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SPATIAL HETEROGENEITY OF PHYSICAL PROPERTIES OF THE SOILS IN UKRAINE

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Aim. To investigate structural composition (lumpiness), bulk density and penetration resistance in soils of Polissia, Forest-Steppe and Steppe. **Methods**. The experimental plots were allocated on the fields in a regular network. The measurements performed before harvesting testified to an equilibrium condition of soil physical properties. The data ware processed by the geostatistical method. **Results**. The key parameters of spatial heterogeneity (variation factors, histograms, autocorrelation function, variogrammes, 2-D and 3-D diagrams, etc.) were received. The heterogeneity of physical properties, revealed in all soils, is characterized by moderate and increased values. As a result the investigated fields were divided into three agrotechnological groups by qualitative parameters of their physical properties. **Conclusions**. The recommendations on pre-sowing or basic tillage of various intensity – without tillage (if parameters are close to the requirements of the sown culture), with moderate tillage of zone type (if parameters are close to modal values) and with tillage of the enhanced intensity (if parameters are unsatisfactory and more intensive pre-sowing tillage is required) were formulated for each group.

Keywords: soil spatial heterogeneity, physical properties, precise tillage.

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INTRODUCTION

Spatial heterogeneity of soil physical properties is not an intensively studied direction of science. There are singular publications on this topic. In particular, Shein *et al*. [1] discovered an especially wide range of bulk density fluctuations in the ploughed layer of gray podzolic soils – from 0.98 to 1.48 g/ccm and the density of a considerable part of the investigated allotment did not exceed the allowed limit for most crops, grown on loamy soils (1.30 g/ccm), therefore this part of the allotment did not require any pre-sowing tillage. The work of Tymbaev [2], performed on the same soil, demonstrated that the heterogeneity of bulk density was formed in the course of May–July; in addition, there was a considerable compaction (up to +0.35 g/ccm) in some parts of the allotment and loosening – in others. These processes were observed in the field of black fallow the least, and under the grain crop – the most. In the work of Bolenius *et al*. [3] soil penetration resistance varied at the depth of 10 cm (from 200 to 1,200 kPa) and 30 cm (from 700 to 2,700 kPa). The yield of barley on the experimental field fluctuated from 11.5 to 4.5 t/ha, respectively.

Regardless of evident shortage of materials about spatial heterogeneity of soil physical properties, it is obvious that the accumulation of such data is an urgent task, the solution to which will allow implementing considerable advantages of precise agriculture for the differentiation of soil tillage. Precise agriculture is still almost exclusively used only while administering fertilizers and chemical means of plant protection.

The aim of the work was to obtain the materials about spatial heterogeneity of soil physical properties, which could be used as a basis to formulate the suggestions on precise tillage of field soils.

MATERIALS AND METHODS

The studies were performed on six fields, three of which were located in Polissia (conventional names –

Romaniv, Kolky and Vediltsy), two – in the Forest-Steppe (Korotych and Kommunar) and one – in the Steppe (Donetsk).

Romaniv, Volyn region. Gray podzolic (Albeluvisols Umbric), sod-podzol (Albeluvisols Gleyic) and gleyed black soils (Umbrisols Gleyic) prevail in the soil cover. The terrain is flattened. The soil texture is light clay loam. The size of the field is 63 ha, the number of experimental plots is 35. Cereal and forage crops are cultivated. The agrotechnical methods of crop cultivation are not differentiated, regardless of evident mottling of the field.

Kolky, Volyn region. The soil cover is a complex of sod-podzol gleyed (Albeluvisols Gleyic), sod-gley (Gleysols Listic) and meadow-bog (Leptosols Umbric) soils. The terrain is flattened. The soil texture is argil sand. The size of the field is 11 ha, the number of experimental plots is 27. Forage crops are cultivated (on the non-boggy part). The field has been dewatered by an open network of partially non-functioning channels. The studies have been conducted only on the non-boggy part. The agrotechnical methods are not differentiated in the field.

Vediltsy, Chernihiv region. Sod-mesopodzol (Albeluvisols Gleyic) loamy soils. The terrain is flattened. The size of the field is 105 ha, some part of the field is grassy, the number of experimental plots on the non-grassy part is 117. Cereal and forage crops are cultivated.

Korotych, Kharkiv region. Dark gray heavy loamy podzolic soil prevails. The terrain is slightly sloping. The size of the field is 31 ha, the number of experimental plots is 35. Cereal and forage crops are cultivated by the method, traditional for the Forest-Steppe.

Kommunar, Kharkiv region. Typical low humus leached (Chernozems Chernic) heavy loamy chernozem. The terrain is flattened. The size of the field is 30 ha, the number of experimental plots is 26. Cereal and forage crops are cultivated.

Donetsk, Donetsk region. Ordinarily (Chernozems Chernic) heavy loamy chernozem. The terrain is flattened. The size of the field is 105 ha, the network of experimental plots (51) is established on the part of the field of 50 ha. Cereal and forage crops are cultivated.

Field experiments. The main research method, used in the work, was a geostatistical approach. A regular network of experimental plots, 5 × 5 m each, was established in the field. The plots were geopositioned for the agreed sampling and registration of the yield. The bulk density was measured in the ploughed and subsurface layers (the method of rings, the ring volume is 100 ccm, 5 repeats), the penetration resistance – up to the depth of 35 cm (the Reviakin's method, a plunger of a flat type, 10 repeats), soil humidity – at the depth, similar to that for the bulk density (the method of drying at 105 ^{o}C, 5 repeats), soil samples were selected to determine the structural composition. The time of field experiments is 2–2.5 months after the last treatment, i.e. the measurements characterized the balanced state of soil physical properties [4, 5]. The yield per 1 sq.m. was determined in field conditions in 5 repeats.

LABORATORY EXPERIMENTS AND DATA PROCESSING

The laboratory conditions were used to determine the structural composition, including the definition of the content of aggregates (Savvinov's method, 4 repeats), and to perform statistical and geostatistical data processing. In particular, the variation coefficient and the range of fluctuations were found, the histogram was drawn (to determine the type of distribution and the degree of its deviation from the Gaussian – normal distribution), the variogramme was made (to estimate specific geostatistical parameters – the threshold of dispersion, correlation radius and nugget-effect), 2-D and 3-D-diagrams were built (to establish the contours with different parameters of physical properties and consequently to define their areas), the autocorrelation function and its spectral dispersion density was estimated (to assess the credibility of heterogeneity availability and its fluctuations). The standard Surfer program and the interpolational Kriging method were used in the estimation.

The ultimate aim of the mathematical processing was to discover the working sites and to formulate directions for precise pre-sowing and basic tillage of soil.

RESULTS AND DISCUSSION

Structural composition. The structural composition and especially the availability of separate aggregates therein is the most important indicator of the physical state of the sowing layer prior to the tillage and sowing. According to agricultural requirements [6], not more than 20 % of aggregates are allowed after the tillage, and there should be none prior to sowing. It should be noted that in the experiment, described in [7], even 10 % of aggregates in the sowing layer diminished the advantages of the structural composition of chernozem soil completely.

