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MAIZE YIELD DEPENDING ON FERTILIZATION AND SOIL COMPACTION

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Abstract: *Soil fertility is a combination of mineral and biological properties of soil and the circulation of plant nutrients in the soil-plant system is constantly happening within it. In order for the root system to develop and function normally, it is necessary that there is enough oxygen in the soil. Only well-drained soils provide enough oxygen and good activity of microorganisms. Since most of the operations, from sowing to harvest, are performed with the help of heavy mechanization, soil compaction occurs and its structure deteriorates. Within compacted soil, there is a weaker development of the root system, weaker microbiological activity, slowing down the absorption of water and nutrients, thus slowing down the growth of plants. Growing plants on such soils result in reduced yields and increased production costs. The aim of this study was to determine the impact of manure and mineral fertilizers on soil compaction and maize yield. The experiment was performed on the territory of the municipality of Leskovac on smonica soil type. The experiment included four variants of fertilization with organic and mineral fertilizers. Compaction was measured after sowing and after maize harvest, by penetrologger Eijkelkamp hardware version 6.0, software version 6.03. The application of manure in combination with mineral fertilizers significantly reduced soil compaction. The greatest compaction was recorded at a depth of 40-50 cm, after which it stagnated and slightly decreased to a depth of 80 cm. The average compaction measured after harvest was 24.10% higher than that measured after sowing. The soil moisture content was higher on plots with manure and mineral fertilizers than on non-fertilized plots. Maize yield was significantly higher in variants where manure* *was used together with mineral fertilizers compared to variants with the only use of mineral fertilizers and variants without fertilizers. Variants with the lowest soil compaction achieved the highest yields. The recommendation to maize producers is to apply more organic matter on heavy and compacted soils, primarily manure, but also mineral fertilizers, in order to have high and stable yields.*

Key words: *soil compaction, manure, mineral fertilizers, maize, yield.*

INTRODUCTION

Soil is one of the most important elements of plant production and is the basic substrate for plant roots. It is a very dynamic environment in which the growth of the root depends on its depth, plant species, root characteristics, compaction, moisture, etc. (Navaz et al., 2013). Soil composition and its properties are the basic preconditions for high yields of cultivated plants. Thus, Živanović (2012) points out that soil type has a very significant impact on maize yield, sometimes higher than hybrids and fertilizers. Since most of the operations from sowing to harvest are performed with the help of heavy mechanization, it results in soil compaction and deterioration of its structure. In such soils, unfavorable conditions for the development of the root system prevail, microbiological activity is weaker, which results in a yield reduction and an increase in production costs by 20-40%. The soil is exposed to various forms of degradation. Thus, Lynden (2000) points out that soil compaction participates with about 11% in the total extent of degradation. The usage of heavy mechanization causes deterioration of the structure, both in the upper and lower layers of the soil. This reduces land productivity and increases energy consumption (Mueller et al., 2010). Hamza and Anderson (2005) emphasize the importance of water content in the soil, especially in the upper layers, where fewer mechanization passes lead to less evapotranspiration, which preserves soil moisture. Soil compaction has a detrimental effect on crop production and is one of the greatest problems that modern agriculture has to face (Trükmann et al., 2008).

In general, compacted soil has a weaker development of the root system, its length and penetration into deeper layers, slowing down the absorption of water and nutrients, slower plant growth, which in turn results in poorer plant development and reduced yields (Nosalevicz and Lipiec, 2014; Prakash et al., 2014; Dimitri and Destain, 2016).

How compact the soil will be will also depend on the crop being grown. By growing maize, the soil is compacted more than when wheat is grown (Miloševet al., 2007).

The usage of organic fertilizers, especially in combination with mineral fertilizers, significantly increases the better use of water in the soil, even in profiles of 1-1.5 m. This creates better conditions for the growth of maize root, its biomass, and total yield. In addition, the use of organic fertilizers promotes sustainable soil productivity and better environmental management (Wang et al., 2020). Githongo et al. (2021) also emphasize the importance of the use of organic fertilizers, primarily manure, and minimal tillage in increasing soil fertility and organic carbon content in the soil. The application of manure, at least two to three seasons earlier, significantly increases the content of phosphorus, potassium, and organic carbon in the soil, and thus the yield of maize (Njoroge, et al., 2019). Motavalliet al. (2003) have examined the influence of manure on the reduction of soil compaction with a sandy texture, and have concluded that the application of manure reduced soil compaction, increased nitrogen intake, and led to a significant increase in maize yield. Savin et al. (2011) point out that manure application is the best agro-technical measure that will reduce soil compaction. Increased soil compaction has the following consequence - the biomass of the roots increases in the uncompressed part. The use of organic fertilizers increases the biomass of maize roots in the uncompressed part of the soil and decreases in the compacted part (Bawa et al., 2019).

