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Effect of different types of soil tillage for sunflower on some soil physical characteristics. Part I: soil moisture

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Abstract: The investigation was carried out during 2014–2016 in the land of General Toshevo town in the South Dobrudzha region on slightly leached chernozem soil type. The effect of the types of soil tillage for sunflower given bellow was followed: ploughing at 24–26 cm, chisel-plough at 24–26 cm, disking with disk harrow at 10–12 cm and direct sowing (no-tillage) on the soil moisture content. Based on bulk density, wilting point and the determined soil moisture content the plant-available water was calculated. The additional soil tilths of the areas subjected to ploughing, chisel-ploughing and disking with disc harrow included double spring pre-sowing cultivation with harrowing. To destroy the emerging weeds in the variant with direct sowing, a total herbicide was applied. The soil moisture content was evaluated during three main stages of sunflower development: emergence, flowering and technical maturity. The investigated parameter was determined for each of the studied layers – 0–10, 10–20, 20–30, 30–40 and 40–60 cm. In years with normal amounts of rainfalls, no significant differences in the soil moisture under the different ways of soil tillage were observed. Conventional ploughing and tillage without turning of the soil layer contributed to accumulation of more moisture and to higher moisture storage down the soil profile under heavy and intensive rainfalls. Tillage without turning of the soil layer, minimal and no tillage maintained more and better soil moisture in years with limited precipitation and in periods of drought.

Keywords: plant-available water; soil moisture content; soil tillage; sunflower.

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Introduction

Soil is simultaneously a subject and a means of labour in agricultural production. The only agronomy practise through which man exercises direct impact on soil is tillage. The mundane use of one or another soil tillage system without taking into account the specific conditions of a given agro ecological region can deteriorate main soil parameters which are of decisive importance for plant development. This means that it is important for practise to make the right choice of soil tillage that would maintain the physical properties of soil necessary for the normal growth of plants (Jabro et al. 2009). Bulk density, moisture content and temperature are among the primary physical characteristics of the soil which are influenced by the applied soil tillage types (Licht and Al-Kaisi 2005), and which are significant for the normal growth of the agricultural crops.

Permeation of water from rainfalls or thawing snow, as well as the increase and storage of water in the soil profile depends on the amount and intensity of the rainfalls, the temperature of the water and the soil, the slope and form of the terrain, the hydro-physical properties of the soil and its bulk density (Moraru and Rusu 2012). Under the well-expressed water deficiency in the agricultural production observed in the recent years, the effect of the soil tillage is important for the accumulation and storage of moisture in the soil all the year round, and on sloping terrains also for regulation of the water runoff during critical periods of erosion under rainfalls of maximal amount and intensity.

The direct sowing and minimal soil tillage, according to a number of studies, favour the better preservation of moisture in soil, especially in years with lower amounts of rainfalls or in stages which are critical for the development of the crops (Fabrizzi et al. 2005; Fan et al. 2013; Jin et al. 2011; Liu et al. 2013; Romaneckas et al. 2009; Rusu 2014). Other researchers accentuate on the fact that the dynamics of the soil moisture under no tillage and the ploughed areas do not exhibit a significant difference that would affect the productivity of the grown crops (Jabro et al. 2016; Moraru and Rusu 2012). The soils with intensive cultivation contribute to the better utilization of the moisture from rainfalls (Wang et al. 2015) and have higher moisture content during the spring (Lafond et al. 2006; Strudley et al. 2008; Tsuji et al. 2006). Other authors point out that the use of ploughing increases the losses of soil moisture (Azim Zadeh et al. 2002; Halvorson et al. 2000; Mohammadi et al. 2009). Asghari-Meidani (2006) has reported that under dry conditions soil moisture was highest under chisel plough. Shams Abadi and Rafiee (2007), as well as Mohammadi et al. (2009), have also registered the efficiency of chisel plough under drought, and the authors explained this with the improved physical properties of soil when using this type of soil tillage.

Sunflower (*Helianthus annuus* L.) is the most widely distributed technical crop in Bulgaria. This is no coincidence, having in mind that sunflower oil is a traditional vegetable oil consumed in Bulgaria during the past 80 years (Delchev 2013; Delibaltova and Dallev 2017; Tonev 2006; Yanchev and Kirchev 2007). When preparing the areas for planting of sunflower, besides conventional tillage, other technologies come into use, which include other soil tillage tools as well.

