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Long-term application of soil tillage systems in crop rotation and their effect on phosphorus distribution in the soil units of Haplic Chernozems

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Abstract
In a 6-field crop rotation (grain maize – wheat – sunflower – wheat – bean – wheat) initiated at Dobrudzha Agricultural Institute in 1987, the effect of soil tillage systems with and without turning of the plow layer on the content of available phosphorus in the cultivated soil horizon was investigated. All tested soil tillage systems at the end of the second rotation of the 6-field crop rotation had strong effect on the redistribution of phosphorus down the root-deep soil layer. The constant minimum and nil tilths were characterized with higher content of phosphorus in the topmost plow layer. The content of available phosphorus formed in them was with 74.3 % higher than the content established under the soil tillage systems which involved systematic or alternative turning of the plow layer. All systems which included plowing enriched the 10-20 cm layer with averagely 19.7 % of available phosphorus, and at depth 20-30 cm the content of available phosphorus increased 2.5 times.

Redistribution of phosphorus depending on the size of the structural soil units was most expressed in the 0-10 and 10-20 cm layers. Highest amounts of available phosphorus were found in the soil units with size less than 5 mm, mainly in the <0.25 mm fraction. At depth 20-30 cm the role of the size of soil units for phosphorus redistribution decreased strongly.

Key words: 6-field crop rotation, systems for soil tillage, available phosphorus, soil units

Introduction
The phosphate regime of soil is a significant trait of soil fertility, and the use of various agronomy practices is the tool for its purposeful regulation. Besides maximum differentiation of technology, simplification of the agro technology used for cultivation of the field crops is also necessary in accordance with the specificity of the soil type and the requirements of the plants (Dilkova et al., 1984).

A number of authors have reported that the long-term reduction of deep plowing leads to higher amounts of phosphorus in the soil surface layer, and to its considerable decrease in the underlying layers (Kondarev and Dimov, 1981; Klochkov, 1983; Tsvetanova-Lazarova and Stoychev, 1987; Haziev et al., 1999). Tsvetanova – Lazarova (1989) has established that fertility decrease in the 10-20 and 20-30 cm layers at plowing without turning of the layer and especially at nil tillage was primarily due to the multiple decrease of phosphorus content. According to Ivanov et al. (1988) the effect of direct sowing with tilths without turning of the layer on the phosphate regime was two-directional. On the one hand, the mobility and availability of the residual fertilizer phosphates increased under the effect of local fertilization and mulching, and on the other hand the distribution by layers in the plow horizon was unfavorable.

Nankova and Kalinov (1992) reported that long-term direct sowing and tillage without turning of the layer determined higher amount of mobile phosphorus in the surface layer and better expressed differentiation by layers in comparison to the traditional plowing used before all crops in the crop-rotation.

Dimitrov and Mitova (1997) also pointed out that the percent of the slimy fraction in the 20-40 cm layer tended to increase after annual plowing as a result from turning of the plow layer. The aim of this investigation was to determine the effect of different soil tillage systems in a multi-field crop rotation on the redistribution of available phosphorus by soil units in the upper layers of the root-deep horizon.

Material and methods

The investigation was carried out in a stationery field trial in 6-field crop rotation under the following rotation scheme: grain maize – wheat – sunflower – wheat – bean – wheat. The trial was initiated at Dobrudzha Agricultural Institute – General Toshevo in 1987 on slightly leached chernozem soil (Haplic Chernozems, WRBSR, 2006). The trial was designed by the non-standard method, with 72 m^2 size of the plots, in 8 replications.

The mineral fertilization used in the rotation of all crops involved the same PK background - 12 kg P_2O_5/da and 8 kg K_2O/da in the form of TSP and KCl.

The norm of nitrogen fertilization was differentiated according to the type of predecessor and the crop. The direct nitrogen fertilization for grain maize was e 160 kg N/ha; for sunflower - 60 kg N/ha; and for bean - 40 kg N/ha. Depending on its position in the crop rotation, wheat was fertilizes with the following amounts of nitrogen: after grain maize - 140 kg N/ha, after sunflower - 160 kg N/ha and after bean - 120 kg N/ha. Nitrogen fertilization was done with NH_4NO_3. In the spring crops the nitrogen fertilizers were introduced early in spring with a single application, and in wheat 1/3 of the nitrogen norm was applied prior to planting, and the rest of the amount – in spring at tillering stage. At the end of each rotation the tested soil tillage systems were treated with the same amounts of nitrogen phosphorus and potassium fertilizers.