Table 1 demonstrates statistical and geostatistical characteristics of lumpiness in the investigated objects. In Polissia, only Vediltsy was used due to its better expressed structure. Noteworthy are extremely high variation coefficients. The variation coefficient for Kommunar object reached 0.70 at a very considerable range of fluctuations between the maximal and minimal values. The agronomic consequences of high variability of the lumpy fraction of the structure in the upper soil layer are extremely unfavorable, as even its insignificant presence in the soil leads to the deterioration of the sowing quality, the increased evaporation of available moisture and the decrease in the rate of emergence and fullness of seedlings. All these affect the development of plants until the harvest. In all the objects (Fig. 1–4) the content of aggregates above 20 % was observed on the area of 33 % (Vediltsy), 29 % (Korotych), 26 % (Kommunar) and 65 % (Donetsk). Thus, the removal of aggregates from the surface (sowing) layer is a very important task of tillage. Taking into consideration the fact that this work requires considerable energy consumption, it is cost-efficient to have precise differentiated tillage only on the needed part of the allotment.

Other specificities of spatial heterogeneity of the structural composition are the emergence of nugget-effect in some cases, the termination of variation at the dispersion threshold value of 30–117 and the correlation radius of 150–300 m (the parameter, defining the distance on the spherical variogramme, after which there is no dispersion increase). It means that structure heterogeneity is traced in different distances, and the sizes of allotment sites, similar in structure properties, should be sought in the same range. The sites with increased lumpiness are well observed on 2- and 3-D diagrams. The sizes of working sites for differentiated tillage are usually changed depending on the content of the lumpy fraction on different sites of the field. For instance, if the main autumn tillage is intended for sowing a spring crop in the following year, the differentiation may be related only to the sites with over 20 % of aggregates. If the pre-sowing tillage is intended, tillage differentiation is obligatory. It is clear on 2-D diagrams, which sites require enhanced and more qualitative division of the sowing layer.

Structure variability of agronomically valuable size is much lower. Therefore, its mottling should be considered less in terms of precise tillage. Moreover, the increase of the number of aggregates of this size in the structural composition is achieved not so much due to mechanical tillage, as due to long-term and systematic application of the elements of precise agricultural technology.

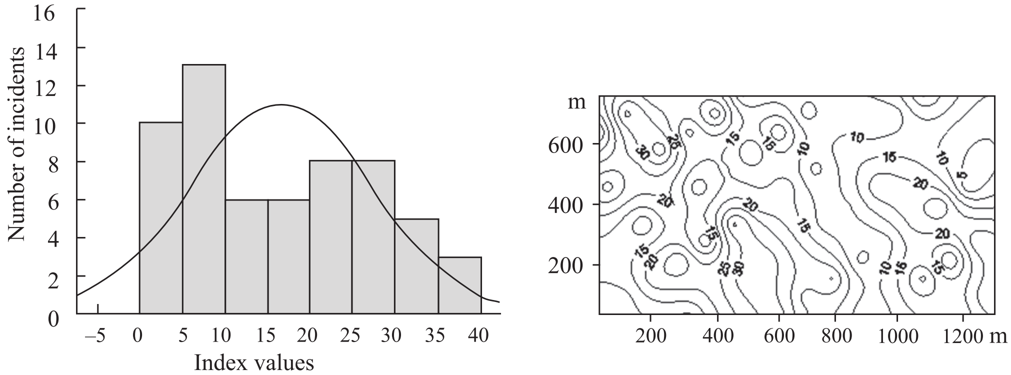
Finally, the share of dust is negligible and, according to our data, is not relevant for precise tillage planning. At the same time, the parameters presented may be used as monitoring criteria – tillage should be performed in a way that would not increase soil dispersion.

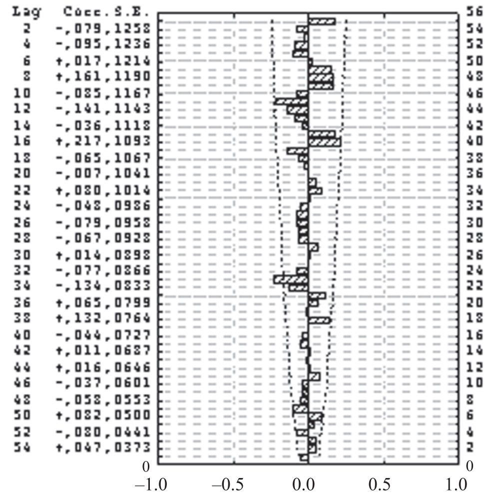
Below are the specificities of geostatistical characteristics of the structure in the investigated fields. The histograms of the distribution of indices for all the fractions are remarkable for weak left or right asymmetry, but the deviations from the classic Gaussian curve are still small. Autocorrelation function and its reliability are noted on practically

Table 1. Statistical and geostatistical indices of the lumpy fraction of the structural composition (%) on the investigated objects*

Index	Vediltsy	Korotych	Kommunar	Donetsk
Range of fluctuations	37.5	46.4	47.1	34.7
Average value	16.6	18.3	16.9	22.6
Median	15.3	16.3	13.0	23.0
Variation coefficient	0.64	0.57	0.70	0.43
Dispersion	114.3	108.6	142.3	95.4
Asymmetry coefficient	0.39	1.42	1.19	0.04
Nugget-effect	79	0	0	22.2
Dispersion threshold	117	30	–	35
Correlation radius, m	300	150	–	250

*The geostatistical indices (nugget, threshold and radius) were obtained on condition of variogramme approximation using a spherical model.





Content of lumps, %	Area	
	%	ha
< 5	2.0	2.2
5–10	18.0	18.9
10–15	24.0	25.2
15–20	22.6	23.8
20–25	18.4	19.4
25–30	9.4	9.8
30–35	5.3	5.6
> 35	0.2	0.2

