Scientific Papers. Series A. Agronomy, Vol. LXVII, No. 1, 2024
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

ASSESSMENT OF SPATIAL HETEROGENEITY OF AGROPHYSICAL PROPERTIES OF ARABLE SOILS FOR PRECISION TILLAGE

Irina PLISKO, Kateryna ROMANCHUK, Svitlana KRYLACH, Karina KUTSOVA

National Scientific Center «Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky», 4 Chaikovska Street, 61024, Kharkiv, Ukraine

Corresponding author email: irinachujan@gmail.com

Abstract

The assessment of spatial heterogeneity of structural-aggregate composition, hardness and bulk density of soil was carried out using statistical and geostatistical data processing methods, which included empirical Bayesian kriging and spatial autocorrelation (Moran's index). The research was carried out on the example of arable soils of territorial objects, located in the area of the Left Bank Forest Steppe of Ukraine. It was found that the presence of heterogeneous relief forms within the objects, uneven distribution of precipitation, and the influence of economic activity significantly influenced the formation of small-scale soil heterogeneity. It was proved that the content of the lumpy (> 10 mm) and dusty (< 0.25 mm) fractions was characterized by the greatest variability, while the density and hardness indicators showed little variability. The impact of the studied indicators on the formation of crop yields was evaluated. On the basis of the analysis of 2-D diagrams, the peculiarities of the spatio-temporal distribution of the investigated soil parameters were evaluated and the field delimitation into working plots for differentiating the methods and intensity of mechanical soil tillage is substantiated.

Key words: *agrophysical properties, arable soils, precision tillage, spatial heterogeneity.*

INTRODUCTION

In today's conditions, with the rapid increase in the number of the population and, at the same time, the depletion of soils within the agricultural lands, the issue of rational and ecologically safe land use using the latest information technologies becomes extremely relevant. One such technology is precision agriculture.
In the scientific literature, the term "precision agriculture" has different interpretations. According to the official definition of International Society for Precision Agriculture "Precision Agriculture is a management strategy that gathers, processes and analyzes temporal, spatial and individual plant and animal data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production." (Precision…, 2024).
Academician V.V. Medvedev called "precision agriculture" one of the most technologically developed areas of modern agriculture, which takes into account geospatial information on soil properties and plant condition for differentiated tillage, fertilization, pesticide application, etc. (Medvedev (Ed), 2009). However, the author emphasized that the spatial heterogeneity of soil in small areas is not studied, which, in turn, inhibits the development of precision agriculture.
In Ukraine, certain technologies of precision agriculture are used only on 20-30% of cultivated areas (about 8 million hectares), and domestic agricultural holdings use elements of precision agriculture on 50% of the areas - when applying plant protection products and only on 4% of the areas - when sowing and applying mineral fertilizers.
Usually, in precision agriculture, the most frequently used elements of technology are the application of fertilizers and plant protection products, which can be carried out differently, taking into account the heterogeneity of the field and the condition of the plants (Savytskyi, 2017; Burliai & Okhrymenko, 2021). At the same time, an unresolved issue is the differentiation of the methods and intensity of mechanical soil tillage, which will contribute to increasing the efficiency of the implementation of accurate spatially differentiated agricultural technologies, depending on the heterogeneity of the main agrophysical properties of arable soils.
A large number of scientific works by both Ukrainian and foreign scientists are devoted to

the issue of the heterogeneity of soil properties (Medvedev, 2010a; Zukov & Zadorojhnaya, 2016; Beuschel et al., 2019; Yakovenko et al., 2019; Širáň & Makovníková, 2021; Myslyva et al., 2023; Plisko & Byndych, 2020; Bertici et al., 2022). The heterogeneity of the agrophysical properties of the soil both in spatial and temporal scales significantly affects the productivity and fertility of the soil, the quantity and quality of agricultural products (Techen et al., 2020; Yao et al., 2014).