The aim of this study was to determine the effect of manure and mineral fertilization on soil compaction and maize yield.

MATERIAL AND METHODS

The experiment was set up during 2021 on the territory of the municipality of Leskovac (village Todorovci), on smonica soil type. Samples of soil for chemical analysis were taken from the plots before the experiment was set up. The experiment was set up according to the plan of the block system with three repetitions. The previous crop was winter wheat. The experiment included four variants of fertilization:

I. 20 t ha^{-1} manure;

II. 20 t ha^{-1} manure + 300 kg ha^{-1} NPK (16:16:16) + 200 kg ha^{-1} KAN in top dressing;

III. 300 kg ha^{-1} NPK (16:16:16) + 200 kg ha^{-1} KAN in top dressing and

IV. No fertilization.

Soil preparation included autumn plowing to a depth of 30 cm, where manure and mineral fertilizer were applied. Pre-sowing preparation was performed immediately before sowing with a seed drill. Sowing was done in the second half of April. Treatment against seed weeds was performed the day after sowing, with *Basar* and *Rezon* preparations. Treatment against broadleaf and narrow-leaf weeds was performed with *Siran* and *Maton* preparations. Fertilization with KAN was done in the phase of 3-5 leaves, after the first inter-row cultivation. No diseases or pests were present during the vegetation. Maize was harvested at technological maturity. The yield was calculated on each plot and reduced to 14% grain moisture. Maize yield and soil compaction depending on fertilization were statistically analyzed by analysis of variance using WASP 1.0 software.

Compaction was measured after sowing and after maize harvest, by the penetrologger Eijkelkamp, hardware version 6.0, software version 6.03. Compression measurements were performed in accordance with the NEN 5140 standard, with a penetration speed of 2 cm sec^{-1}, where the deviation was not greater than 0.5 cm s-1, all according to the standard (ASAE S313.1). Before the beginning of the measurement, a reference plate, a certain position of the plot (GPS), and soil moisture were set. Soil moisture at the time of compaction measurement was determined by the Theta probe and is expressed in % vol. Measurements were performed on the inner part of the plot at a depth of 0 to 80 cm in 5 repetitions. Compression results are presented as average and are shown graphically.

Climatic and soil characteristics

Table 1 shows the total monthly precipitation and average monthly temperatures during the maize vegetation period. The total amount of precipitation during the vegetation period, in 2021, was 270 mm. During the same year, in June, July, and August, 103 mm of precipitation fell, so this year can be considered less favorable for corn production. Average temperatures during maize vegetation were 17.7 ^{0}Ci and can be considered favorable for maize production.

Table 1. Precipitation (mm) and mean temperatures (^{0}C) in Leskovac

	Apr.	May	June	July	Avg.	Sep.	Oct.	Apr./Oct.
The 2021 growing season								
mm	45	47	55	44	4	24.0	51	270
^{0}C	10.3	17.4	20.7	24.5	23.7	16.8	10.8	17.7
Multi-year average 1985-2014								
mm	48	46	37	25	24	30	36	246
^{0}C	12.5	16.5	19.5	22.0	22.5	18.0	14.0	17.8

Compared to the multi-year average, the average monthly temperatures in June, July, and August were higher, while the average monthly temperatures in October were lower. Compared to the multi-year average (246 mm), this year had a higher amount of precipitation. Total precipitation during the vegetation was 46 mm higher than the multi-year average. This is especially true for precipitation in critical months, such as June, July, and August.

Table 2. Chemical properties of the soil

Type of soil	pH		Humus	Nitrogen	Available (mg/100g of soil)	
	H_2O	KCl	(%)	(%)	P_2O_5	K_2O
Smonica-Vertisol	6.77	5.89	2.18	0.15	20.5	27.3

Soil acidity was determined by the Kapen method, humus was determined by the Kotzman method, total nitrogen by the Kjeldahl method, and available phosphorus and potassium by the Engner-Riehm Al method.

According to the pH values in KCl (5.89), the soil belongs to the group of moderately acidic soils. According to the content of humus in the arable layer (2.18), the soils belong to the group of poorly humus soils (Škorić, 1991). Based on the content of total nitrogen (0.15), the soil is moderately provided with this element. The phosphorus content of 20.5 mg/100 g shows that the soil is optimally provided with this element. Also, the potassium content of 27.3 mg /100 g indicates the optimal provision with this element. Although these soils belong to the group of potentially fertile lands, their intensive use mainly requires the application of reclamation measures.