Out of the 24 soil tillage systems, seven were selected for the purpose of this investigation; they were based on different soil tillage tools and way of cultivation (Table 1).

Table 1. Tested systems of soil tillage

Soil tillage system	Depth of tillage, cm	
	Spring crops	Wheat
1. Plowing (check)	24-26	14-16
2. Disking	10-12	10-12
3. Cutting	24-26	8-10
4. Nil tillage	Direct planting	Direct planting
5. Plowing-disking	24-26	10-12
6. Plowing-nil tillage	24-26	Direct planting
7. Disking-nil tillage	10-12	Direct planting

At the end of two complete rotations since the initiation of the trial, soil samples were taken from layers 0-10 cm, 10-20 cm and 20-30 cm. The soil structure was determined through dry and wet sifting of soil, establishing the percent ratio of the structural soil units of different size (>10, 10-5, 5-3, 3-1, 1-0.25, <0.25 mm). Phosphorus available to plants was determined by the acetate – lactate method with subsequent blue colorimetric detection (Ivanov, 1984).

The statistical analysis included the use of the software BIOSTAT version 5.1 (Penchev, 1998), STATISTICA version 5.0 and SPSS 13.0.

Results and discussion

The role of soil tilths for providing optimum physical and chemical conditions for micro biological activity, which has considerable contribution to the transformation of the nutrients introduced in soil, is indisputable.

The dispersion analysis on the results obtained at the end of the second rotation revealed high statistical significance of the independent effect of all tested factors (Table 2). This tendency was confirmed for the different combinations of their interaction.

Table 2. Variance analysis of the available phosphorus content

Source	df	Mean Square	F	Sig.
For All factors				
Tillage systems (1)	6	37.600	21.125	0.000
Soil Depth (2)	2	1719.691	966.183	0.000
Soil Size (3)	5	95.137	53.451	0.000
1 x 2	12	297.958	167.404	0.000
1 x 3	30	8.846	4.970	0.000
2 x 3	10	5.578	3.134	0.001
1 x 2 x 3	60	8.425	4.733	0.000
In Depth 0-10 cm				
Soil Size (3)	5	51.031	13.760	0.000
Tillage systems (1)	6	359.132	96.835	0.000
1 x 3	30	17.078	4.605	0.000
In Depth 10-20 cm				
Soil Size (3)	5	44.045	43.006	0.000
Tillage systems (1)	6	58.387	57.009	0.000
1 x 3	30	5.833	5.695	0.000
In Depth 20-30 cm				
Soil Size (3)	5	11.216	18.485	0.000
Tillage systems (1)	6	215.998	355.971	0.000
1 x 3	30	2.785	4.590	0.000

The dispersion analysis on the data for each of the investigated layers down the root-deep horizon additionally characterized the significance of the effect of the factors "soil tillage system" and "size of the soil units" on the content of available phosphorus in soil.

The strength of the effect of the tested factors within the entire trial on the phosphate regime of soil was clearly expressed (Figure 1). This effect was highest in the interaction tillage system x soil depth, followed by soil depth. The interaction between the three factors was also very well expressed.

Down the soil layers, the effect of the type of soil tillage had stronger influence on the available phosphorus content (Figure 2). It was found that this effect was highest in the 20-30 cm layer and lowest – in the 10-20 cm layer, where the strength of the effect of the soil unit size sharply increased, as well as the combined interaction of these two factors.

At the end of the second rotation, regardless of the equal amounts of introduced fertilizers, available phosphorus content had significantly differentiated values as a result from the applied soil tillage system (Table 2). Highest values of its content, averaged for the effect of the tested factors, were determined at systematic disking and alternation of plowing with nil tillage.