The aim of this investigation was to study the effect of different ways of soil tillage for growing of sunflower on the soil moisture of the slightly leached chernozem type.

Materials and methods

Soil and climatic conditions

The investigation was carried out during 2014–2016 in the area of General Toshevo, a town situated in the South Dobrudzha region, which is a part of the Dobrudzha plateau reaching to the north to the mouth of the Danube River in Romania.

The soils are represented by slightly leached chernozems (Yolevsky et al. 1959). Their humus horizon is comparatively thick (60–80 cm), with moderate humic content in the plough layer. The total nitrogen reserve in the surface horizons characterizes these soils as having moderate storage of this macro element. The reserves of P_2O_5 are low to moderate, and of K_2O – from moderate to good. The soil reaction is neutral (pH 6.5–7.4).

The analysis of the meteorological data shows that the investigation was carried out in years with variable climatic conditions (Figure 1). The sum of rainfalls in April was close to the norm only in 2015, while in the other two years of the investigation it was lower. The high amount of rainfalls in June of 2014 should be mentioned, which was with 210.0% above the average long-term value.

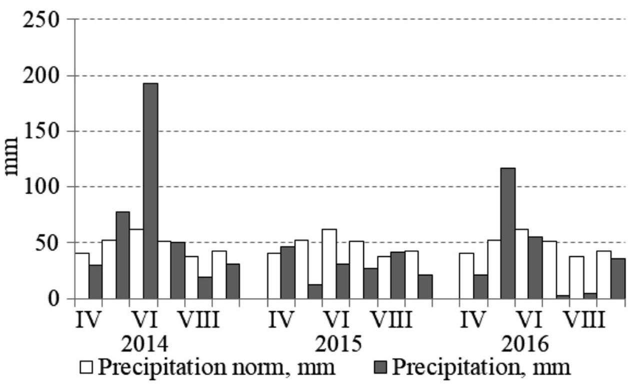

Figure 1: Precipitation during the vegetation period of 2014–2016 (mm).

For the next important month from the vegetative growth of sunflower, July, only year 2014 was close to the climatic norm by the amount of rainfalls. The other two years of the investigation – 2015 and 2016, were drier. In September of 2016, the amount of rainfalls was close to the norm, and in 2014 and 2015, it was with 26.3 and 51.2%, respectively lower than the average long-term norm. During the entire period of vegetative growth of sunflower, the sum of rainfalls was highest in 2014 (with 40.4% above the norm), followed by 2016 (with 17.1% below the norm) and 2015 (with 37.0% below the norm).

Although the amount of rainfalls over the years of the investigation was different, periods of long drought were not observed and therefore they ensured the normal development of the sunflower plants. Sunflower is a plant with wide ecological plasticity and adaptability, which are directly related to its characterization as a comparatively drought-resistant crop (Drumeva and Yankov 2020).

Field experiment

The investigation included for types of soil tillage for sunflower – ploughing at 24–26 cm (CT) – check variant, chisel plough at 24–26 cm (CC), disking with disk harrow at 10–12 cm (DD) and no-tillage (NT). The experiment was designed according to the long plot method. Each variant was tested on a plot being 576 m^2, divided in eight equal replications with size of 72 m^2 (12×6 m). Each plot contained 17 rows of sunflower. In each variant and replication, in rows – 8 and 9, the germinated plants along 2 m by the rows were removed. This was applied at 2 m from the beginning of each of the specified rows. Thus, plots without plants with dimensions of 2×2.1 m were formed, from the centre of which samples were taken to determine the soil moisture content. So, the effect of transpiration of sunflower plants was eliminated and the studied soil tillage variants were better evaluated in terms of their impact on the soil moisture in the studied soil layers. Sunflower was grown after previous crop wheat. Soil tillage for wheat included double disking with disk harrows at 10–12 cm after harvesting of sunflower.

After wheat harvesting, no intermediate tillage has been applied and the soil tillage for sunflower was performed early in August. The additional soil tillage of the areas cultivated with ploughing, chisel-plough and disking included double spring pre-sowing cultivation with harrowing. To destroy the emerging weeds in the variant with no-tillage, a total herbicide was applied once or twice. In the cases with heavy infestation with weeds, spraying in the autumn and in spring, prior to sowing, was done. Only a single pre-sowing spraying was applied when there were no weeds.

