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EFFECT OF THE SOIL TILLAGE SYSTEM ON THE ROOT DEVELOPMENT OF MAIZE

Peter Yankov* **and Miglena Drumeva**

Department of Plant Production, Shipbuilding Faculty,
Technical University Varna, Varna, Bulgaria
*Corresponding author. E-mail: p_s_yankov@abv.bg

ABSTRACT

The investigation was carried out during 2008-2010 in the trial field of Dobrudzha Agricultural Institute on slightly leached chernozem. With a view of clarifying the effect of alternated soil tillage on the development of the maize roots, the following variants of a stationary field trial were analysed: ploughing at 24-26 cm for maize – disking at 10-12 cm for wheat (check variant); chisel plough at 24-26 cm for maize – chisel plough at 8-10 cm for wheat; disking at 10-12 cm for maize – disking at 10-12 cm for wheat; no-tillage (direct sowing) for maize – no-tillage (direct sowing) for wheat. The root development of maize was followed by layers at every 10 cm in the 0-50 cm profile through measuring the soil units of size 30x30x10 cm. The soil samples were taken at stage milk maturity. The root mass was determined at air humidity. The variations of the maize root weight by layers in the investigated profile, depending on the soil tillage system in the crop rotation, were statistically significant. The root mass of maize formed till stage milk maturity was highest after alternation of deep and shallow chisel ploughing. In the ploughing-disking system, the amount of maize roots was lower but they were more evenly distributed down the investigated soil profile. The long-term alternation of both disking and no-tillage reduced the mass of maize roots in the active soil layer at this stage of the crop's vegetative development. After annual alternation of minimal soil tillage with direct sowing, there was higher differentiation of the root system down the layers of the soil profile. Most of maize roots were concentrated in the surface soil layers while their amount in the zone under the depth of the shallow disking strongly decreased.

Key words: maize, root mass, soil tillage systems.

INTRODUCTION

Roots are the only parts of the plants providing direct contact with the soil, which is their source of nutrients and moisture. Root growth is determined both by plant genetic characters and by soil physical and chemical properties (Muñoz-Romero et al., 2010). Clark et al. (2003) suggested that the ability of roots to grow and explore the soil for water and nutrients is a key determinant of plant growth rates. The major factors influencing root growth are: an appropriate pore system into which roots can grow, root impedance, soil water content, soil temperature, oxygen and nutrient supply (Johnson et al., 2006).

Tillage is the only agronomy practice through which man can directly influence soil. Depending on how properly the soil tillage systems have been applied, the main soil characteristics can either improve or deteriorate, which is critical for plant development. Therefore a number of authors point out that a strictly differential approach is required when choosing the way of soil tillage in crop rotation according to the conditions of a given agro ecological region, taking onto consideration all local specifics (Malhi and Lemke, 2007; Liu et al., 2009; Kravchenko, 2010; Kvasha and Dmitriev, 2013).

According to Bronick and Lal (2004) the changes in the composition and structure of soil caused by the tillage are very important for the soil moisture and aeration regime and for the growth and development of the plant roots.

Li et al. (2002) have pointed out that the negative effect of soil compaction on plants is related to both the greater resistance to the penetration of their roots down the soil and to the decrease of their shoot mass leading to lower efficiency of mineral nutrients and soil moisture uptake and to less intensive transpiration.

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Besides ploughing and disking, various modifications of both minimal tillage and tillage without turning of the soil layer, and direct sowing of the agricultural crops have found their place in the agricultural practice during the last decades. They help to protect soil from erosion, preserve the available soil moisture, reduce the energy and labor expenses, reduce the moves of the agricultural machines on the field surface when performing the necessary agronomy cultivation for growing of the crops, etc.

A considerable part of the plant roots is concentrated in the 0-10 cm layer, from which the plants extract moisture and nutrients. This layer is very risky with regard to the evenly distributed and optimal moisture content and hence – with regard to the accessibility to nutrients for the agricultural crops. In comparison to ploughing, some compaction of soil occurs at the depth of the plough layer after no-tillage; this compaction, although within the range of the optimum, makes difficult the penetration of roots to the underlying soil layers and their access to water and nutrient (Tsvetanova-Lazarova and Stoychev, 1987; Stoynev and Sabev, 1990; Chan and Mead, 1992; Chassot et al., 2001; Sainju et al., 2005).