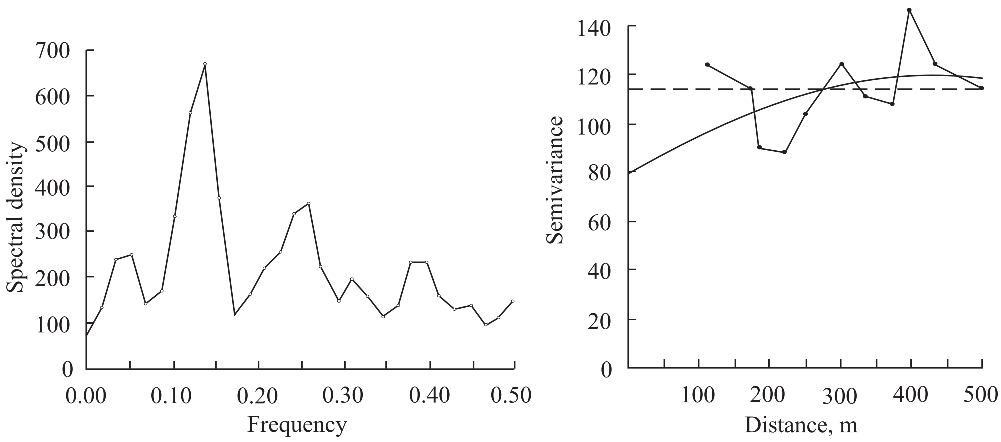
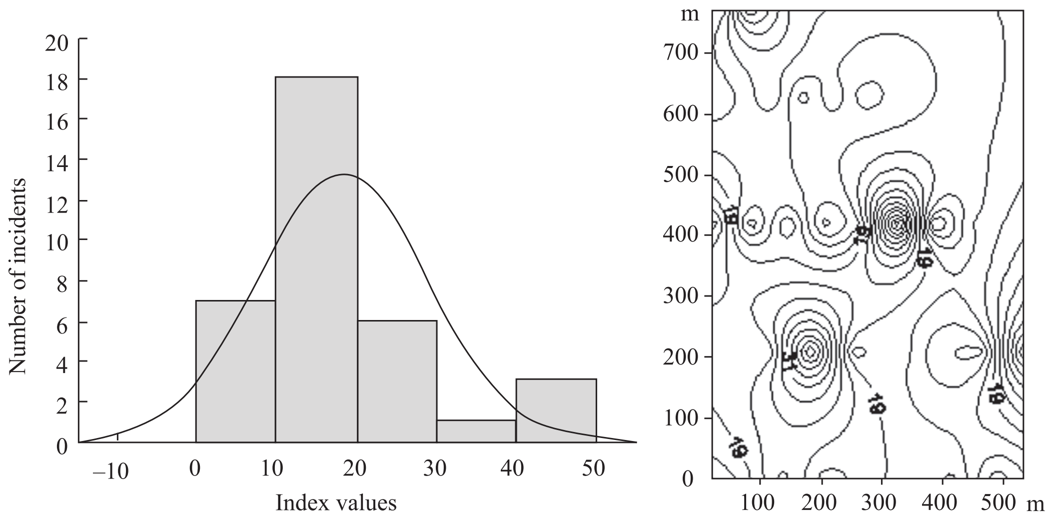
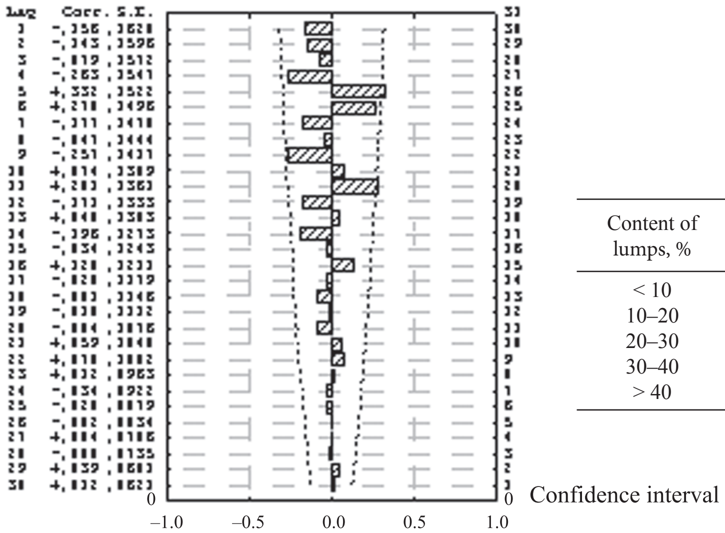


Fig. 1. Spatial heterogeneity of the content of lumps in the sowing layer (Vediltsy)

all the lags (steps). The variogramme is more frequently approximated using the linear or spherical model, and the spectral density of dispersion usually has several peaks of fluctuations with a wide range of frequencies. In general the spatial heterogeneity of the investigated land allotments is absolutely evident. There are also remarkable differences between the sites, which is evident while comparing 2-D and 3-D diagrams. Due to more complex topography, the allotment with dark gray soil (Korotych) has a wider network of isolines of structural fraction parameters. It requires more precise differentiation of agrotechnologies on this allotment compared to another allotment (Kommunar) with dominating typical chernozem.

Bulk density. The coefficients of bulk density variation in all the investigated fields may be considered not high and moderate, as their value is in the range of 5–11 % (Table 2). It should be noted that in the work [8] the soil was called heterogeneous,





Content of lumps, %	Area	
	%	ha
< 10	1.6	0.5
10–20	69.3	21.6
20–30	25.8	8.0
30–40	3.0	0.9
> 40	0.4	0.1

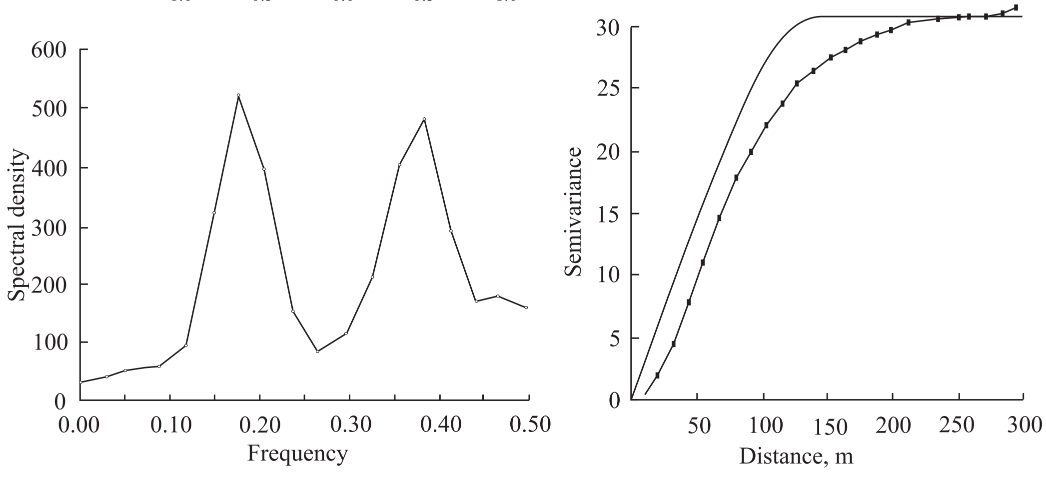
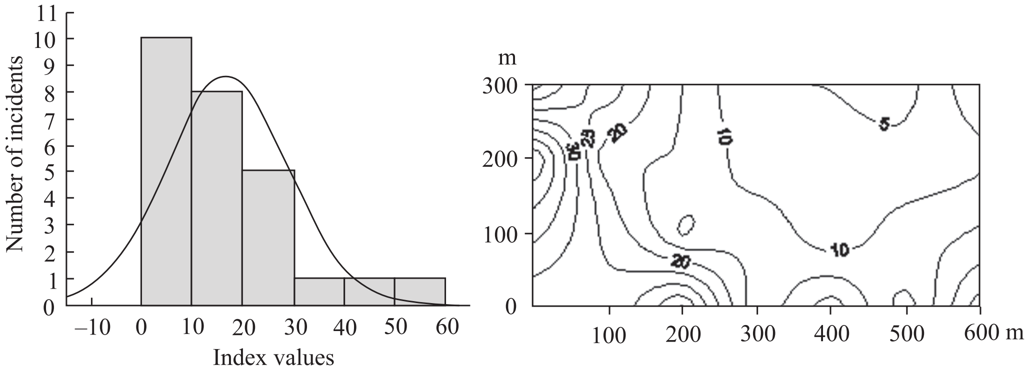
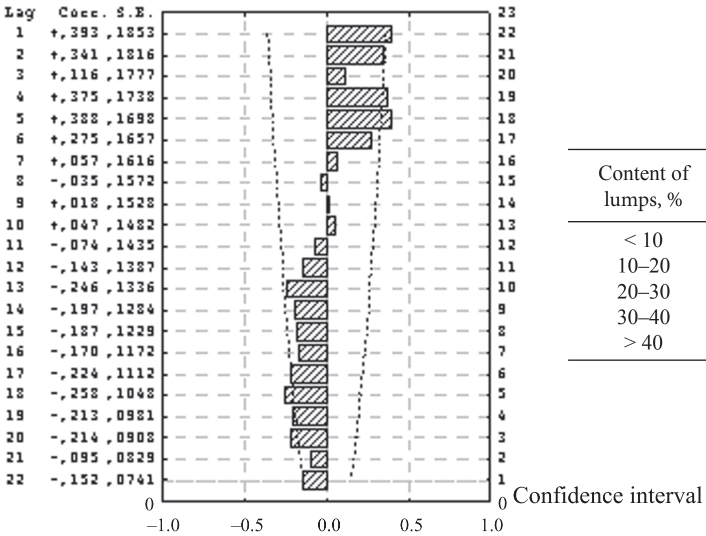