Nitrogen fertilization of sunflower was applied with 60 kg N/ha. Ammonium nitrite was used. In all variants involving soil tillage for sunflower, the nitrogen fertilizer was applied once in spring, prior to the last pre-sowing soil tillage. The experiment was performed against the same phosphorus background – 120 kg P_2O_5/ha. Triple superphosphate was applied after harvesting of the crops, prior to the soil tillage. Potassium fertilizer was not necessary to be applied because the soils in the area do not suffer from the lack of this macronutrient. In the variant with no tillage, the mineral fertilizers were sprinkled on the soil surface without incorporation.

Sunflower was planted at sowing norm 65,000 plants/ha. The weeds emerging during the vegetative growth of the crop were controlled in all tested variants by using the appropriate herbicide.

Soil moisture

The soil moisture was determined by soil samples taken with a probe from each of the studied layers – 0–10, 10–20, 20–30, 30–40 and 40–60 cm. Three samples were taken from each replication of the variants, from plantless plots at the following periods: at emergence of sunflower, at flowering stage and at technical maturity. Immediately after taking, the soil samples were weighed and dried at 105 °C to constant weight. Then they were weighed again to determine the soil moisture content in each layer. Based on the determined moisture content and the soil bulk density in the respective layer, the total soil water storage was determined. Based on the difference between it and the non-productive moisture content, the productive moisture content in soil was calculated. For the soil layers 0–10, 10–20 and 20–30 cm we have used our results, some of which were already published in the second part of this study (Yankov and Drumeva 2020). Data of Yolevsky et al. (1959) were used for the bulk density of soil in the 30–40 and 40–60 layers, as well as the wilting point of the slightly leached chernozem soils.

Statistical analysis

The analysis of variance (ANOVA) was carried out to follow the statistical significance in the differences of the values of the investigated soil moisture under different types of tillage when growing sunflower. Mean comparisons were performed using the Fisher's LSD (the least significant difference) test at $P < 0.05$, 0.01 and 0.001.

Results and discussion

Moisture content is a limiting factor of agricultural production in South Dobrudzha. The amount of rainfalls over the years of the investigation and the vegetative growth of sunflower varied. Therefore, in each economic year and main stage of the crop development, their effect and post effect on the productive moisture content were considered under the investigated soil tillage types. The effect of the tillage on the water regime of soil includes the three major moments of the infiltration process – water absorption, rate of filtration and water retention. Provided all other conditions are equal, the water absorption capacity is determined by the degree of soil loosening, while the filtration rate and the water retention capacity are conditioned by the changes in the internal and physical structure of the soil.

The results from the multi-factor dispersion analysis showed that all investigated factors had significant effect on the content of the productive moisture in soil at $P = 0.001$ (Table 1). Their combined double interaction was also significant at $P = 0.001$, with the exception of the combination "soil tillage × depth of layer". This combination of factors was probably not statistically significant due to the fact that 26 cm was the highest depth to which the investigated types of tillage were

Table 1: Results from the analysis of variance dispersion analysis on the effect of the investigated factors on the plant-available water.

Source	df	Mean Square	*F*	Sig.
Year conditions (A)	2	13,718.378	195.214	0.000
Crop stage (B)	2	267,439.722	3.806	0.000
Soil tillage (C)	3	2373.423	33.774	0.000
Depth of layer (D)	4	27,855.611	396.388	0.000
A × B	4	13,941.810	198.393	0.000
A × C	6	915.146	13.023	0.000
A × D	8	397.809	5.661	0.000
B × C	6	672.557	9.571	0.000
B × D	8	1168.734	16.631	0.000
C × D	12	57.333	0.816	0.634
A × B × C	12	813.849	11.581	0.000
A × B × D	16	691.697	9.843	0.000
A × C × D	24	20.621	0.293	1.000
B × C × D	24	56.787	0.808	0.727
A × B × C × D	48	42.742	0.608	0.982

performed, while the values of the studied parameter were followed to 60 cm. Of the triple interaction, statistically significant at $P = 0.001$ were the combinations “year conditions × crop stage × soil tillage type” and “year conditions × crop stage × depth of layer”. The rest of the triple combinations, as well as the combined quadruple interaction of the investigated factors were not significant.