For its normal development, maize requires well cultivated soil providing a suitable bed for planting of seeds, their even vertical and horizontal distribution and uniform emergence, and ensuring unobstructed development of their roots in the ploughing and underlying layers (Ilyn and Ilyn, 2001; Kashevarov et al., 2004; Shpaar, 2006).

Investigating the effect of soil tillage and initial fertilization on the development of the maize roots, Qin et al. (2005) found out that the density of maize roots was significantly higher in the 25 cm layer after ploughing in comparison to direct sowing. The authors concluded that root growth depended on the soil tillage and the initial fertilization but was primarily a function of the year, the soil type and the depth.

Mosaddeghi et al. (2009) also reported higher mass of maize roots after conventional soil tillage.

Klochkov (1983) pointed out that the variations of maize roots weight over layers and depending on the type of soil tillage were observed in the layers up to depth 30 cm. The relative percent of roots in this soil horizon was higher after minimal and no-tillage in comparison to the deeper more intensive types of tillage.

The aim of this investigation was to follow the effect of some systems of soil tillage on the development of maize roots.

MATERIAL AND METHODS

The field experiments were carried out during 2008-2010 in the experimental field of Dobrudzha Agricultural Institute – General Toshevo on slightly leached chernozem soil type [1]. The mechanical composition of these soil types determines favourable moisture and aeration regime (Yolevsky et al., 1959). The depth of the humus horizon was about 70 cm, the mean content of humus in the plough layer being 3.7%. Soil reaction was neutral.

In a stationary field trial initiated in 1987, twenty-four soil tillage systems have been tested based on different soil tillage tools and operations. The design of the variants was according to the non-standard method carried out in two parallel crop rotations. The size of the trial plots was 25 m^2. The agricultural crops typical for this region (wheat, sunflower, bean and grain maize) were involved in a 6-field crop rotation.

The data on air temperature showed that April, at the end of which emergence of the maize plants occurred, was warmer than normal in 2008 and 2010 (Figure 1).

The mean diurnal air temperature in April of 2008 was lower than normal. The rest of the months, in which the active vegetation of maize occurred, were warmer than the norm. The sum of the vegetation rainfalls in 2010 was with 29.0% higher than the precipitation norm. In one of the years the amount of rainfalls was close to the long term climatic sum (2008). Year 2009 was with lower sum of vegetation rainfalls – 206.4 mm, which constituted 83.5% from the mean long-term sum. Although the amount of rainfalls varied over the years of the investigation, they had comparatively even distribution providing normal development of the maize plants.

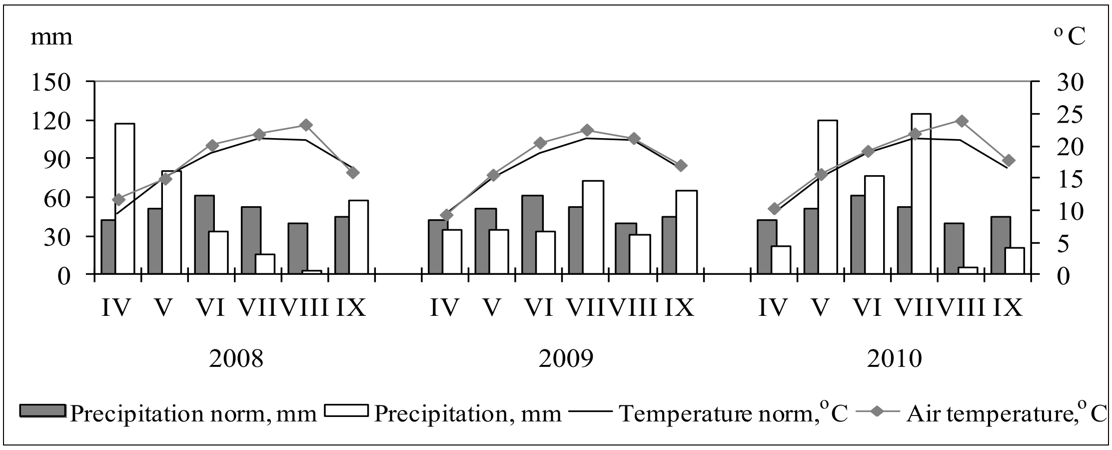


Figure 1. Air temperature and precipitation during the vegetation period of 2008-2010