Fig. 2. Spatial heterogeneity of the content of lumps in the sowing layer (Korotych)

if the variation coefficient for any property exceeded 25 %. The moderation of variability is also confirmed with insignificant dispersion and relatively balanced 2-D and 3-D diagrams (Fig. 5, 6). At the same time, for instance, the allotment site in Kolky had the density of over 1.5 g/ccm, which is unfavorable for most crops, grown here, especially prior to sowing.

But the values up to and exceeding 1.6 g/ccm are even more unfavorable. It is impossible to work the soil using common tools with good quality, to sow





Content of lumps, %	Area	
	%	ha
< 10	32.5	9.8
10–20	41.8	12.6
20–30	18.6	5.6
30–40	6.0	1.8
> 40	1.1	0.3

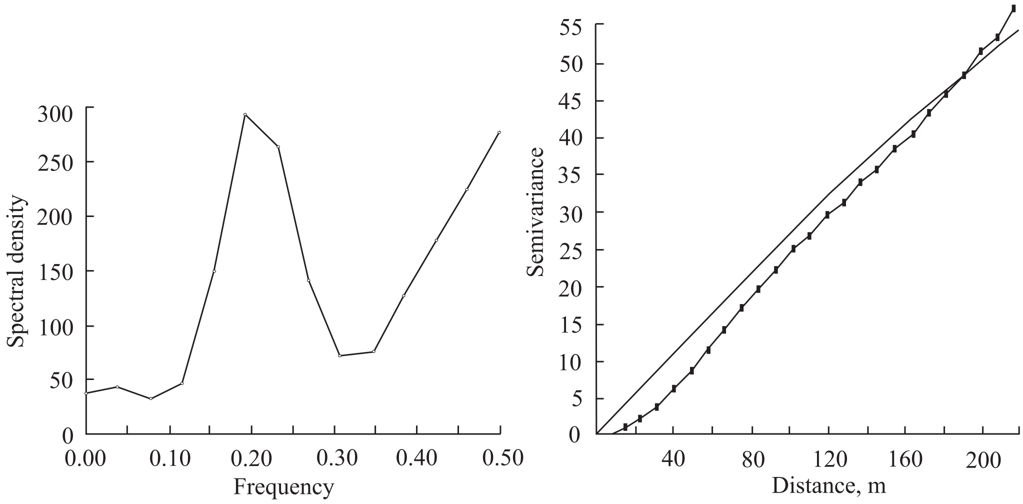
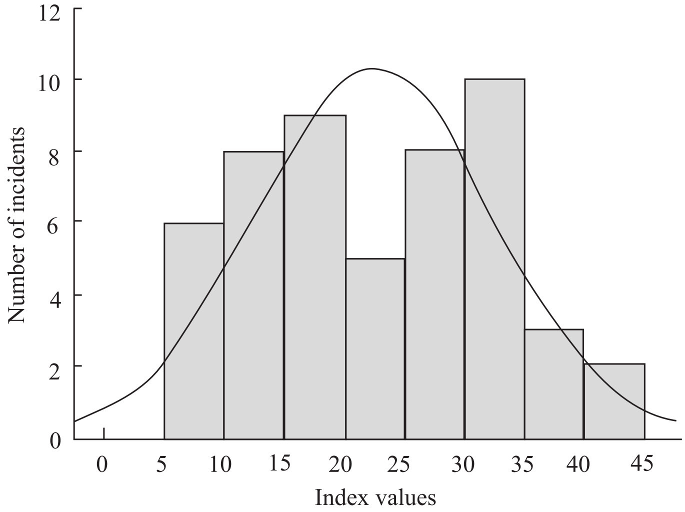


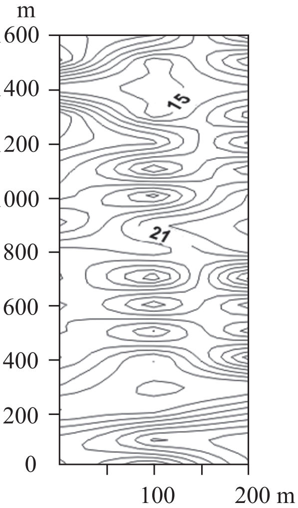
Fig. 3. Spatial heterogeneity of the content of lumps in the sowing layer (Kommunar)

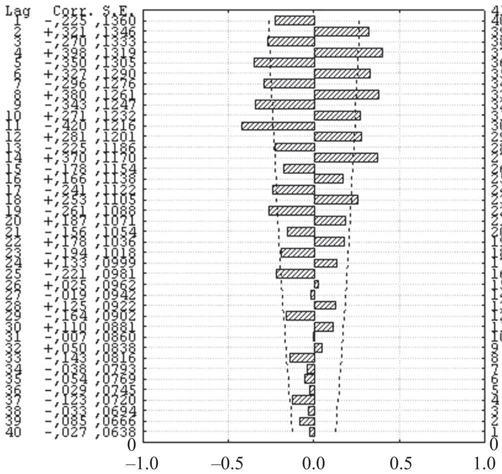
and to receive any emerging crops in such conditions. This is one of the main reasons of mottling, remarkable for Polissia. If such sites are permanent in time, they should be either excluded from tillage at all or worked on using more active (for instance, rotor) tools.

At the same time 10–25 % of the allotment area in Kolky and Vediltsy and over 50 % of other investigated fields have parameters of bulk density, similar to optimal ones (below 1.3 – in the Forest-Steppe and below 1.4 g/ccm – in Polissia). Therefore, tillage on these sites of allotments is not required prior to sowing more demanding crops.

