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Pedotransfer Modeling In Precision Agriculture

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Aims. To find opportunities for application of the pedotransfer models in planning of the precise agriculture using spherical variograms' uniformity, similar values of dispersion thresholds and correlation radii, authentic correlation connections between baseline and functional soil parameters. **Methods**. Both the soil texture and humus content are used as the base components of the models, while the indicators for soil tillage method choice, such as, structural composition, bulk density and penetration resistance – as the effectiveness functions. **Results.** The agrotechnological contours for differentiation of soil tillage intensity revealed on the basis of settlement models and natural researches on a field appeared to be similar enough both as for configuration and area. **Conclusions.** Pedotransfer models are perspective in precise agriculture under condition of development of remote methods of definition of base parameters.

Keywords: pedotransfer models, soil texture, structure, humus content, agrotechnological enclosures of a field.

INTRODUCTION

The retarded mastery of the precise agriculture even in the countries with a good technical equipment of agricultural production occurs as a result of the complex procedure for the establishment of the spatial heterogeneity of field and development on it of enclosures with different levels of fertility [1, 2]. This requires laying in the field of the regular network of elementary plots and proceeding of the plenty of various field and laboratory analyses. That explains numerous attempts to search for the more effective methods of field parcellization (splitting) into the agro-technologically acceptable enclosures with different fertility. In this case the harvest colorfulness data obtained from harvesting are used most frequently [3−5]. However, this method does not always accurately reflect the heterogeneity of the soils within the field, since it is known, how many factors (including the random ones) influence on the harvest value. The detailed hypsometric maps are also used. That is half-way reasonable, since far from all elements of fertility depend on a change in the relief [6−8]. The dependences of fertility on the electrical conductivity are unreliable in the same manner exactly, since only in some soils enriched by electro-active components and moisture the like dependences can occur [9, 10]. The studies connected to the remote methods application seem to be more promising, as they allow to detect sufficiently reliably the soil texture and humus content – the most important base components in any pedotransfer models [11−13]. Either, the online study of the soils' physical and chemical properties applying the attached of penetrometer and spectrophotometer respectively described earlier [14].

The purpose of this exploration is an attempt to use the pedotransfer models, whereto physical clay and humus are the base components and the soil physical state parameters are the functions, and to select the tillage methods on the basis hereof.

MATERIALS AND METHODS

The field in the Forest Steppe of the Kharkiv Region, whereto three types of soil are detached: chernozem typical eroded slightly (chernozem chernic), chernozem podzolized (chernozem chernic), and dark gray podzolized soil (phaeozem albic), is used as the object. Within the area of 40 hectares the regular network of 45 elementary plots was placed. For each of them the content of physical clay, total humus, bulk density, penetration resistance, and structural composition were determined; the harvest was also taken into account. Statistical and geostatistical indices, pair and multiple correlation coefficients were calculated. The final stage of data processing consisted of the 2D-diagrams construction according to the experimental data (applying the Surfer software). Further on, the same diagrams for blocky, bulk density, and penetration resistance (as indicators of the precise soil tillage) following the calculated pedotransfer models were also drawn. As the result of the comparison of calculated and experimental diagrams the opportunity of applying the differentiated (precise) methods of soil tillage on the basis of pedotransfer models has been proven.

RESULTS AND DISCUSSION

The estimation of pair and multiple correlation coefficients between the base (humus and physical clay) and functional (blocky, bulk density and penetration resistance) indices granted the completely encouraging information about the opportunity for the formalization of the interrelation between them (Table 1). The tendency of soils toward compaction, strengthening and block formation is reduced alongside to increase organic matter and physical clay in their composition. Of course, this assertion is appropriate only for the investigated range of base characteristics and, probably, it will be disrupted with sandy particles increase and humus decrease in the soil content. In particular, as for sod-podzolic soils of the Polissia. Therefore, the further developed pedotransfer models can be appropriate, most likely, only for the loamy chernozem-like soils of the Forest Steppe, even then subject to their thorough checking. However, despite the limitations in the application of models, their prospects are undoubted, since the regulation of the soil physical properties in the before seed period appears to be important for the harvest forming [15]. The block elimination from the seed layer is especially urgent, as it accelerates the crop germination due to the more rational expense of the accessible moisture reserves. The development of roots into the depth of the subsurface layer is simultaneously improved. That mitigates the dangerous consequences of frequent drought in May drought and increases the adaptation of plants to the moisture deficiency. The results of correlation coefficients calculation between the functional parameters and harvest of barley performed according to the accessible data also confirm this dependence (Table 2).