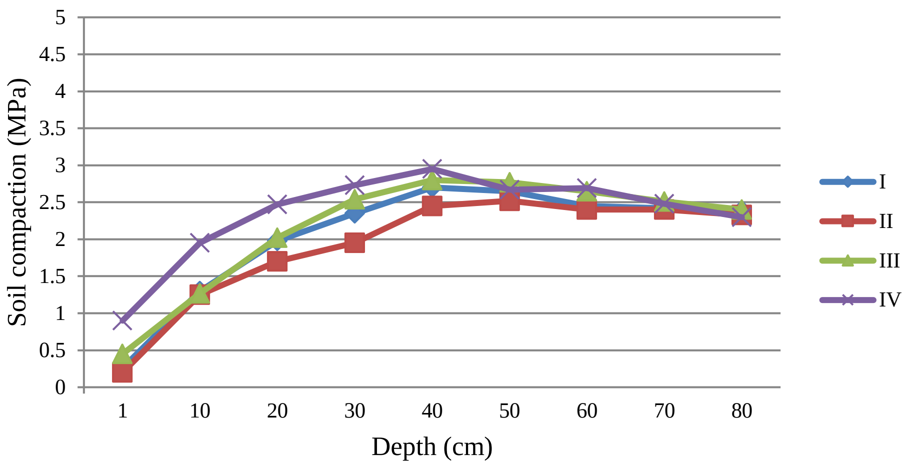
RESEARCH RESULTS AND DISCUSSIONS

Soil compaction

Maize is a highly productive plant species that has pronounced requirements when soil is in question (Bekavac, 2012).

The soil is an extremely dynamic environment and the substrate where the plant makes roots. Root growth depends on the plant species, layer depth, root characteristics, soil compaction, moisture, etc. (Nawaz et al. 2013). Soil compaction, for the most part, is caused by heavy mechanization during various agro-technical operations applied in plant cultivation. In such soils, a difficult absorption of water and nutrients, poorer development of the root system, and slower growth of plants appear which altogether results in poorer plant development and reduced yields. Graf. 1 and 2 shows the compaction of soil depending on fertilization, measured after maize sowing and harvesting.

Graf. 1. Soil compaction after sowing (MPa)



I-manure; II-manure + NPK + KAN; III- NPK + KAN i IV- without fertilizers

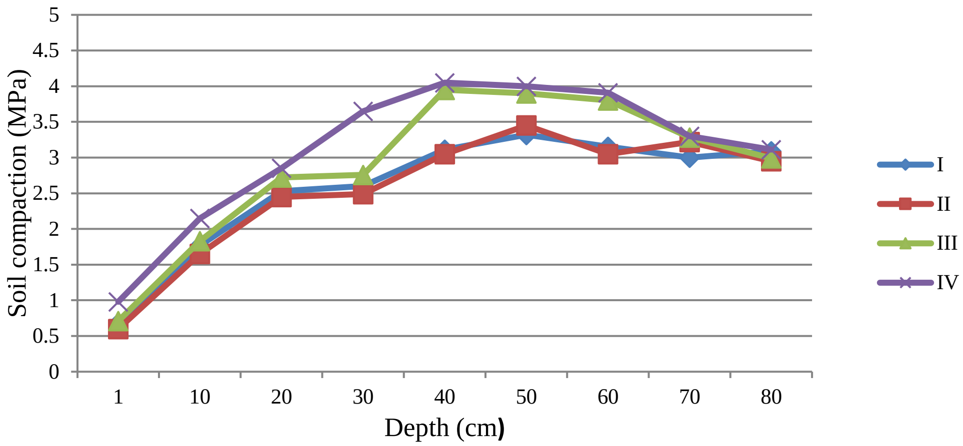
LSD (fertilizations): 0.05-0.16; 0.01-0.21; (depth): 0.05-0.26; 0.01-0.30

Soil compaction, depending on the method of fertilization, was measured at a depth of up to 80 cm, immediately after sowing maize. The average compaction at depths up to 80 cm ranged from 1.91 MPa on variant II to 2.35 MPa on variant IV. The highest (2.35 MP) was on variant IV (without the use of fertilizers) and the lowest (1.91 MPa) on variant II (manure + NPK). Statistically, the use of fertilizers significantly reduced soil compaction compared to the variant without the use of fertilizers. There were no statistically significant differences in soil compaction between variants I and II. Statistically significant differences in soil compaction were found between variants II and III, as well as between variants II and IV.