With the aim to clarify the effect of the alternation of soil tillage types on the development of the roots of maize, the following variants of the stationary field trial were analysed:

• ploughing at 24-26 cm for maize – disking at 10-12 cm for wheat (check variant);

• chisel plough at 24-26 cm for maize – chisel plough at 8-10 cm for wheat;

• disking at 10-12 cm for maize – disking at 10-12 cm for wheat;

• no-tillage (direct sowing) for maize – no-tillage (direct sowing) for wheat.

All types of soil tillage for maize (with the exception of no-tillage) included additional single disking in autumn and pre-sowing cultivation by harrowing in spring. To control the weeds emerging in the variant with direct sowing, single or double treatment with total herbicide was applied. In cases of strong weed infestation, treatment in autumn and in spring prior to sowing was used. Only a single pre-sowing treatment was applied when there were no weeds.

Maize was fertilized with $N_{160}P_0K_{80}$. Phosphorus was not introduced because the post-effect of the phosphorus fertilizers applied on wheat was utilized. Treatment with potassium was done before main soil tillage, and nitrogen was applied prior to sowing. Maize hybrid Anasta was planted manually at density 55000 plants/ha. Weeds were controlled by using suitable vegetation herbicides. Mechanical post-planting tillage in the investigated variants of soil tillage was not done.

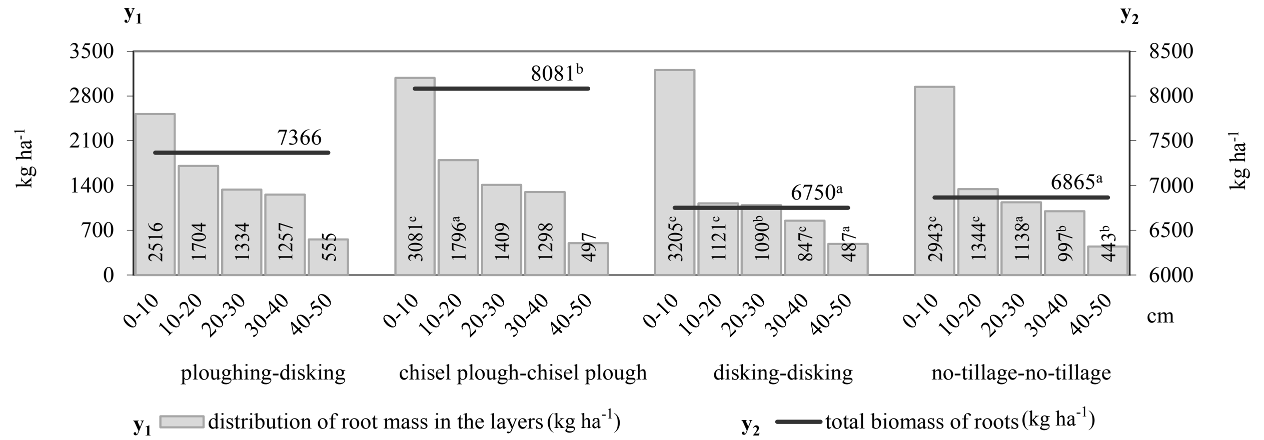
The development of the root system was followed by layers every 10 cm down the 0-50 cm profile through washing the soil units of size 30x30x10 cm. The soil samples were taken at stage milk maturity. The root mass was measured at air humidity.

Data were processed statistically with the help of software SPSS 16.0 and Microsoft Excel 2007.

RESULTS AND DISCUSSION

The analysis of the obtained results showed that the roots of maize grown after wheat and chisel ploughing as main soil tillage developed best, and the roots of maize grown after direct sowing and constant disking were least developed – the variations were significant at different levels of P (Figure 2). After alternating chisel ploughing at different depths, the weight of the root mass in the 0-50 cm layer was 8081 kg ha^{-1}, and in the variant with annual disking – 6750 kg ha^{-1}. In the system ploughing - disking the total weight of maize roots was 7366 kg ha^{-1}. The root mass reached 6865 kg ha^{-1} after long-term no-tillage.