The statistical and geostatistical estimations of base and functional indices are represented in Table 3. Although, the variability of base indices is

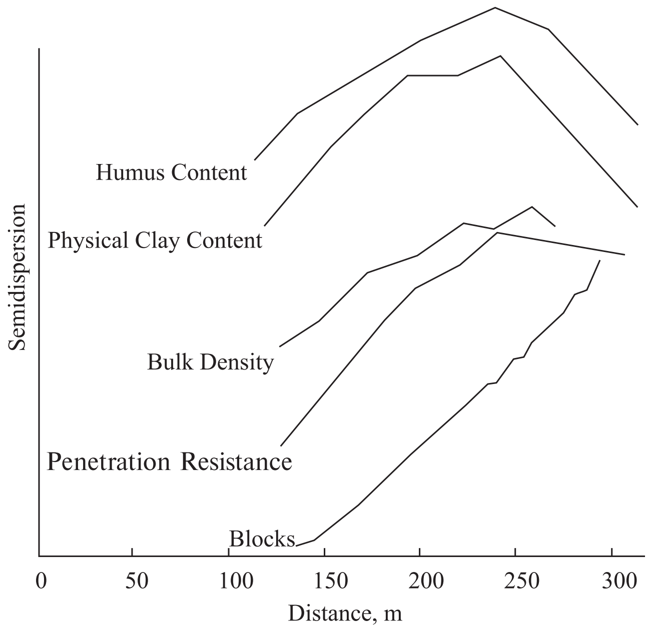

Fig. 1. Co-Variograms of Base and Functional Indicators For 0 to 10 cm Soil Layer of the Examined Field

Table 1. Pair and Multiple Correlation Coefficients Between Base and Functional Indicators Within the Soil Layer of 0 to 10 cm

Base Indicator	Functional Indicator		
	Blocks	Bulk Density	Penetration Resistance
PhC	−0.52	−0.81	−0.75
H	−0.53	−0.73	−0.68
PhC, H	−0.55	−0.84	−0.77

PhC – Physical clay; H – humus.

Table 2. Pair Correlation Coefficients Between Crops' Harvest and Soil Physical Parameters

Physical Parameter	Depth, cm	Correlation Coefficient
Blocks' Content	0−10	−0.57
	0−5	−0.68
Bulk Density	10−15	−0.70
	20−25	−0.60
	30−35	−0.48
Penetration Resistance	0−10	−0.79
	10−20	−0.77
	20−30	−0.70
	30−40	−0.64