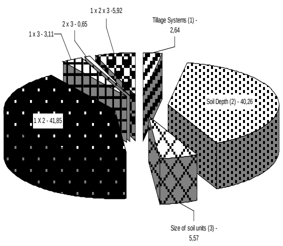

Figure 1. Strength of the effects of the tested factors

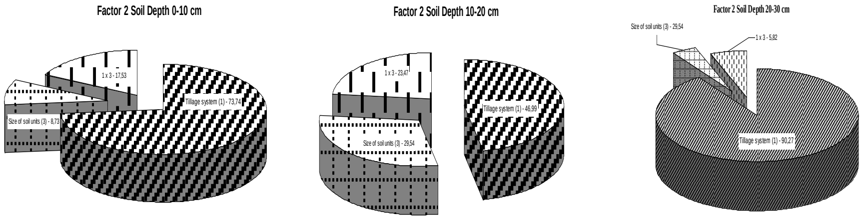

Figure 2. Strength of effect of factors Tillage system (1) and Size of soil units (3) on the content of available phosphorus according to soil depth (2)

Considering the results by soil layers, it becomes evident that most dynamic were the changes in the surface layer (0-10 cm), where, depending on the used soil tillage system, phosphorus content varied from 24.23 mg P_2O_5/100 g soil (plowing-nil tillage) to 8.00 mg P_2O_5/100 g soil (plowing-disking).

Table 2. Content of available phosphorus depending on the soil tillage system, mg P_2O_5/100 g soil

No	Tillage systems	For all factors	0-10 cm	10-20 cm	20-30 cm
1	Plowing	10.81 b	11.54 b	8.91 b	11.98 e
2	Disking	11.42 c	19.87 d	11.16 d	3.23 b
3	Cutting	9.48 a	15.10 c	9.67 c	3.68 b
4	Nil	9.17 a	16.09 c	8.92 b	2.49 a
5	Plowing-disking	9.33 a	8.00 a	10.49 d	9.51 c
6	Plowing-nil	11.62 c	12.01 b	11.96 e	10.90 d
7	Disking-nil	10.68 b	24.23 e	5.18 a	2.63 a

The 10-20 cm layer had the lowest amplitude of variation of the phosphorus values depending on the soil tillage system.

In the underlying layer (20-30 cm) the differentiation in the content of available P increased to amplitude of variation 9.49 mg P_2O_5/100 g soil, which was lower than the variation in the surface layer. This layer, too, reflected strongly the differences in the nutrition regime of soil, conditioned on the one hand by annual plowing and the systems of its alternation, and on the other – by the tillage systems without turning of the soil layer. Similar results have been reported by Hristov (2003) who found that the use of minimal tillage and tillage without turning of the layer increased the content of available phosphorus in comparison to traditional soil tillage.

There is an evident contribution of the systems involving plowing for the increase of available phosphorus at depth 20-30 cm and obtaining of values approximating to a maximum degree the values determined at annual plowing. A similar, though less expressed tendency was found at annual cutting as well. The probable reason is that at this type of tillage the soil layer is loosened without turning and mixing the soil. It is known that the phosphate ion has slow mobility in soil and therefore the main contribution for the enrichment of the underlying layers was of the factor depth of cutting.

Significant was the role of the tilths for the redistribution of available phosphorus depending on the size of soil units (Table 3). It can be definitely stated that averaged for all tested soil tillage systems the amount of available phosphorus started increasing with the soil units of size <5 mm, reaching maximum values with the fraction <0.25 mm.

Table 3. Content of available phosphorus depending on the size of soil units, mg P_2O_5/100 g soil

No	Soil size	For all factors	0-10 cm	10-20 cm	20-30 cm
1	> 10 mm	9.06 a	13.67 a	8.26 ab	5.26 a
2	10 - 5 mm	8.91 a	13.23 a	7.60 a	5.91 bc
3	5 - 3 mm	9.63 b	14.52 ab	8.61 b	5.74 ab
4	3 - 1 mm	10.32 c	15.11 b	9.41 c	6.44 c
5	1 – 0.25 mm	11.48 d	16.91 c	10.44 d	7.08 d
6	< 0.25 mm	12.76 e	18.14 c	12.49 e	7.66 e

The slimy fraction in soil carries higher amounts of available P in comparison to all other sizes of soil units in all investigated soil layers. Their amount was highest in the surface layer, gradually decreasing down the soil profile.

The complex expression of data clearly reflects the effect of each tested soil tillage system on the redistribution of available phosphorus down the soil profile according to the size of soil units (Figure 3). In the surface 0-10 cm layer highest content of available phosphorus was detected in the largest soil units (>10 mm) at the systems nil tillage and nil tillage-disking, and lowest – in the systems involving plowing. The system with annual plowing at different depths in the crop rotation was characterized with strongly expressed differentiation in phosphorus redistribution depending on the size of soil units: from 5.30 to 20.20 mg P_2O_5/100 g soil. The gradual increase of available P content with the decrease of the size of soil units was typical for this system. Similar tendency was observed in the other systems which involved plowing, too, but the amplitude of variation between the maximum and minimum values was less expressed in comparison to constant plowing.