The plant-available water estimated in April at sunflower emergence varied according to the applied types of soil tillage and the amount of autumn and winter rainfalls (Figure 2). In two of the years, 2015 and 2016, the soil moisture in the investigated layer was highest under ploughing and chisel plough. There were no statistically significant differences between these two variants with regard to the value of the studied parameter. The above two types of soil tillage were followed by disking with disk harrow and direct sowing. Under them, the plant-available water in the all 0–60 cm layers was with 6.0 and 9.7% lower, respectively, in comparison to the check variant, averaged for the two years. There were no significant differences in the soil moisture between disking and ploughing in 2014. In 2015, these differences were significant for some of the investigated layers at different levels of probability.

The lower amount of soil moisture in the soil with minimal and no tillage in these two years as compared to the ploughed and chisel-ploughed soil can be explained by the amount of rainfalls during the autumn-and-winter period and in April, and with the different water uptake from them. In 2014 and 2015, the rainfalls

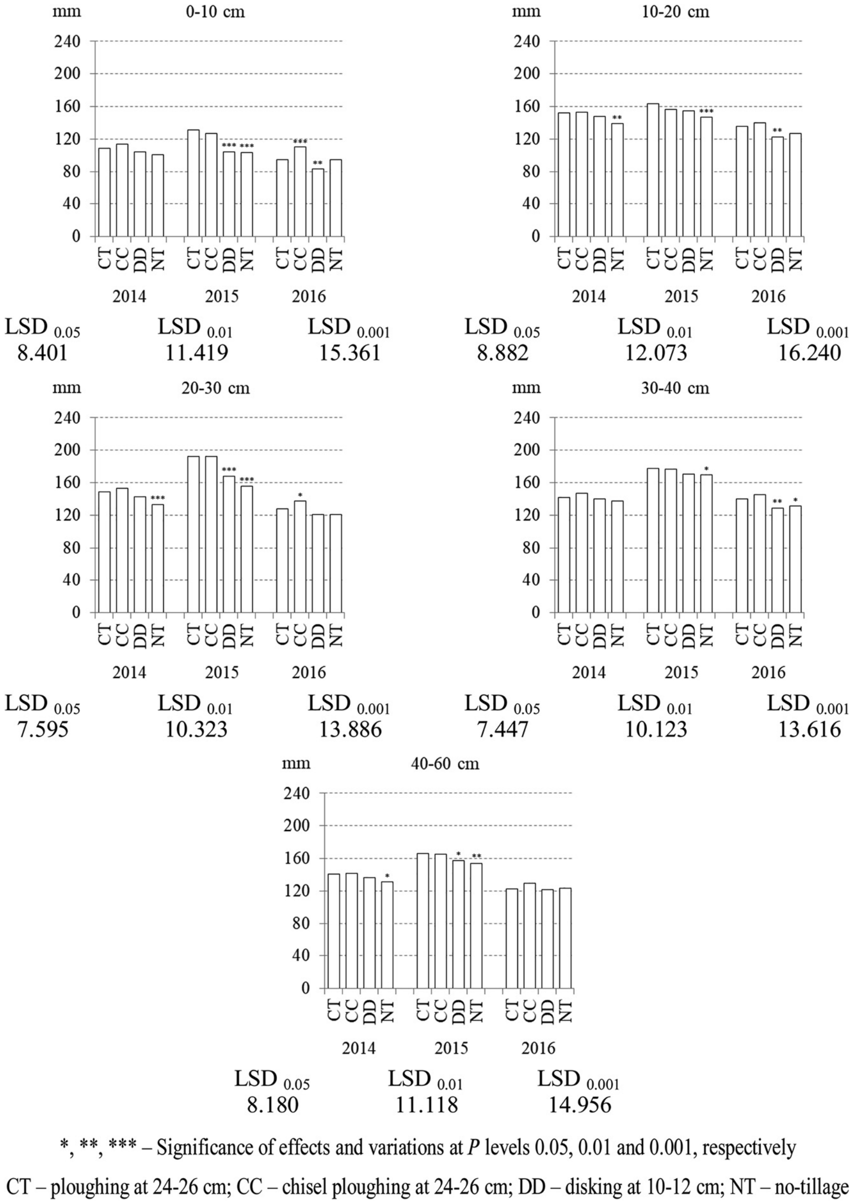

Figure 2: Plant-available water at sunflower emergence under different soil tillage types (mm).

from the beginning of October to the end of March were with 13.0 and 30.2%, respectively higher than the long-term sum. This amount of autumn and winter moisture reflected on its content in the soil layers in areas with different types of soil tillage in spite of the fact that in April of 2014 the amount of rainfalls was lower, and in 2015 it was equal to the climatic norm.