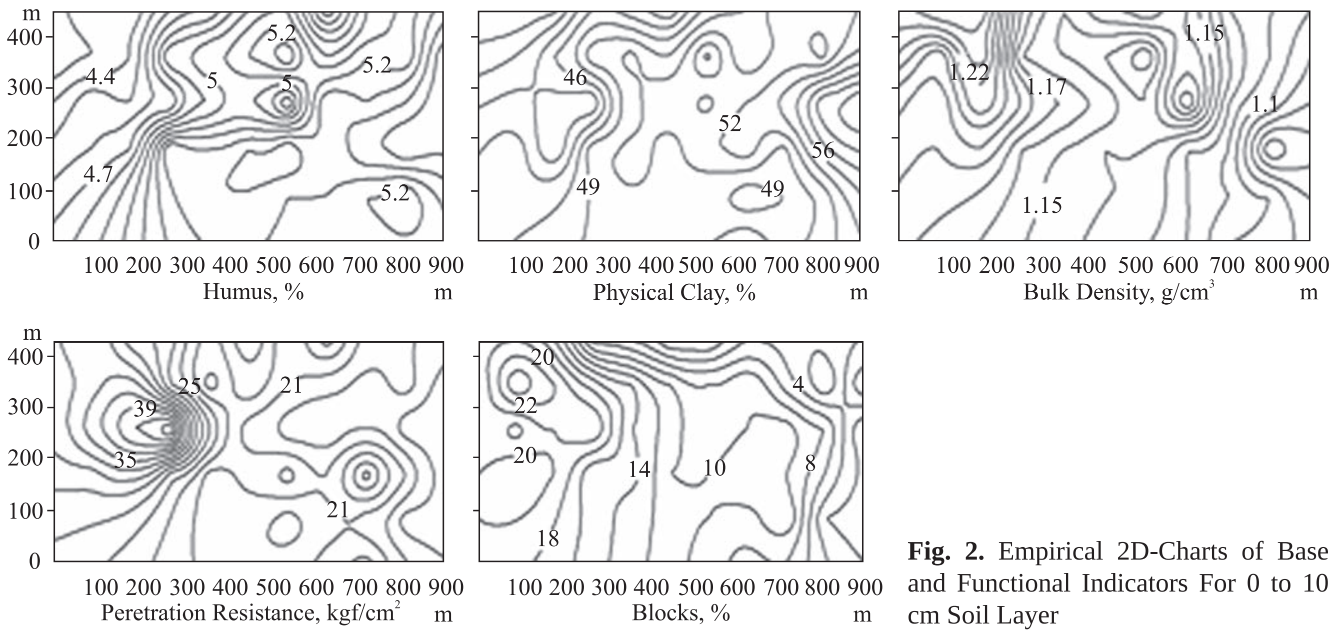

Fig. 2. Empirical 2D-Charts of Base and Functional Indicators For 0 to 10 cm Soil Layer

moderate, while as for the functional ones − increased, the presence of autocorrelation function, i.e., its significant difference from zero, proves existence of spatial heterogeneity within the examined field. The omitted in the current article, though explicit peaks in the curves of the dispersion spectral density give evidence on the same. The uniform (exception of lumpy fraction) spherical variograms with the very close in value correlation radius parameters catch attention (Fig. 1). It means that studied indices vary within the field space similarly, while the dispersion threshold is reached at one and the same distance approximately. Within this very zone exactly (dispersion fluent subsidence) the bounda-ries between the separate elements of precise agriculture should be searched for.

However, the statement of the kind is insufficient. Indeed, it is necessary to establish the precise configuration of the plots possessing the characteristics diverse in quality. For that end, it is necessary to draw 2D-charts (Fig. 2). Even preliminary analysis of the charts and comparison between them allow to state the presence of sufficiently explicit spatial localization of the investigated indicators. In accordance with the negative correlation coefficients the following should be concluded: the less the humus and physical clay content in the soil is, the higher the balanced bulk density, penetration resistance and block forming ability are. While referencing these charts to the soil map of the examined field it has been revealed that erodity and podzolization (podsolize) rate increase similarly. In other words, it is possible to assert con-

Table 3. Statistical and Geostatistical Estimations of Base and Functional Indices (Soil Layer 0 to 10 cm)

Parameter	Humus	Physical Clay	Balanced Bulk Density	Penetration Resistance	Blocks
Average	5.0 %	49 %	1.15 g/cm^3	24 kgf/cm^2	10.9 %
Total Excursion	2.0 %	21 %	0.20 g/cm^3	30 kgf/cm^2	26 %
Standard Deviation	0.44	4.39	0.04	6.94	6.6 %
Dispersion	0.2	19.3	0.0	48.2	43.6
Variation Coefficient	0.09	0.09	0.04	0.29	0.60
Asymmetrical Coefficient	−0.90	0.11	0.26	1.02	0.27
Nugget Effect	0.02	2	0	0	0
Dispersion Threshold	0.197	16	0.0015	54	?
Correlation Radius, m	250	240	250	260	?
Variogram	Spheroid	Spheroid	Spheroid	Spheroid	Linear
Authentic Autocorrelation Function Availability	+	+	+	+	+

