. Similar results were noted in other physical properties: penetration resistance and air filled capacity. Penetration resistance is lower at DH+RIP and higher at DH as is reported in other research (Hammad and Dawelbeit, 2001; Arvidsson et al., 2013). It is usual to BD and PR has similar trends as their relation is usually highly correlated (e.g. Bogunovic and Kisic, 2017). Our findings also show that decreasing tillage depth generally increased penetration resistance and reduced air filled porosity as it is noted elsewhere (e.g. Arvidsson et al., 2013; de Moraes et al., 2016; Bogunovic et al., 2017b; Bogunovic and Kisic, 2017). This is mostly due to depth of tillage interventions which can affect soil structure, differential porosity, water conservation and thus PR. Air filled porosity is higher at topsoil than to subsoil at both treatments. Except the fact that numerous scientists confirmed that ripping improve macroporosity (Mielke and Wilhem, 1998; Kribaa et al., 2001; de Moraes et al., 2016), higher percent of air filled pores are also result of higher biological activity at topsoil compared with subsoil. DH treatment is more compacted (higher BD and PR), and has lower air filled porosity in subsoil compared to DH+RIP. As Yadav et al. (2011) noted in fine textured soils expressed sodicity trough leaching (natural or anthropic) accumulated in subsoil and left sodium bound to the negative charges of the clay due to increase in its concentrations. This affect to structure distortion, increase compaction, which is visible in our results and trough comparison of DH treatment with DH+RIP treatment where ripping improve physical state of the subsoil.

Results from amendment comparisons showed that control treatment in comparison to other treatments have the highest bulk density, while the air filled porosity and water holding capacity was the lowest. On the contrary, G_6+OM records the highest water holding capacity and air filled porosity, while the PR was the lowest compared to other treatments. It is not unseen situation. Beneficial effect of organic amendments for physical, chemical and biological properties are well known. Stabilization of soil aggregates by organic matter can increase resistance to settling, traffic induced compaction and rainfall disaggregation effect of soils (Thomas et al., 1996; Aksakal et al., 2016; Mujdeci et al., 2017). Improved structure by organic matter addition usually was notable by enhanced bulk density, macroporosity, infiltration and other soil properties (Birkás et al., 2007; Karažija et al., 2015; Mujdeci et al., 2017). In saline-sodic soils beneficial effect of organic matter can be noted trough different effects as: increased process of Na^+ leaching, decreased the exchangeable sodium percentage and the electrical conductivity and increase water infiltration, water-holding capacity and aggregate stability (Lax et al., 1994; El-Shakweer et al. 1998). Furthermore, gypsum addition in two treatments in current study helps to improve chemical properties which can have favorable effect on physical state of soil. Usually, foreign literature reveals that gypsum improves the structural stability of sodic soil by lowering the ESP, trough displacement of Na^+ with Ca^{2+} (Hanay et al. 2004; Dang et al., 2010; Abdel-Fattah et al., 2015; Ahmed et al., 2015). Although we hypothesize on gypsum effect on soil chemical properties in present work, better physical soil state at G_6+OM and G_6S_2 treatments compared to control treatments can support our hypothesis. Sulphur addition act as acidifying agent in present calcareous soils (table 1) and his presence release Ca^{2+} from carbonates which improves structure.

Yields are generally low on present field. Poor pedogenetic conditions expressed through poor texture, high total salt concentration and sodium concentration are major reason for low soil quality and productivity. Buried channels through several decades of land abandoned affected the waterlogging and poor infiltration which affected oat density. Furthermore, organic production after re-cultivation of present area has limitations on crop protection and this is reason for high level of weed infestation. All this factors affect low yields of oat, but relative differences are still expressed and can be guidelines for future years and test crops. It can be noted that DH+RIP shows 15% higher yields of oats compared to DH. This is in agreement with Hammad and Dawelbeit (2001) who find beneficial impact of ripping to 30 cm on crop yields compared to shallow tillage. Furthermore, Laddha and Totawat (1997) on sandy loam soil reported higher yields of Sorghum, green gram, Sorghum equivalent and Stover on chisel treatment in addition to disc harrowed treatment. Nevertheless, better yields under DH+RIP treatment in the present investigation are attributable to the overall effect of favorable soil physical conditions, creating a better environment for crop growth. G_6+OM treatment showed highest yields due to gypsum and farmyard manure and their overall beneficial effect on soil physical and chemical properties, while gypsum in combination with sulphur showed the lowest yields. This can be attributable to technological mistake, when the application of Sulphur into soil was performed several days before seeding. Data collected from next years will confirm or decline above mentioned hypothesis.

Conclusion

Results show that DH+RIP treatment recorded lower bulk density, penetration resistance and higher air filled porosity compared to DH treatment. Soil amendments also show implications on soil physical properties. Lowest compaction was noted at G_6+OM, while control treatment records the highest. DH+RIP treatments showed 15% higher yields compared to DH treatments. Amendments also record different response on oat yield. G_6+OM treatment recorded 34% higher yields of oats compared to control, while G_6S_2 treatment recorded only 82% of grain yields compared to control. This can be justified with too short period between sulphur application into this treatment and sowing date, which probably act phytotoxic on oat. Research should be continued with expanded monitoring of soil hydraulic properties, carbon dynamics, soil structure and aggregate stability in order to find most appropriate and sustainable soil management on saline-sodic soils under organic production.

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