Ploughing and chisel-plough of this soil type, when done in August, which is usually a dry month in these geographic latitudes, causes the formation of larger soil units and fissures, which increase the non-capillary porosity of the cultivated soil layer. This favors the water absorption and infiltration to the lower horizons in periods with more abundant rainfalls. Other authors also reported higher moisture content under conventional ploughing (Gbadamosi 2013; Heidarpur et al. 2011; Strudley et al. 2008; Wang et al. 2015). In the areas with minimal and no-tillage, the surface layer is slightly loose or more compact under the effect of climatic factors and therefore, the water absorption, the infiltration rate and the moisture reserves are lower in comparison to the areas with intensive tillage. The lower water permeability of these areas forms greater surface run-off water flow. The same period in 2016 was dryer: the autumn and winter rainfalls were with 9.7%, and in April with 49.3% lower than the norm. Under these conditions, the highest content of productive moisture was registered in the areas with chisel plough. The differences between the values of the investigated parameter in this variant and under ploughing in the 0–10 and 20–30 cm layers were significant at different levels of probability.

Some authors also reported higher moisture content in chisel-ploughed soils in dry years in relation to the improvement of the physical properties of soil (Asghari-Meidani 2006; Mohammadi et al. 2009; Shams Abadi and Rafiee 2007). The content of soil moisture in the investigated horizon under disking with disk harrow was with averagely 7.0% lower in comparison to the areas with ploughing. The differences were significant for layers 0–10, 10–20 and 30–40 cm, at $P = 0.01$. Under direct sowing, the plant-available water was with 3.7% less than under ploughing. Statistically significant was only the difference for layer 30–40 cm at $P = 0.05$.

In periods with lesser rainfalls, the lower productive moisture in the cultivated soil layer in the areas with ploughing and minimal tillage can be explained with its loss via capillaries due to the soil crust formed on the surface when the soil dries, and with the formation of fissures increasing the evaporating surface. In such periods, under chisel plough and direct sowing the plant residues, which remain on the surface, function as mulch. It reduces the contact between the soil and the atmosphere, decreases soil temperature and evaporation (Zhang et al. 2009), and therefore the soil moisture is better stored in the surface soil layers after these types of soil tillage. Other authors have also reported higher moisture content under no-tillage in comparison to the conventional one (Fabrizzi et al. 2005; Jin et al. 2011; Kühling et al. 2017).

The rainfalls in July of 2014, when flowering of the crop occurred, were close to the climatic norm; in the previous month of June, however, the amount of precipitation exceeded with 210.0% the long-term sum. These rainfalls affected the content of productive moisture in the investigated soil horizon under the different types of soil tillage (Figure 3). The highest amount of soil moisture in the all 0–60 cm layers was registered in the ploughed areas. They were followed by the areas with chisel plough, minimal and no-tillage. The statistical results for the separate soil layers were significant at different levels of probability. The findings of Kühling et al. (2017) were the opposite; according to them, in years with rainfalls exceeding the mean amounts, the soil moisture content in the areas with direct sowing was significantly higher during the entire vegetative growth of the crop. Slawiñski et al. (2012) determined higher percentage of moisture content in the variant with chisel plough in the soil profile down to 30 cm in the soil types Fluvisol and Cambisol.

In spite of the natural soil subsidence of the slightly leached chernozem, after leaving it to rest during the vegetative growth of sunflower, the ploughed areas became looser in comparison to the areas cultivated with other soil tillage tools. In humid periods, this determined their greater water absorption capacity and their better moisture storage along the soil profile.

The same period of 2015 and 2016 was characterized by amounts of rainfalls under the norm. There were no significant differences in the content of productive moisture in the investigated layers under the separate type of tillage in 2015. A probable reason for the absence of significant differences in the content of soil moisture in the studied types of soil tillage is that the main amount of rainfalls for the month was in the first decade, which coincided with the flowering stage of sunflower and the time of taking soil samples.