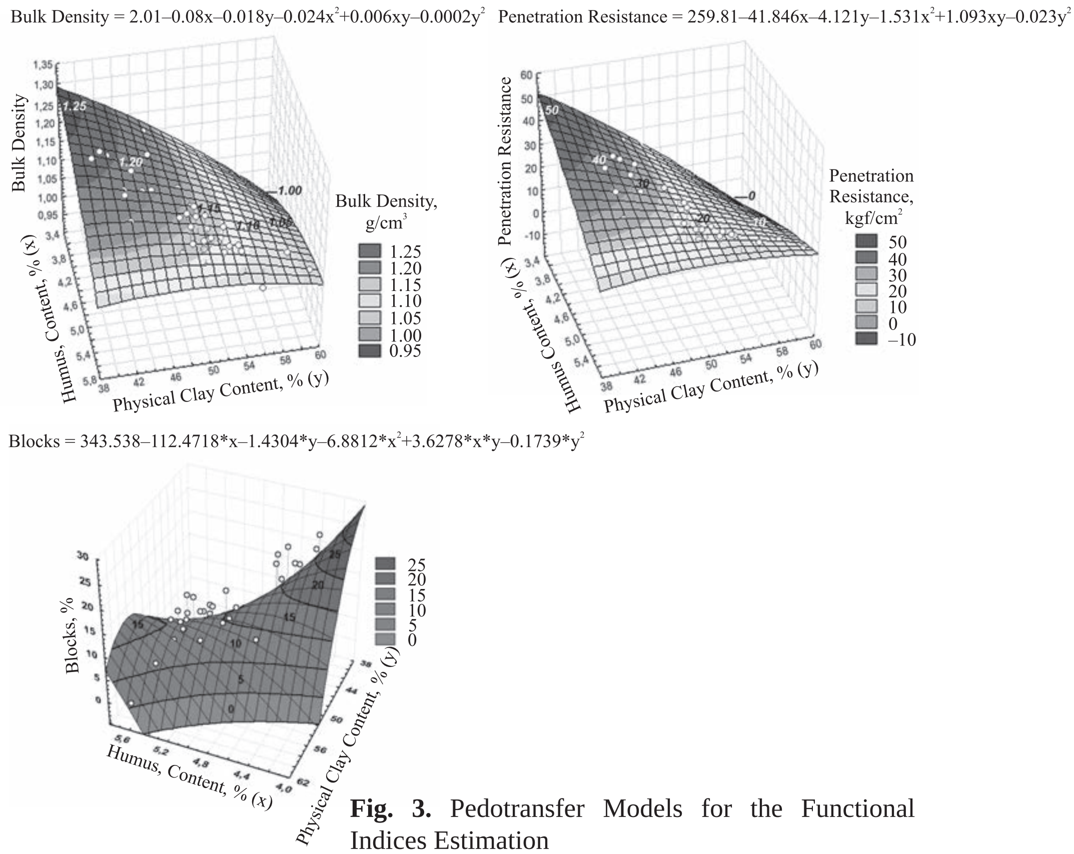

Fig. 3. Pedotransfer Models for the Functional Indices Estimation

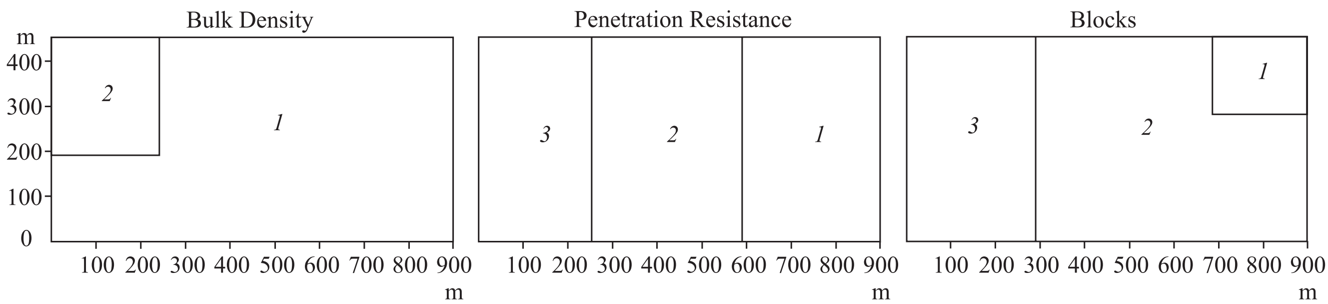

Fig. 4. Estimated 2D-Charts For the Functional Indices: *1* – no more tillage needed; *2* – one-time before seed cultivating needed; *3* – 2–3-time cultivating, or rotary tillage needed

fidently that these very features of soils lead to the differentiation of indices in the field and precisely they require the adequate differentiation of agrotechnological methods.

The charts' processing using the same Surfer software allowed to obtain the areas of contours with different indices (Table 4), while the application of normative indices (Table 5) – to combine separate contours into the agrotechnological groups with various tillage technologies. The areas of the basic agrotechnological groups for different tillage within the field obtained by both experimental and calculation method are shown in Table 6.