After annual disking at the same depth, 47.5% of the total amount of roots was positioned in the surface (0-10 cm) layer to depth 50 cm. By root mass in this horizon constant direct sowing ranked second with 42.9%, followed by chisel ploughing without turning of the soil layer with 38.1%. Comparatively lowest was the amount of roots in the 0-10 cm layer after alternation of deep ploughing with shallow disking – 34.2% from their total mass in the investigated soil profile. Differences between studied soil tillage systems and check variant were statistically significant at p=0.001.



Soil layer	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$	Soil layer	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
0-10 cm	122.67	185.83	298.72	30-40 cm	152.70	231.33	371.86
10-20 cm	79.03	119.73	192.46	40-50 cm	65.37	99.02	159.18
20-30 cm	156.77	237.49	381.77	0-50 cm	466.73	707.06	1136.60

Figure 2. Root mass and their distribution in soil layers at stage milk maturity of maize plants grown in different soil tillage systems (kg ha^{-1})

To the maximum measured weight of roots in the surface layer of the soil cultivated for a long period at the same depth with disking tools corresponded the lowest amount of roots in the underlying soil horizons (10-40 cm) – statistically significant at different levels of p. In the 10-20 cm layer the mass of maize roots was highest after the system chisel plough - chisel plough – 1796 kg ha^{-1}, statistically significant at p=0.05. It is interesting to mention the fact that after alternation of ploughing with disking the roots of maize were relatively evenly distributed down the soil profile. As a result, after this soil tillage system, the percent of roots from their total biomass in the 10-20 cm layer was highest – 23.1%. At this depth the amount of roots under constant direct sowing was 1344 kg ha^{-1} or 19.6% from the total biomass of roots in the investigated soil profile.

Under the system ploughing - disking, 18.1% from the total amount of roots were positioned in the 20-30 cm layer. The alternation of deep and shallow chisel ploughing ranked second with 17.4%. Differences between these soil tillage systems were not statistically significant. The distribution of the total root mass in this soil layer was 16.6% at constant direct sowing and 16.1% at annual disking. The differences between these soil tillage systems and check variant are statistically significant at different levels of p. At depth 30-40 cm the trend observed in the topsoil horizon was the same, the percent of maize roots under the investigated soil tillage systems decreasing.

Under the system chisel plough - chisel plough, 6.2% of the total root mass was positioned in the 40-50 cm layer, under direct sowing – 6.5%, under constant disking – 7.2% and under alternation of ploughing with disking – 7.5%. The lower mass of roots of maize plants established at direct sowing and annual disking was statistically significant at different levels of p to the check variant.

The analysis of variances revealed that the effect of the investigated soil tillage systems on the distribution of the roots of the maize plants at stage milk maturity in the 0-50 cm horizon by layers was significant (Table 1). The influence of this factor on the investigated trait was statistically significant at p=0.001 for the 0-10, 10-20, and 30-40 cm layers, and at p=0.01 for the 20-30 cm layer. At depth 40-50 cm the impact of the applied soil tillage systems on the quantitative distribution of the maize roots was significant at p=0.05.

Table 1. Analysis of variance for the impact of the studied factor on distribution of root mass of maize

Depth	df	Mean Square	F
0-10 cm	3	2698.348	18.902
Error	8	142.755	
10-20 cm	3	2969.028	24.444
Error	8	121.463	
20-30 cm	3	702.708	11.847
Error	8	59.317	
30-40 cm	3	1384.707	22.998
Error	8	60.210	
40-50 cm	3	63.710	6.643
Error	8	9.590	

According to Duncan's test, the investigated soil tillage systems fell within different groups (Table 2). In the 0-10 cm layer, depending on the amount of roots after the investigated soil tillage systems, three groups were formed. The first group included the alternation of ploughing with disking, and was "worse" with regard to the investigated trait at this depth. The second group included the systems chisel plough - chisel plough and no-tillage - no-tillage. The alternation of deep and shallow chisel ploughing belonged to the third group, which was "best" with regard to the studied trait together with annual disking at 10-12 cm. A probable reason for this is the more even distribution of soil moisture in this horizon under the tillage without turning of the soil layer and the minimal and no-tillage (Yankov, 2002).