The rainfalls in July of 2016 were very little and constituted only 5.4% of the norm for this month. Under these conditions, the highest content of productive moisture was registered in the variant with chisel plough. The differences were significant for layers 10–20, 20–30 and 30–40 cm at different levels of probability. This variant was followed by direct sowing, with differences significant for layers 10–20 cm ($P = 0.05$) and 20–30 cm ($P = 0.01$). There was no significant difference in the content of soil moisture between the areas with ploughing and disking. These results outlined a tendency towards better storage of moisture in the slightly leached chernozem soils during periods of drought by using chisel plough and direct sowing. Other authors have also reported similar results (Fabrizzi et al. 2005; Heidarpur et al. 2011; Romaneckas et al. 2009).

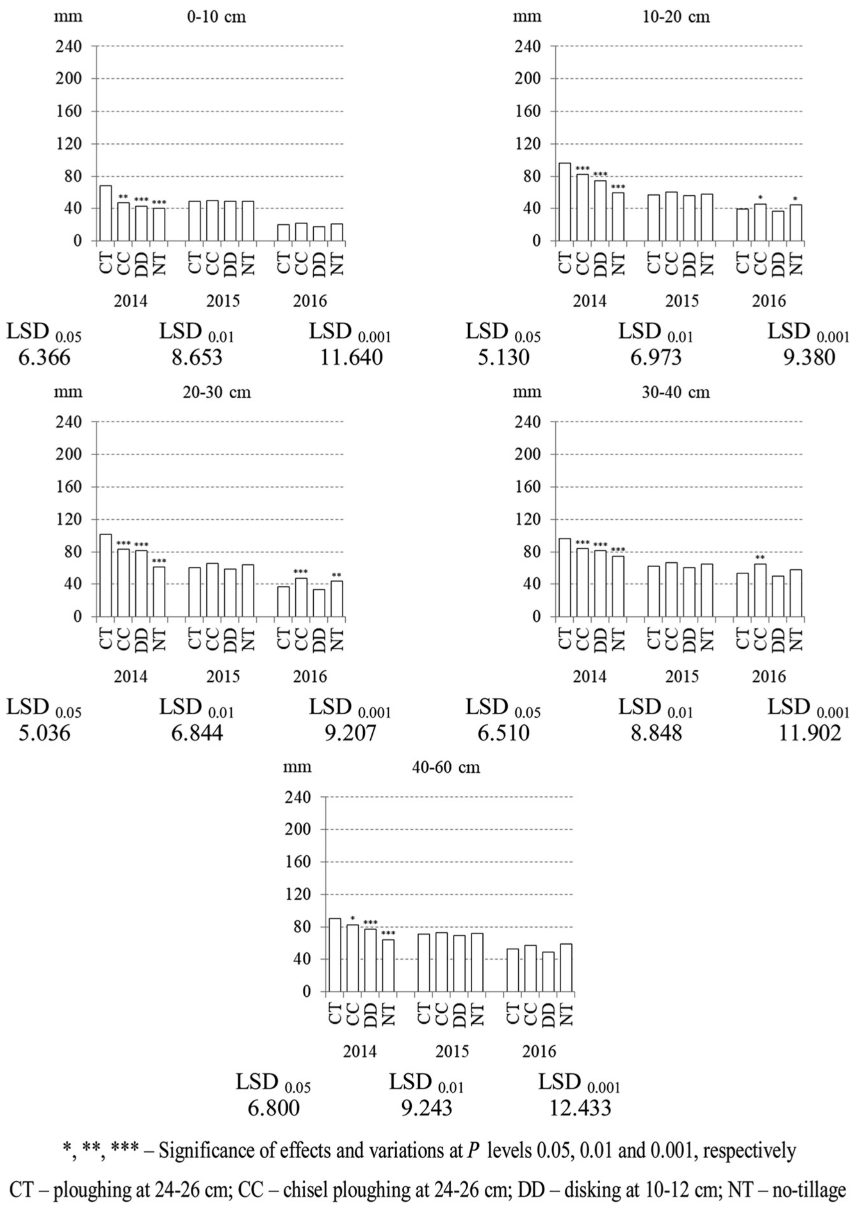

Figure 3: Plant-available water at flowering stage of sunflower under different types of soil tillage (mm).