The normative indices of the balanced bulk density have been developed on the basis of the long-standing generalized model studies [16]. The data on the blocks and increased penetration resistance adverse effect are available at published sources [17, 18].

The next stage of the research was dedicated to the search for the pedotransfer model for the functional indices estimating on the basis of baseline indices. The results of processing and models themselves are shown in Fig. 3. They reflect the sufficiently explicit regularities between the baseline and functional indices, i.e., illustrate the necessity of important condition fulfillment for the successful construction of the pedotransfer models [19, 20].

Table 4. Contours' Areas For Base and Functional Indicators For 0 to 10 cm Soil Layer of the Examined Field

Humus, %	Area		Physical Clay, %	Area		Bulk Density, g/cm^3	Area		Penetration Resistance, kgf/cm^2	Area		Blocks, %	Area	
	%	ha		%	ha		%	ha		%	ha		%	ha
3.6–3.9	0.38	0.15	40–44	6.62	2.66	1.05–1.08	1.88	0.75	15–20	24.80	9.95	<5	15.4	6.2
3.9–4.2	1.42	0.57	44–48	23.94	9.61	1.08–1.11	6.22	2.50	20–25	41.66	16.72	5–10	25.5	10.1
4.2–4.5	8.96	3.60	48–52	53.29	21.39	1.11–1.14	21.56	8.65	25–30	12.82	5.15	10–15	26.6	10.5
4.5–4.8	14.60	5.86	52–56	11.54	4.63	1.14–1.17	44.48	17.85	30–35	12.18	4.89	15–20	20.0	8.1
4.8–5.1	29.04	11.66	56–60	4.42	1.77	1.17–1.20	16.30	6.54	35–40	6.76	2.71	>20	12.5	5.1
5.1–5.4	37.20	14.93	60–64	0.18	0.07	1.20–1.23	6.38	2.56	40–45	1.78	0.71	–	–	–
5.4–5.7	8.40	3.37	–	–	–	1.23–1.26	3.18	1.28	–	–	–	–	–	–

Furthermore, 2D-charts were drawn together with the agrotechnological groups' area calculation using both the models and data on the humus and physical clay content in 20 additionally taken samples, regularly placed within the explored field. The estimated 2D-charts and the field areas obtained as a result of the experiment and calculation are given respectively in Fig. 4 and in Table 6.

2-D-charts of balanced bulk density, penetration resistance and blocks are close in the localization of similar values, but nevertheless, they differ essentially in their agricultural significance. Thus, the bulk density of the field does not almost exceed the critical values within its whole area (more than 1.3 g/cm^3 for the majority of the crops). Therefore, this index is possible not to be used while solving the issue on the differentiation of before seed tillage. Just opposite conclusions are reasonable as concerning the other indicators – penetration resistance and blocky. The values of these two parameters strictly require the appropriate correction of some parts of the field. Since the largest area that needs correction appeared to be detected applying the block index, it is exactly that should be used for the final choice of the before seed tillage intensity. It should be noted, according to agricultural requirements for the seed layer, there must be no blocks in it completely, since they cause the rapid drying up of this layer and detain the sprouts appearance [21]. However, there are discrepancies as for the size of blocks in the soil science and agriculture. In the soil science any lump 10 mm in diameter is considered as a block, while in agriculture it should be more than 40 mm.

Thus, all mentioned above states the possibility in principle to detect the agrotechnological groups for different tillage methods implementation within a field using for this the pedotransfer models. The base index for the latter is the humus and physical clay content, and the functional one – the balanced bulk density, penetration resistance and lumpiness. It is assumed, this task was solved successfully, but concerning the practical aspect, numerous difficulties appear. Thus, the determination of the humus and physical clay content is unfortunately not simpler and even more expensive than the direct measurement of the bulk density, blocky, and furthermore, the penetration resistance of soil. Even on the condition that elementary verifying plots, as in current exploration, will be only 20 instead of 45 initial ones. Indeed, similar analyses require the significant time expenditures for the selection of soil samples, their delivery into the laboratory, and also further complex

Table 5. Provisional Standards For Seed Layer Physical Parameters Estimation Towards Substantiation of Mechanical Tillage Intensity*

Seed Layer Value	Tilled Layer Quality Value	Recommendations For Before Seed Tillage Intensity
Blocks Amount, %		
< 5	Productive	No Tillage Needed
5–15	Satisfactory	Moderate Tillage
> 15	Unsatisfactory	Intensive Tillage
Bulk Density, g/cm^3:		
< 1.2	Productive	No Tillage Needed
1.2 – 1.3	Satisfactory	Moderate Tillage
> 1.3	Unsatisfactory	Intensive Tillage
Penetration Resistance, kgf/cm^2:		
< 20	Productive	No Tillage Needed
20–30	Satisfactory	Moderate Tillage
> 30	Unsatisfactory	Intensive Tillage

*The standards are appropriate for the medium and heavy texture soils.