At depth 10-20 cm, according to the test, there were again three groups formed. Under constant disking, the greater soil density impeded the development of maize roots in this layer and therefore it fell to the "most unfavorable group".

The reason for the greater soil density after this soil tillage system is the strong powdering of the soil structure and the annual compaction of the zone immediately underlying the cultivated layer caused by the soil tillage tools (Yankov, 2007). Next was direct sowing. The systems ploughing - disking and chisel plough - chisel plough belonged to the third and best group with regard to the investigated trait.

Table 2. Statistical clustering of the soil tillage systems based on the layer distribution of root mass of maize (Duncan)

Soil tillage system	Depth (cm)				
	0-10	10-20	20-30	30-40	40-50
	Groups (Values)				
Ploughing 24-26 cm – Disking 10-12 cm	a (2516)	c (1704)	b (1334)	c (1257)	b (555)
Chisel plough 24-26 cm – Chisel plough 8-10 cm	b, c (3081)	c (1796)	b (1409)	c (1298)	a, b (497)
Disking 10-12 cm – Disking 10-12 cm	c (3205)	a (1121)	a (1090)	a (847)	a (487)
No-tillage – No-tillage	b (2943)	b (1344)	a (1138)	b (997)	a (443)

Two groups were outlined in the 20-30 cm layer. The systems with minimal and no-tillage were referred to the first of them, and the second one included ploughing - disking and chisel plough - chisel plough. The alternation of shallow and deep tillage contributed to soil density more favourable for the development of the roots of the plants down the soil profile. According to the test, the investigated soil tillage systems were divided into three groups in the 30-40 cm layer. The annual disking still had unfavourable effect on the development of the maize roots in this layer as well. It was followed by direct sowing. The less favourable effect of no-tillage on maize root mass in comparison to the systems ploughing - disking and chisel plough - chisel plough was probably due to the greater soil compactness resulting from the activity of the physical and climatic factors. The test placed the alternation of ploughing with disking in the third group "most favorable" for the development of maize roots down the soil profile. It included also the system chisel plough - chisel plough. This soil tillage without turning of the layer contributed to the normal growth of the maize roots to the underlying layers because of the fact that it did not form compacted horizons and preserved the natural structure of soil. Stoynev and Georgiev (1984) pointed out that the deep loosening of the soil facilitated the water filtration and the penetration of the roots to greater depth.

In the last investigated layer (40-50 cm) the test divided the studied soil tillage systems into two groups by the amount of the maize roots. The first group included annual disking, direct sowing and the alternation of shallow with deep chisel ploughing in crop rotation, which were “bad” with regard to the investigated trait at this depth. The system chisel plough - chisel plough fell into the second, “more favourable” group with regard to the investigated index, together with the alternation of ploughing with disking. Duncan’s test confirmed the favourable effect of the lower soil density after the deeper more intensive types of soil tillage on the growth of roots down the soil profile. Similar conclusions were made by Dao (1993), who pointed out that the compaction of the underlying layers deteriorated aeration and water infiltration, impeded the development of the root and the shoot parts of the plants thus decreasing the yield from them.

Based on the results from the distribution of the soil tillage systems in groups in the 0-50 cm soil profile, application of deepening main soil tillage of the spring crop involved in the crop rotation can be recommended every 3 to 5 years in order to sustain and improve the physical properties of soil. Thus normal and powerful development will be ensured down the soil profile of the roots of this crop, as well as of the autumn previous crops; this root development will allow more fully utilizing the soil moisture and the nutrients from the underlying horizons.

CONCLUSIONS

The variations of the weight of maize roots in the investigated soil profile by layers depending on the soil tillage system in the crop rotation were significant.

The formation of the root mass of maize at stage milk maturity was highest after alternation of deep and shallow chisel ploughing.

In the system ploughing - disking the amount of maize roots was lower but they had more even distribution down the investigated soil profile.

The long-term alternation of both disking and no-tillage decreased the root mass of maize at this stage of its vegetative development in the active soil layer. At annual alternation of minimal tillage with direct sowing, the differentiation of the roots down the investigated layers increased. Applying this system, most of the roots concentrated in the surface layers, and their amount in the zone lying under the depth of shallow disking strongly decreased.

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