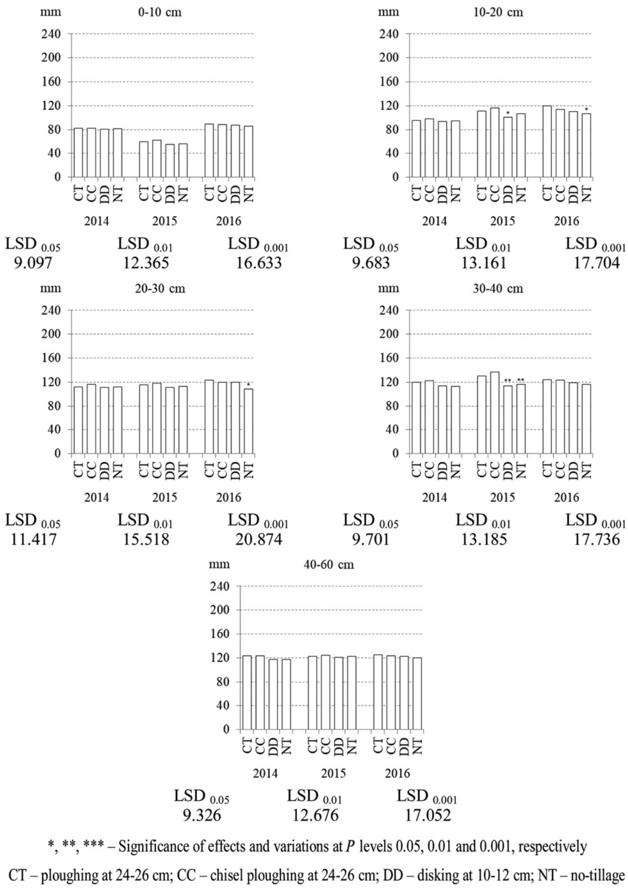

Figure 4: Plant-available water at stage technical maturity of sunflower under different types of soil tillage (mm).

The differences in the productive moisture between the separate soil tillage types decreased at stage technical maturity of sunflower (Figure 4). In 2014, a year characterized as humid during the entire vegetative growth of sunflower (April–September), the rainfalls in September were with 26.3% lower than the long-term sum. Under these conditions, significant differences in the content of soil moisture under the separate soil tillage types were not observed in the investigated layers. The same period of 2015 was characterized with rainfalls, which were with 51.2% below the climatic norm.

The period of the vegetative growth of the plants in this year was also dry – the precipitation was with 37.0% less than the long-term sum. There were no significant differences in the productive moisture between the areas with chisel plough and with ploughing. Under disking with disk harrow, the plant-available water in layers 10–20 cm (P = 0.05) and 30–40 cm (P = 0.01) was less than under ploughing. Under direct sowing, the difference was statistically significant only for layer 30–40 cm (P = 0.01). The amount of rainfalls in September of 2016 was close to the climatic norm, and during April–September, it was with 17.1% lower than the long-term sum. No significant differences were found in the content of soil moisture in the investigated layers between the areas with ploughing, chisel plough or disking. Only after direct sowing, the lower amount of productive moisture in layers 10–20 cm and 20–30 cm was significant at P = 0.05 in comparison to ploughing.

At the end of the vegetative growth, the transpiration and water uptake of the sunflower plants strongly decreased. This time of the year is usually hot and dry in this part of South Dobrudzha. The absence of significant differences in the content of productive moisture in the studied layers was an indication of comparatively equal values of this parameter under the investigated soil tillage types under these conditions. The soil, left to rest since April, tended towards its natural state under the different soil tillage types over time. The bulk density, and hence, the capillary porosity increased. This led to more intensive loss of moisture via the capillaries, both from the surface and from the underlying soil horizons. The formed fissures also increased the evaporating surface. After chisel plough and direct sowing, a part of the plant residues mineralized and their mulching effect decreased. Moraru and Rusu (2012) have also pointed out that the differences in the soil moisture content between the separate soil tillage types decrease over time.

Conclusions

In years with normal amount of rainfalls, considerable differences in the soil moisture under the different types of soil tillage were not observed. Conventional ploughing and tillage without turning of the soil layer contributed to the accumulation of more moisture and better moisture storage down the soil profile under conditions of abundant and intensive rainfalls. The tillage without turning of the soil layer, the minimal and no-tillage better and more completely maintained the soil moisture in years with limited amounts of rainfalls and in periods of drought.

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