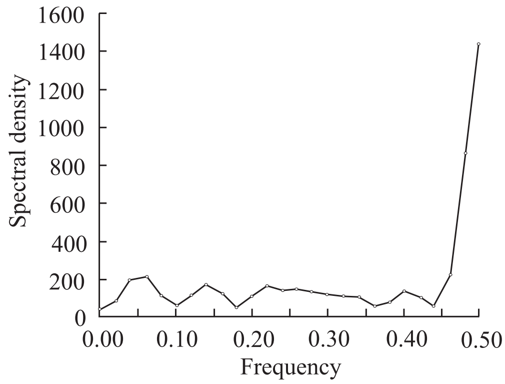
As the median and the average value of indices almost coincide, and histograms are close to Gaussian







Content of lumps, %	Area	
	%	ha
< 15	9.1	4.5
15–20	26.1	13.1
20–25	32.2	16.1
35–30	24.3	12.1
30–35	7.01	3.6
> 35	1.2	0.6



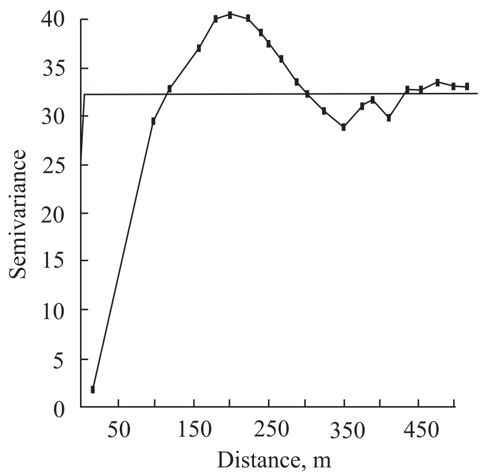


Fig. 4. Spatial heterogeneity of the content of lumps in the sowing layer (Donetsk)

ones, one may state the normality of this index distribution. At the same time there are some, at least insignificant, asymmetry coefficients. Their sign and value (especially evident in the upper part of the pre-sowing layer) are obvious evidence of their anthropogenic origin. The matter is the overthickening in the tillage pan, which turned out not to have any complete manifestation and is locally limited only to specific (rather more humid and low) spots (hatched site of allotment in Fig. 6).

The autocorrelation function tends to the reliable deviation from zero. It confirms the regular character of spatial variability of physical properties.

Based mainly on 2-D diagram of spatial information about bulk density, it is possible to recommend the tillage after the division of allotments into three parts – for usual tillage, minimal tillage and no tillage.

Penetration Resistance. The variation coefficient fluctuates in the range of 0.10–0.27 (Table 3) for the investigated objects which is considered to be mode-rate and increased estimate and almost always guarantees the presence of spatial heterogeneity. Actually the autocorrelation function is present, which is irrefutable evidence of the presence of a specific spatial structure of penetration resistance on all the fields and the substantiation of future plotting (division) of the field. In other words, working sites for differentiated administration of different tillage methods may be found on each investigated field. However, it pertains to theory, whereas in practice the working sites should have a specific size and configuration to ensure work cost-efficiency according to the principles of precise agriculture.

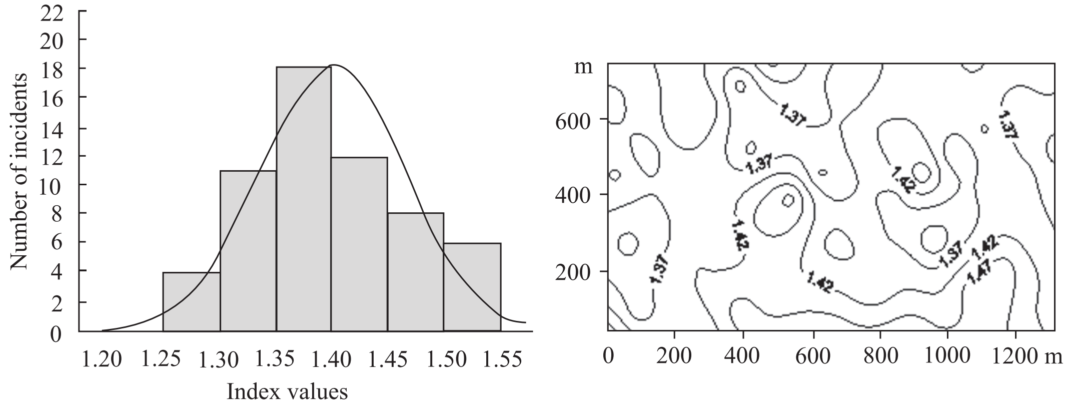
Other specificities of spatial heterogeneity of penetration resistance are also remarkable. The similarity between median and average values confirms the nor-

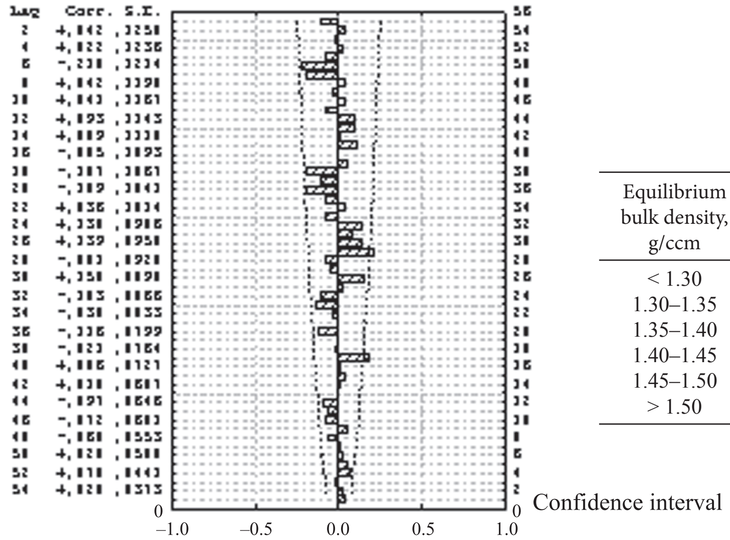
Table 2. Statistical and geostatistical indices of bulk density in the sowing layer (g/ccm) on the investigated objects

Index	Romaniv	Kolky	Vediltsy	Korotych	Kommunar	Donetsk
Range of fluctuations	0.60	0.45	0.25	0.47	0.31	0.61
Average value	1.19	1.47	1.40	1.31	1.30	1.16
Median	1.17	1.47	1.39	1.31	1.28	1.17
Variation coefficient	0.11	0.06	0.05	0.08	0.05	0.10
Dispersion	0.02	0.007	0.004	0.01	0.005	0.01
Asymmetry coefficient	−0.10	−0.046	0.22	0.43	0.61	−0.12
Nugget-effect	0	0	0.004	0.0004	0	0
Dispersion threshold	0.009	–	0.045	0.004	0.017	0.08
Correlation radius, m	250	–	450	300	120	350

Table 3. Statistical and geostatistical indices of penetration resistance (kgf/sq.cm) of the ploughed layer and tillage pan in the soils of the investigated objects

Object, layers	Range of fluctuations	Median	Average value	Standard deviation	Dispersion	Variation coefficient	Presence of reliable autocorrelation function
Kolky:							
ploughed	14	21	21	3.7	13.4	0.18	+
tillage pan	20	34	32	6.0	35.9	0.19	+
Romaniv:							
ploughed	18	18	18	4.8	22.8	0.27	+
tillage pan	25	28	29	7.4	0.2	0.25	+
Vediltsy:							
ploughed	27	23	23	0.2	38.9	0.27	+
tillage pan	18	40	39	4.0	15.7	0.10	+
Korotych:							
ploughed	7	10	11	2.1	4.5	0.19	+
tillage pan	23	24	24	4.5	20.2	0.18	+
Kommunar:							
ploughed	13	22	21	3.3	10.9	0.16	+
tillage pan	20	39	37	3.1	26.4	0.14	+