Table 6. Comparison of Empirical and Estimated Areas of the Main Agrotechnological Groups of the Field For Different Performance Before Seed Tillage (According to the Blocks Content, %), ha

Empirical Groups' Areas			Estimated Groups' Areas		
1 (<5) 6.2	2 (5–15) 20.6	3 (>15) 13.2	1 3.4	2 22.2	3 14.4

of preparatory procedures before measurement exactly. Hence, it follows that the pedotransfer simulation on the purpose indicated in the article can become urgent only when other, simpler and more efficient methods of measurement of base indices will be found, *in situ* and *on-line* desirably. In this context, remote methods and laser diffractometry technique are promising. The survey of the new base indices measurement methods (according to published data) are given [22–24]. Taking into account the significant prospects for the precision agriculture, including the precise soil tillage, it would be desirable to hope that soon the new remote measurement methods of the humus and physical clay content in the soil will be developed.

Conclusions. The method of the field contours distinguished by the physical properties in the seed layer was substantiated for differentiated (precise) tillage performance within them. The choice of the tillage intensity (the number of before seed cultivations) is performed in accordance with the standards (as for the studied field – the blocky standards).

For calculation, the pedotransfer models, whereto the humus content and physical clay are the base components, while the bulk density, penetration resistance and block content taken as the indicator for the field physical state estimation before accomplishment of before seed cultivation are the functional ones, have been proposed.

The comparison of the experimentally obtained contours, with the ones calculated applying the models resulted satisfactory.

The arguments for the intensification of scientific research aimed to develop the noncontact methods of base indices measuring, i.e., physical clay and humus, and thus, accelerated introduction of the precise soil tillage methods were adduced.

Педотрансферне моделювання у точному землеробстві

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Мета. Використовуючи однотипність сферичних варіограм, подібні значення порогів дисперсії і радіусів кореляції для них, достовірні кореляційні зв'язки між базовими і функціональними показниками ґрунтів, вишукати можливість для застосування педотрансферних моделей у плануванні точного землеробства. **Методи.** Як базові компоненти моделей застосовано гранулометричний склад і вміст гумусу, а цільових функцій – індикатори, на підставі яких обирають способи обробітку ґрунтів, – структурний склад, щільність будови і твердість. **Результати.** Із застосуванням розрахункових моделей і натурних досліджень визначено на полі агротехнологічні контури для диференціації інтенсивності передпосівного обробітку, які виявилися досить схожими за конфігурацією і площею. **Висновки.** Педотрансферні моделі перспективні у точному землеробстві за умови розвитку дистанційних методів визначення базових показників.

Ключові слова: педотрансферні моделі, гранулометричний склад грунту, вміст гумусу, агротехнологічні контури поля.

Педотрансферное моделирование в точном земледелии

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Цель. Используя однотипность сферических вариограмм, близкие значения порогов дисперсии и радиусов корреляции для них, достоверные корреляционные связи между базовыми и функциональными показателями почв, изыскать возможность для применения педотрансферных моделей в планировании точного земледелия. **Методы.** В качестве базовых компонентов моделей применены гранулометрический состав и содержание гумуса, а целевых функций – индикаторы, на основании которых выбирают способы обработки почв, – структурный состав, плотность сложения и твердость. **Результаты.** Выявленные на основании расчетных моделей и натурных исследований на поле агротехнологические контуры для дифференциации интенсивности предпосевной обработки оказались достаточно подобными по конфигурации и площади. **Выводы.** Педотрансферные модели перспективны в точном земледелии при условии развития дистанционных методов определения базовых показателей.

Ключевые слова: педотрансферные модели, гранулометрический состав почвы, содержание гумуса, агротехнологические контуры поля.

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