The average soil compaction for all fertilizer variants ranged from 0.45 MP at a depth of 1 cm to 2.70 MP at a depth of 40 cm. As the depth increased from 40 to 80 cm, the compaction slightly decreased, to 2.35 MP at a depth of 80 cm. A statistically very significant increase in soil compaction was recorded in the profile from 1 to 40 cm, after which the compaction decreased without statistically significant differences.

The average moisture content ranged from 19% when variant IV was in question (without the use of fertilizers) to 22.1% on variant I (where manure was used). The highest moisture content (22.1 and 21.4%) was on variants I and II, where the lowest soil compaction was recorded. These results are in agreement with the results obtained by Savin et al. (2011) who point out that soil moisture reduces compaction.

Graf.2.Soil compaction after harvesting (MPa)



I-manure; II-manure + NPK + KAN; III- NPK + KANi IV- without fertilizers

LSD (fertilizations): 0.05-0.28; 0.01- 0.32; (depth): 0.05-0.31; 0.01-0.42

Soil compaction, depending on the method of fertilization, was measured immediately after harvesting maize (graf. 2). It was found that the average compaction, for all variants of fertilization at a depth of up to 80 cm measured after harvest, was higher by 24.10% compared to that measured after sowing. The average compaction at depths up to 80 cm ranged from 2.54 MP on variant II to 3.11 MP on variant IV. The highest (3.11 MP) was on variant IV (without the use of fertilizers) and the lowest (2.54 MPa) on variant II (manure + NPK). Statistically, the use of fertilizers significantly reduced soil compaction compared to the variant without the use of fertilizers. There were no statistically significant differences in soil compaction between variants I and II, while statistically significant differences in soil compaction were found between variants II and III, as well as between variants II and IV. The variant without the use of fertilizer had significantly higher soil compaction than the variant on which fertilizer was used.

The average soil compaction for all fertilizer variants ranged from 0.74 MP at a depth of 1 cm to 3.67 MP at a depth of 50 cm. With increasing depth from 50 to 80 cm, the compaction decreased slightly, and at a depth of 80 cm, it was 3.03 MP. Statistically very significant increase in soil compaction was recorded in the profile from 1 to 40 cm, and after a depth of 50 cm compaction stagnated and then decreased slightly without statistically significant differences. Our results are consistent with the results of other authors such as Alakuku and Pavo (1994), who point out that soil compaction is not the same in all profiles, and that it is most pronounced up to a depth of 50 cm. Furthermore, many authors (Aliev, 2001; Yavuzcan et al., 2005; Manuwa et al., 2011; Jerzy and Leszek, 2012) emphasize the pronounced compaction of the soil at a depth of up to 50 cm, which is accompanied by more difficult uptake of water and nutrients. The average soil compaction measured after harvest was higher than that measured after sowing by 0.67 MP, which indicates that maize in the second part of the vegetation had poorer soil conditions. Results obtained by Nikolić et al. (2006) and Simikić et al. (2005) show that the resistance measured in the spring is lower than that measured in the fall, which is the result of multiple mechanizations passes during the season. Our results agree with these allegations.

The average moisture content, for all variants of fertilization measured after harvest, was lower by 14.15% compared to that measured after sowing, while compaction in the same period was increased by 24.10%. The average moisture content ranged from 17.5% on variant IV (without the use of fertilizers) to 19.1% on variant II (manure + NPK). The highest moisture content (19.1 and 18.4%) was on variants II and I, where the lowest soil compaction was recorded. These results are in agreement with the results obtained by Savin et al. (2011), who point out that soil moisture affects the reduction of compaction. The data of Ćirić et al. (2008) also shows that the current humidity is a key factor which soil compaction depends on.

Grain yield

In order for maize to achieve high and stable yields, it is necessary to choose the right hybrids, appropriate agricultural techniques, and favorable climatic conditions. Of all the agro-technical measures, special attention is drawn to fertilization. When it comes to heavy soils with poor chemical and mechanical properties, the intake of organic fertilizers, especially manure, is extremely important. Only fertile, well-drained, and aerated soils provide enough oxygen and good activity of microorganisms, thus creating preconditions for high plant yields (ATA 2013). Table 3 shows the yield of maize depending on fertilization.