Equilibrium bulk density, g/ccm	Area	
	%	ha
< 1.30	0.1	0.1
1.30–1.35	9.9	10.4
1.35–1.40	46.7	49.1
1.40–1.45	29.9	31.4
1.45–1.50	12.6	13.2
> 1.50	0.8	0.8

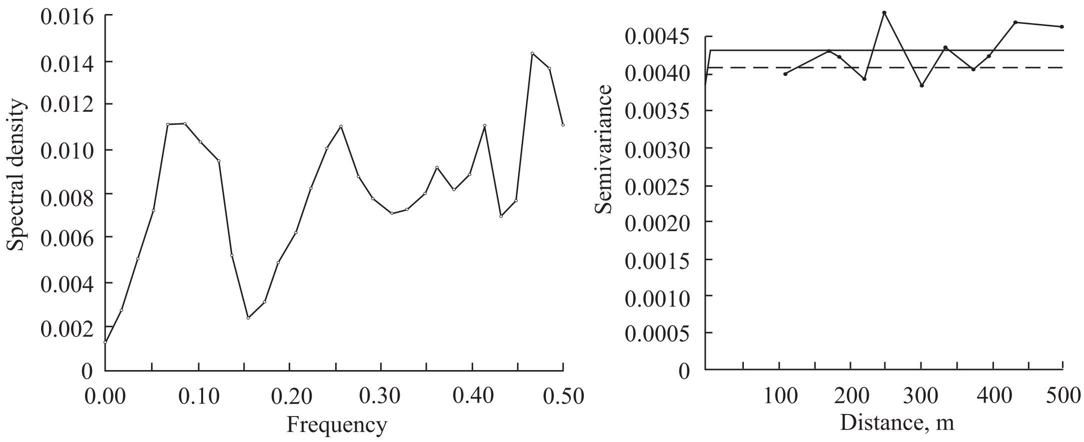
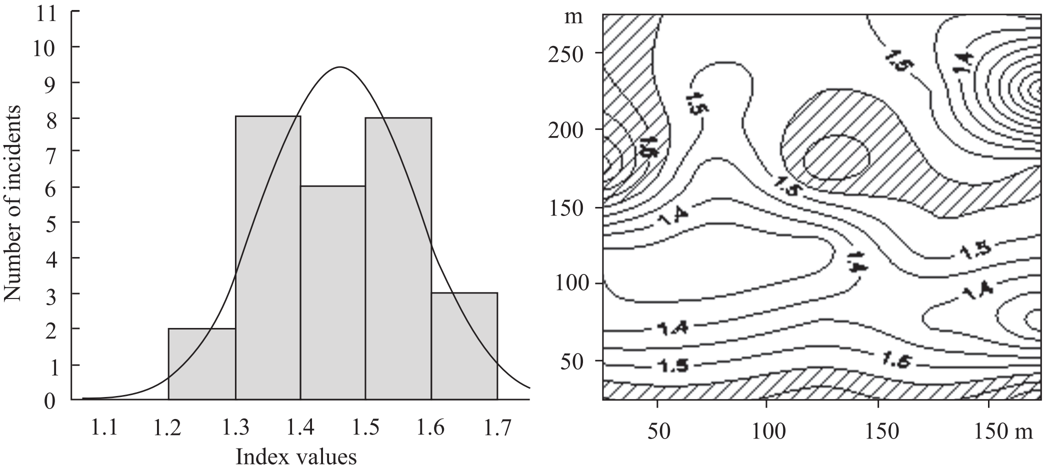
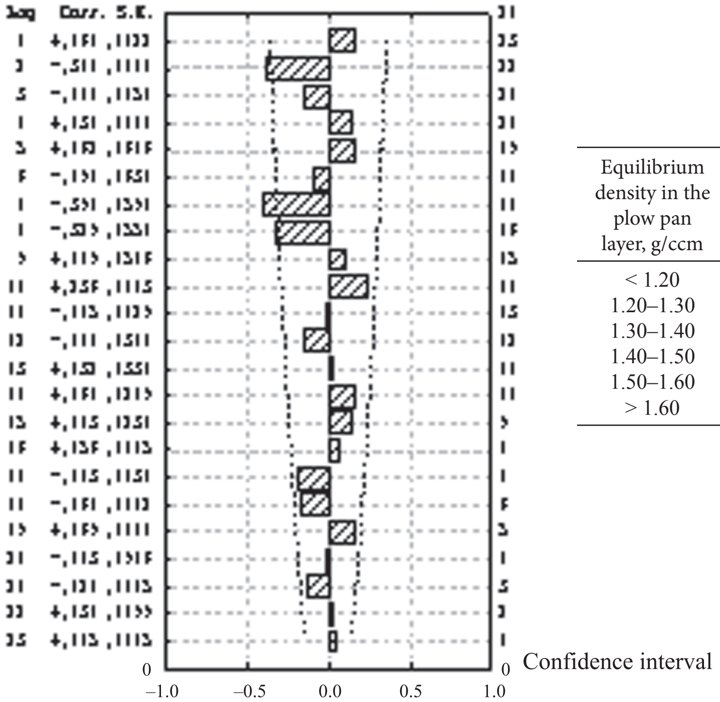


Fig. 5. Heterogeneity of bulk density of the ploughed layer, g/ccm (Vediltsy)

mality of the distribution curve and generally insignificant impact of asymmetry and excess. It also testifies in favor of precise agriculture technology as one should not expect the domination of allotments with maverick solidness values on the fields.

Penetration resistance has considerable differences in the sowing layer and in the tillage pan. This regularity is found in loamy and heavy loamy soils, in soils with high and low fertility levels. It should also be noted that the penetration resistance of the investigated fields is mostly remarkable for considerable values. Certainly, it should be also considered that this is an equilibrium state and a plunger was a flat disk. But even taking it into account, one should admit that such solidness values do not testify in favor of complete tillage minimization for these fields.





Equilibrium density in the plow pan layer, g/ccm	Area	
	%	ha
< 1.20	0.8	0.1
1.20–1.30	1.5	0.1
1.30–1.40	20.4	1.5
1.40–1.50	30.0	2.2
1.50–1.60	42.1	3.2
> 1.60	5.2	0.4

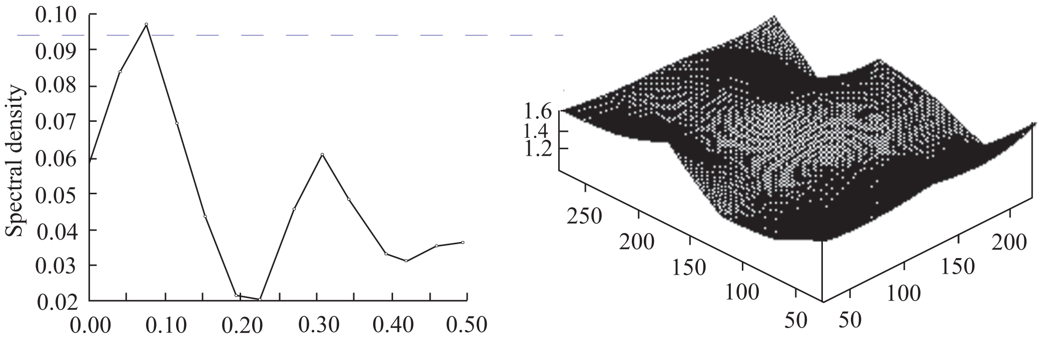


Fig. 6. Heterogeneity of bulk density of the plow pan pan, g/ccm (Kolky)

The visualization of penetration resistance on the investigated fields brings clear demonstration of the specificities of spatial mottling of this index. Almost all 1-D diagrams of soil penetration resistance of elementary sites are one-type (the data are not presented), only the tillage pan is revealed in a different way – according to the depth and value of the drop compared to adjacent layers. It is remarkable that the tillage pan does not have any omission, therefore, only due to this reason it does not require any complete tillage.