The independent application of nil tillage also had high variations in the P values but in contrast to plowing this occurred only between the soil units with largest size (>10 mm and 10-5 mm), while with the agronomically valuable soil units the differences in the content of available P were insignificant.

In the 10-20 cm layer the distribution of P in the soil units smaller than 3 mm was subjected to lower variation within each individual system, with the exception of nil tillage and partially – of the systems which included it. P distribution in the larger soil units in all systems at this depth had more intensive dynamics of variation.

Although the differences in the content of P between the soil tillage systems remained the same in the underlying 20-30 cm layer, this content varied with lowest amplitude in the systems without turning of the soil layer, depending on the size of soil units. Annual plowing and its alternation with disking caused much higher increase of P content with the smaller soil units in comparison to the other soil tillage systems.

Regression analysis was applied to find out the relation of available phosphorus content in the structural units to the tested soil tillage systems. On the basis of the constructed model (Table 4) and the obtained experimental data, a graphic model of the respective equations was worked out (Figure 4).

With b_i are designated the respective weight coefficients: b_1 soil units with size >10 mm (%), b_2 soil units with size 10-5 mm (%), b_3 soil units with size 5-3 mm (%), b_4 soil units with size 3-1 mm (%), b_5 soil units with size 1-0.25mm (%), b_6 soil units with size <0.25 mm (%). In the graphic representation, dark green color defines negative meaning. The lighter green color corresponds to weight coefficients approximating zero. The nuances of yellow and red characterize the increasing percent of the respective factor in a positive direction (Mihova, 2000).