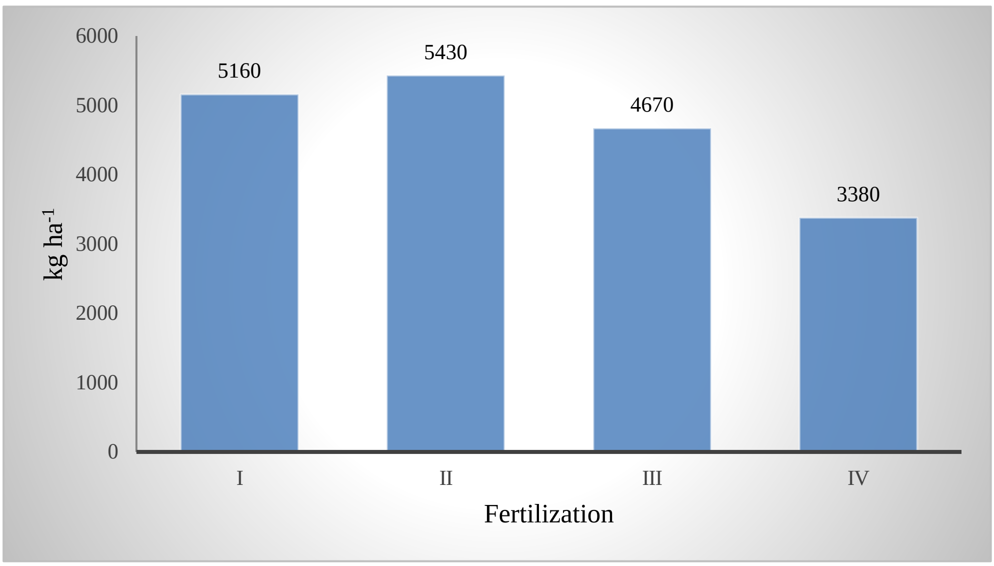
Table 3. Maize grain yield (kg ha^{-1}) depending on fertilization

Yield	Fertilization				Average
	I	II	III	IV	
2021	5160	5430	4670	3380	4660
Reducing (%)	4.42	100	13.99	37.75	

I-manure; II-manure + NPK + KAN; III- NPK + KAN i IV- without fertilizers

The average maize yield for all variants of fertilization was 4660 kg ha^{-1}. The highest yield of 5430 kg ha^{-1} was achieved on variant II, where manure was used in combination with NPK fertilizers. A slightly lower yield of 5160 kg ha^{-1} was achieved on variant I where only manure was applied, and this yield reduction is 4.42%. The yield of 4670 kg ha^{-1} was achieved on variant III, where only NPK fertilizers were applied. This yield reduction, compared to variant II is 13.99%.

Graf. 3. Maize grain yield (kg ha^{-1}) depending on fertilization



I-manure; II-manure + NPK + KAN; III- NPK + KAN; IV- without fertilizers

Wanga et al (2020) says that the combination of organic and mineral fertilizers increases the yield of maize and the use of soil moisture compared to the use of only mineral fertilizers, which is evident in our research. Also, the data of Njoroge et al. (2019) indicate a significant increase in maize yield using manure compared to the usage of mineral fertilizers. The lowest yield of 3380 kg ha^{-1} was achieved on the variant without the use of fertilizers and the yield reduction compared to variant II is 37.75%. When analyzing the results on soil compaction according to fertilization variants, it can be concluded that fertilizers, both manure and NPK fertilizers, influenced the reduction of soil compaction and thus the yield of corn. Results obtained by Riedella et al. (2005) show that there is a negative correlation between soil compaction and maize yield, which is consistent with our results. The data cited by Marinković et al (1999) show that soil compaction directly affects the reduction of yield and this reduction when maize is in question is from 4.7 to 21.3%, which is confirmed by our results. Nevens et al. (2003) point out that maize plants are lower on compacted soil, flowering is late and the yield is lower by 13.2%. Thus, other authors also point to the negative consequences of soil compaction, which are reflected in multiple yield reductions (Friton, 2001; Nikolić et al., 2003; Ramazan et al., 2012).

Based on our results, as well as the results of other researchers, maize producers are advised to apply more organic matter on heavy and compacted soils, primarily manure, but also mineral fertilizers, in order to improve conditions for better growth of the root system, thus achieving higher yields.

CONCLUSION

Based on the results on the impact of fertilization on soil compaction and maize yield, the following can be concluded:

Soil compaction significantly depended on fertilization and soil depth. The application of manure in combination with mineral fertilizers significantly affected the reduction of soil compaction. The average compaction measured after harvest was 24.10% higher than that measured after sowing. The highest compaction was recorded to a depth of 40-50 cm, after which it stagnated and slightly decreased to a depth of 80 cm. The moisture content in the soil was higher on plots with manure and mineral fertilizers than on non-fertilized plots.The yield of maize was significantly higher on the variants where manure was used together with mineral fertilizers in relation to the variants with the use of only mineral fertilizers and the variant without fertilizers. Variants with the lowest soil compaction achieved the highest yields.

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