The range of the indices obtained fluctuates from the penetration resistance values, comparatively easily overcome by the roots of practically all the cultivated crops (not exceeding 20 kgf/sq.cm), to the values, evidently hindering their growth and functioning (in the range of 30–40 kgf/sq.cm). Only some roots can overcome this solidness level on condition of sufficient humidity [5]. However, even in this case, as the mentioned high indices do not have any complete configuration, deep tillage also requires differentiation.

It is noteworthy that successful germination of seeds and the development of roots of the 1st order requires the penetration resistance not to exceed 10 kgf/sq.cm, or even 5–7 kgf/sq.cm for small-seeded crops (such as sugar beets) [9, 10]. Taking the abovementioned into consideration, it is possible to recommend obligatory pre-sowing tillage, if the penetration resistance of the sowing layer exceeds 10 kgf/sq.cm, deep pre-sowing cultivation, if the layer, deeper than 7–12 cm, has the penetration resistance index, exceeding 20 kgf/sq.cm, and at least one deep tillage during the crop rotation (according to the precise agriculture technology), if the penetration resistance of the tillage pan exceeds 40 kgf/sq.cm.

Crop yield data and their correlation with soil physical properties. The range of fluctuations for crop yield (in terms of crop units) on the investigated allotments (dt/ha) is as follows: Romaniv – 20.2–54.3; Kolky – 1.4–20.2; Vediltsy – 9.0–32.2; Korotych – 10.7–29.8; Kommunar – 19.4–43.3; Donetsk – 31.6–60.3. A considerable range was also preserved in the after-effect on the fields, where similar observations were performed (Romaniv, Korotych, Kommunar). It is remarkable that a considerable range of fluctuations was noted both on the fields with more favorable fertility indices (Kommunar) and on the field with the worst agronomic parameters (Kolky). The negative correlation of the investigated indices and the yield was rather high (Table 4).

It is most likely that yield mottling reflects both the heterogeneity of soil physical properties and a number of other factors of natural and especially economic origin. A considerable contribution into mottling is also made by poor quality of sowing, administration of fertilizers, work at seedlings, and harvest. Thus, the matter of solving the task of decreasing the mottling of field fertility should be started with increasing the quality of performing agrotechnical works.

Using the data obtained to plan precise tillage. Reliable spatial heterogeneity of lumpiness, bulk density and penetration resistance, established on the example of the investigated fields, provides for the substantiation of their precise tillage. For this reason let us consider the norms of distinguishing the contours with different parameters of physical properties and their area. The latter may be used as directions for tillage differentiation in the investigated fields proper.

Standards and area for soil agrotechnological groups. A relevant argument in favor of precise agriculture is the data on the ratio of zones with favorable, less favorable and unfavorable agrophysical conditions

Table 4. Coefficients of pair correlation between crop yields and soil physical properties*

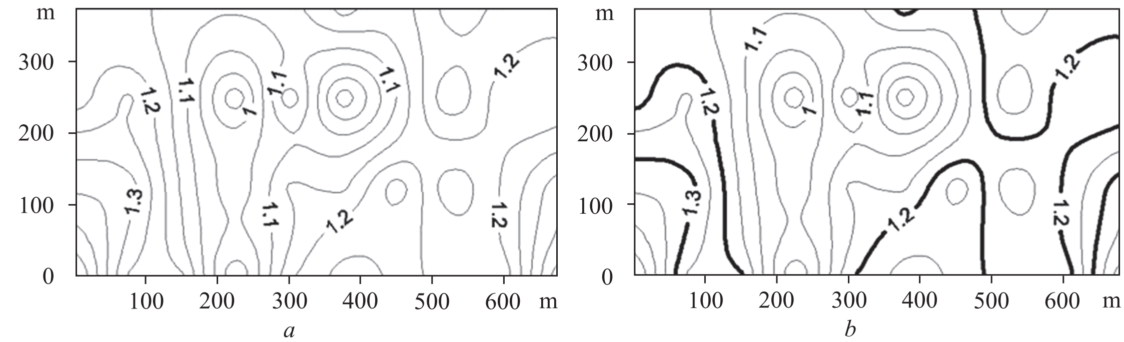
Soil index	Depth, cm	Coefficient correlation
Content of aggregates, %	0−10	−0.57
Bulk density	0−5	−0.68
	10−15	−0.70
	20−25	−0.60
	30−35	−0.48
Penetration resistance	0−10	−0.79
	10−20	−0.7
	20−30	−0.0
	30−40	−0.64

*The data on yields and soil physical properties of different objects are united into one selection.

Table 5. The ratio (%) of areas with the application of different ways of pre-sowing tillage on the investigated objects depending on the level of equilibrium bulk density of soils*

Object	Tillage method		
	No tillage	Minimal	Standard for the zone
Vediltsy	10	50	40
Romaniv	60	30	10
Kolky	25	40	35
Korotych	50	40	10
Kommunar	70	25	5
Donetsk	75	22	3

*Standards to select the tillage method are demonstrated in Table 6.



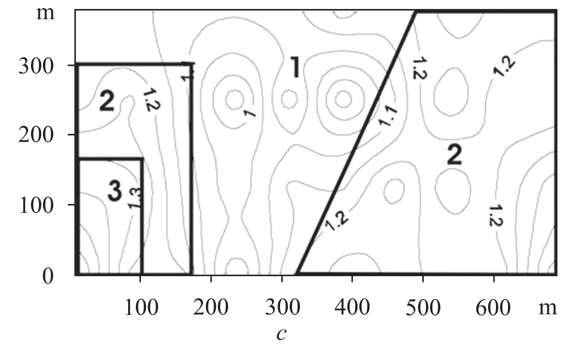


Fig. 7. The sequence of transformation for 2-D diagrams: *a* – diagram, drawn based on the initial data using block-kriging; *b* – after uniting contours according to the standards; *c* – after alignment of contours (1 – site of the allotment, not requiring preliminary pre-sowing tillage; 2 – site of the allotment, requiring at least a single pre-sowing cultivation; 3 – site of the field, requiring thorough, at least double pre-sowing cultivation). Object Romaniv, equilibrium density of the pre-sowing surface layer, g/ccm

on the investigated fields (Table 5). According to these data, the field is divided into specific contours – no tillage, minimal tillage and traditional tillage. The higher the share of sites with favorable parameters of balanced bulk density on the field in the pre-sowing period or prior to the main tillage is, the more relevant (and more cost-efficient) the precise tillage becomes.