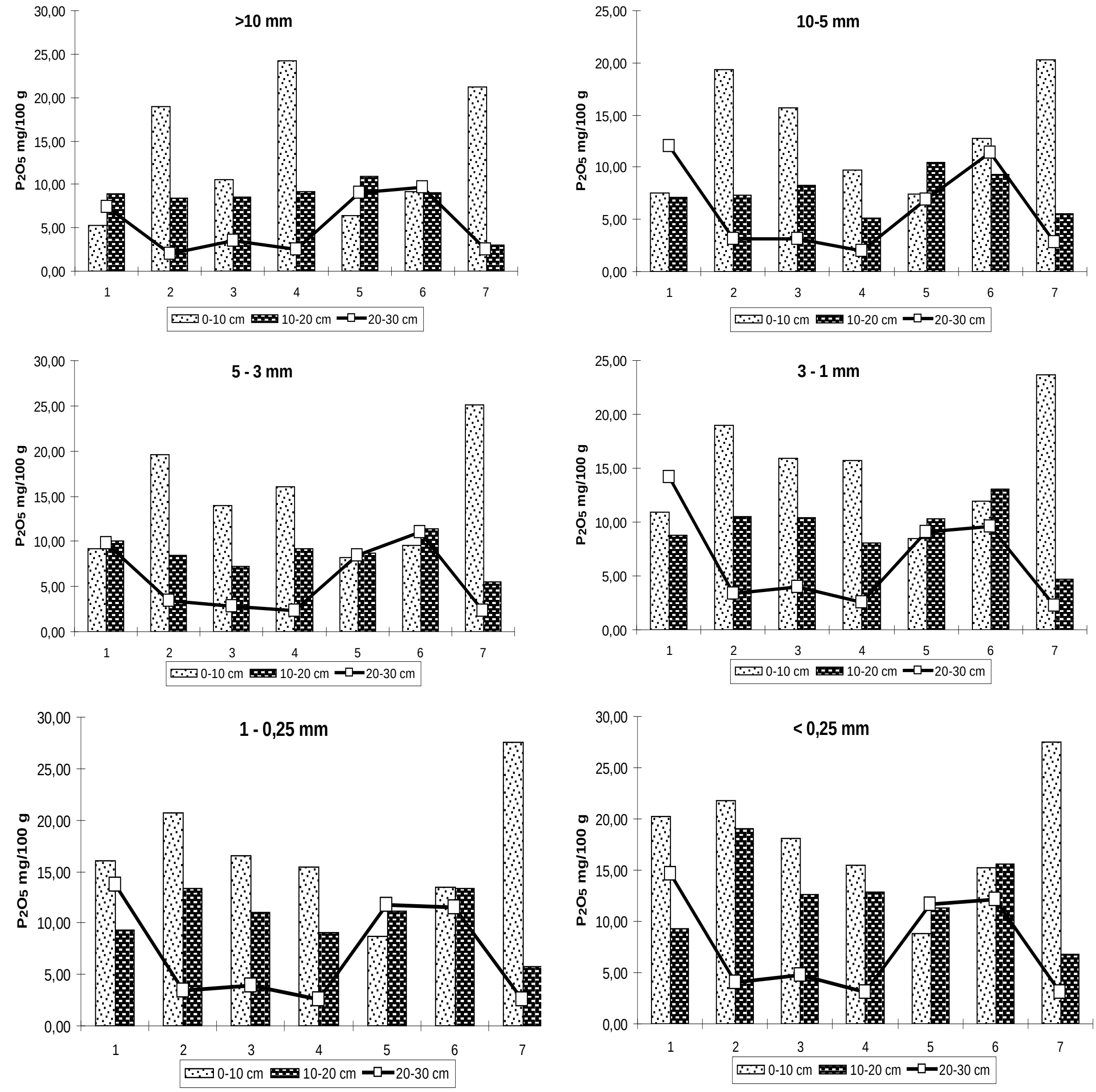

Figure 3. Redistribution of available P according to the soil tillage system and the size of soil units down the soil profile, mg P_2O_5/100 g soil

Based on the applied analysis it was found that in all investigated systems of soil tillage, with the exception of cutting-cutting, the percent of soil units with size <0.25 mm (b_6) had highest weight coefficient. In cutting without turning of the soil layer, the fraction >10 mm (b_1) had highest effect on the content of available phosphorus, while in the systems plowing – plowing, disking-disking and disking-nil tillage these very soil units influenced negatively the amount of the investigated nutrient in the structural soil units. Under constant direct planting and annual cutting, the fraction 10-5 mm (b_2) had lowest weight coefficient, and in the system plowing-disking the soil units with size 5-3 mm (b_3) were with lowest weight coefficient.

The higher amount of structural soil units with size <0.25 mm in the systems involving plowing and disking were a consequence of the constant soil tillage operations carried out at the same depth and of the mechanical destruction of soil by the soil tillage tools which destabilized the soil units by accelerating the processes of mineralization. Under long-term direct planting, the higher weight coefficient of the finest fraction was determined by the processes of physical and chemical erosion, the constant destructive activity of the temperature variations, the kinetic energy of rainfalls and the chemical influence of rain waters.

Table 4. Regression models characterizing the effect of the size of structural soil units on available phosphorus content

General regression model	$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6$	R^2
Plowing-plowing	$Y = 0.479 + 0.178x_1 + 0.265x_2 + 0.647x_3 + 0.765x_4 + 2.405x_5 + 3.440x_6$	0.97
Disking-disking	$Y = 0.093 + 0.163x_1 + 1.051x_2 + 0.607x_3 + 1.219x_4 + 1.838x_5 + 3.214x_6$	0.97
Cutting-cutting	$Y = 0.019 + 2.298x_1 + 0.051x_2 + 0.252x_3 + 0.309x_4 + 1.403x_5 + 1.428x_6$	0.95
Nil-nil	$Y = 0.212 + 0.238x_1 + 0.164x_2 + 1.696x_3 + 0.574x_4 + 2.858x_5 + 4.789x_6$	0.97
Plowing-disking	$Y = 0.132 + 0.168x_1 + 0.215x_2 + 0.156x_3 + 0.446x_4 + 0.494x_5 + 0.642x_6$	0.95
Plowing-nil	$Y = 0.115 + 0.157x_1 + 0.198x_2 + 0.287x_3 + 0.208x_4 + 0.292x_5 + 0.309x_6$	0.95
Disking-nil	$Y = 0.078 + 0.162x_1 + 0.913x_2 + 0.643x_3 + 0.517x_4 + 1.985x_5 + 2.987x_6$	0.97

x_1 percent of soil units with size >10 mm, x_2 percent of soil units with size 10-5 mm, x_3 percent of soil units with size 5-3 mm, x_4 percent of soil units with size 3-1 mm, x_5 percent of soil units with size 1-0.25 mm, x_6 percent of soil units with size <0.25 mm

The comparatively low degree of soil loosening under tillage without turning of the soil layer decreased and excluded the destructive effect of the tilths on the soil structure. As a result the large-sized soil units increased. The determination coefficients (R^2) of the respective equations of linear regression for the different soil tillage systems had value 0.95-0.97, i.e. 95-97% of the total variation of the resultant trait can be explained by the factor-traits x_1, x_2, x_3, x_4, x_5 and x_6. This means that the soil structure also significantly influences the distribution of available phosphorus, i.e. this was a confirmation for its involvement in the constructed model.