While analyzing the data of Table 5, noteworthy is considerable mottling in the ratio of the areas of agro-technological groups in the soils of different natural zones and of different genesis. Natural fertility of soils in Polissia, Forest-Steppe and Steppe has considerable differences. It was rather surprising to find considerable areas of the sites with favorable properties on Polissia objects of Romaniv and Vediltsy. This considerable reserve of minimization (up to complete refusal) of pre-sowing and other work is unfortunately not realized yet, as Polissia is known for low popula-

Table 6. Preliminary standards of estimating physical properties of the cultivated soil layer to substantiate the intensity of tillage practice*

Index	Qualitative estimate of the tilled soil layer	Recommendations on the intensity of pre-sowing tillage
Number of aggregates in the sowing layer, %:		
< 5	Favorable	No tillage needed
5−15	Satisfactory	Moderate tillage
> 15	Unsatisfactory	Intense
Bulk density in the sowing layer, g/ccm:		
< 1.2	Favorable	No tillage needed
1.2–1.3	Satisfactory	Moderate tillage
> 1.3	Unsatisfactory	Intense
Penetration resistance in plow plan, kgf/sq.cm:		
< 20	Favorable	No tillage needed
20−40	Satisfactory	No tillage needed
> 40	Unsatisfactory	Intense

*The standards are applicable to soils of medium and heavy loamy soil texture.

rity of minimal and even more zero or similar tillage technologies. At the same time it testifies in favor of wide application of precise technologies in the mentioned zone.

The fields with chernozem soils almost do not have any sites, requiring enhanced technology of crop cultivation. Instead, there are large areas of soils in the fields, referred by us to the agrotechnological groups with favorable soil properties. Thus, it is possible to state the presence of prerequisites for the development of precise agriculture both in the Forest-Steppe and in the Steppe. However, based on the ratio of areas on the investigated objects, the content and direction of agrotechnologies are different.

Based on 2-D diagrams and standards, land allotments are subdivided into separate sites, forming a maximally justified rectangular form, most suitable for the work of modern tillage machines. Fig. 7 presents the example of field division with the isolation of sites for tillage practice, different in its intensity, – intense, minimal, zero.

Unfortunately, at present there are no technical means, capable of accepting the standards regarding the differentiation of tillage methods in the space of a land allotment. However, there are attempts of elaborating such instruments [11, 12]. The intensity of tillage is automatically selected in the combined rotor-type machine for pre-sowing tillage and sowing, depending on the bulk density prior to the tillage. The higher the density, the higher the speed of rotor spinning is and the better the degree of soil tillage in the sowing layer is.

Prospects of precise tillage in Ukraine. Precise tillage is based on the information about spatial heterogeneity of soil physical properties of the field, the main one being the structural composition (especially the content of the lumpy fraction in the sowing layer), bulk density and penetration resistance. After the geostatistical processing this information is transformed into working sites for the administration of differentiated agrotechnological methods. If the information about spatial heterogeneity of the soil cover is enriched with the data about the administration of geoinformational technologies and new technical means and contains actual data on the external economic situation, it is gradually transformed into a conceptionally new agricultural strategy.

The expressed spatial heterogeneity of soil physical properties in all the investigated fields, located in Polissia, Forest-Steppe and Steppe, brings definitive evidence in favor of the promising prospects of the development of precise soil tillage in Ukraine. The most vivid heterogeneity is manifested in the sowing layer regarding the content of the lumpy fraction, which makes the pre-sowing tillage a very relevant object for precise tillage. The precise basic tillage is also a promising approach, as the fields in all natural zones are different in their bulk density, and some fields (especially in the chernozem zone) with the parameters, close to the requirements of plants, may have zero tillage. It is the Forest-Steppe where the efficiency of precise agriculture may be the highest, although it is also promising in other natural zones as well.

CONCLUSIONS

The lumpiness, bulk density and penetration resistance of the main soils of Polissia, Forest-Steppe and Steppe of Ukraine as reliable indices of their differentiated (precise) tillage were studied. The reliability of indices is proven by the presence of their rather high correlation with the crop yield.

The heterogeneity of soil physical properties, diagnosed using the statistical and geostatistical criteria, is characterized as moderate and enhanced, which creates favorable prospects for the development of precise agriculture in Ukraine.

Depending on the range of fluctuations for soil physical properties and the standards of their quality estimation the investigated fields were divided into agrotechnological groups for differentiated (precise) pre-sowing treatment. The ratio of qualitatively different contours fluctuates depending on the natural zones, but the differentiation in each of them is perceived to be useful and cost-efficient, as it presupposes partial and even complete refusal from pre-sowing tillage and deep basic tillage.

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Просторова неоднорідність фізичних властивостей ґрунтів України

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Мета. Дослідити структурний склад (брилистість), щільність будови і твердість у ґрунтах Полісся, Лісостепу і Степу. **Методи.** Ділянки для дослідження на полі виділено методом накладання регулярної сітки. Вимірювання, проведені перед збиранням врожаю, свідчать про рівноважний стан фізичних властивостей ґрунтів. Дані обробляли геостатистичним методом. **Результати.** Отримано основні параметри просторової неоднорідності (коефіцієнти варіації, гістограми, автокореляційна функція, варіограми, 2-D- і 3-D-діаграми тощо). Неоднорідність фізичних властивостей, виявлена для всіх ґрунтів, характеризується помірними і підвищеними значеннями. За результатами обробки даних досліджені поля розділено на три агротехнологічні групи відповідно до якісних параметрів їхніх фізичних властивостей. **Висновки.** Для кожної групи сформульовано рекомендації щодо передпосівного або основного обробітку різної інтенсивності − без обробітку (там, де параметри наближені до вимог висівної культури), з помірним обробітком зонального типу (де параметри наближені до модальних величин) і з обробкою підвищеної інтенсивності (параметри незадовільні, потрібно виконати більш інтенсивне передпосівне розпушування).

Ключові слова: просторова неоднорідність ґрунтів, фізичні властивості, точний обробіток.

Пространственная неоднородность физических свойств почв Украины

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Цель. Исследовать структурный состав (глыбистость), плотность сложения и твердость в почвах Полесья, Лесостепи и Степи. **Методы.** Делянки для исследования выделены на поле методом наложения регулярной сети. Измерения, проведенные перед уборкой урожая, свидетельствуют о равновесном состоянии физических свойств почв. Данные обрабатывали геостатистическим методом. **Результаты.** Получены основные параметры пространственной неоднородности (коэффициенты вариации, гистограммы, автокорреляционная функция, вариограммы, 2-D- и 3-D-диаграммы и др.). Неоднородность физических свойств, выявленная во всех почвах, характеризуется умеренными и повышенными значениями. По результатам обработки данных исследованные поля разделены на три агротехнологические группы в соответствии с качественными параметрами их физических свойств. **Выводы.** Для каждой группы сформулированы рекомендации по предпосевной или основной обработке различной интенсивности – без обработки (там, где параметры близки к требованиям высеваемой культуры), с умеренной обработкой зонального типа (где параметры близки к модальным величинам) и с обработкой повышенной интенсивности (параметры неудовлетворительны и требуется более интенсивное предпосевное рыхление).

Ключевые слова: пространственная неоднородность почв, физические свойства, точная обработка.

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