The regression model allowed predicting the expected value of the specific trait under given or expected values of the factor involved in the model.

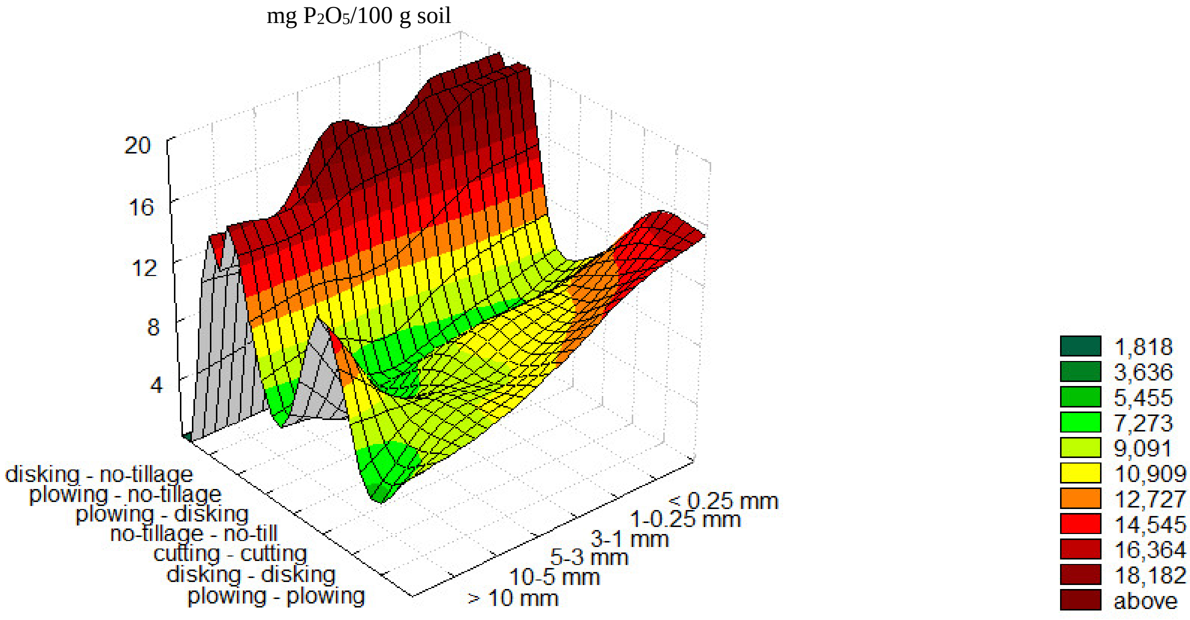

Figure 4. Graphic representation of the regression model of available phosphorus content

Conclusions

All tested systems of soil tillage at the end of the second rotation in a 6-field crop rotation had strong effect on the redistribution of phosphorus down the root-deep soil layer. The constant minimal and nil tilths were characterized with higher phosphorus content in the upper plow layer. The formed amount of available phosphorus was with 74.3% higher than the amount determined under soil tillage systems involving alternative turning of the soil layer. All systems involving plowing enriched the 10-20 cm layer with a mean of 19.7% of available phosphorus; at depth 20-30 cm the content of available phosphorus increased 2.5 times.

The redistribution of phosphorus according to the size of structural soil units was most expressed in the layers 0-10 cm and 10-20 cm. Highest amounts of available phosphorus were contained in the soil units with size <5 mm, mainly in the <0.25 mm fraction. At depth 20-30 cm the role of the size of the soil units for the redistribution of phosphorus decreased, especially under the systems without turning of the soil layer.

Under the systems involving plowing, disking and direct planting, the soil units with size <0.25 mm had highest weight due to the higher amounts of available phosphorus in them. Under tillage without turning of the plow layer, the large-sized fraction (>10 mm) had higher effect on the content of this nutrient.

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