The spatial heterogeneity of the agrophysical properties of soils is also facilitated by the relief, which is relatively strongly related to the content of organic carbon (Poffenbarger et al, 2020). In turn, the content of soil organic matter affects soil aggregation, which leads to changes in the water-holding capacity and structural state of the soil. Therefore, it is important to assess the influence of the relief on the variability of the soil and the agrophysical properties of the soil, which determine the conditions for the growth and development of agricultural crops.

Various approaches and methods are found in the scientific literature for the general and quantitative assessment of the spatial heterogeneity of the soil in the field. Chen S. and Metwally M. et al. propose the division of a field into subfields according to soil classes/zones with different physical and chemical properties based on contrasting yield responses (Chen et al., 2020; Metwally et al., 2019). Călina J. and Popescu C. (Călina et al., 2021; Popescu et al., 2020) have developed a very precise and fast method for determining the size and shape of land areas with heterogienety of properties. The method involves the use of terrestrial or 3D scanning that provides accurate and complete data about the scanned objects, allowing the visualization of real field conditions. Also, from the database obtained, thematic maps can be created that can be used in other works on agricultural farms, in order to practice a modern agriculture such as precision agriculture.

In general, various geostatistical methods are used to assess the spatial heterogeneity of soils (Castrignanò et al., 2018). In particular, spatial correlation methods are used to predict soil properties at points or locations where samples have not been taken with sufficiently high accuracy, thereby reducing the impact on the environment (Nawar et al., 2017). In general, geostatistical evaluation can prove the existence of heterogeneity, establish its extent and determine the expediency of implementing elements of precision agriculture, i.e., find the most informative areas of agricultural land (a separate field or land plot) with spatial heterogeneity of soil properties for the local implementation of differentiated agricultural measures.

In connection with the above-mentioned, the aim of the research was to evaluate the peculiarities of the spatial distribution of the main agrophysical properties of arable soils (within a separate territorial object) using statistical and geostatistical methods of analysis, to reveal the influence of the heterogeneity of the studied soil indicators on the yield of agricultural crops, and to substantiate the implementation of measures with precision tillage.

MATERIALS AND METHODS

The research was conducted during 2020-2021. The object of research (part of the field) with an area of 21 hectares is located outside the settlement of Buda, South City Territorial Community of Kharkiv District, Kharkiv Region, in the Left Bank Forest-Steppe zone of Ukraine. The soil cover is represented by gray and light-gray podzolized soils of heavy loamy and light clay granulometric composition on loess rocks and their weakly and moderately eroded analogues.

Figure 1 shows relief isolines according to topographic map data and a regular grid with soil sampling points within the object.

Figure 1. Map scheme of relief isolines according to topographic map data and a regular grid with soil sampling points within the object (based on Google-map)

The relief of the field is an undulating plain, there are height differences from 140 to 160 m, the slope of the surface varies from 2 to 6 degrees. The cultivated crops are winter wheat (2020) and sunflower (2021).
To determine the heterogeneity of the agrophysical properties of the soil, the method of sampling according to a regular grid with georeferencing of points at the rate of 1 point per 1 ha was used.
In the field conditions, the hardness of the soil in layers 0-10 cm, 10-20 cm, and 20-30 cm was determined with a Revyakin hardness tester (DSTU 5096:2008). The structural and aggregate composition was determined by the sieve method in the modification of N.I. Savvinov (DSTU 4744:2007) with the definition of the main fractions of structural aggregates: lumpy (size > 10 mm), agronomically valuable (10-0.25 mm) and dusty fractions (< 0.25 mm).
The density of the structure of arable soils of the research object was determined by the pedotransfer modeling method developed in the Soil Geoecophysics Laboratory of the NSC ISSAR with the quadratic model (Patent 123878 UA, 2018):

$$Z = 1,6929-0,0103x-0,0645y+0,0001x^2-0,0001xy+0,0006y^2,$$

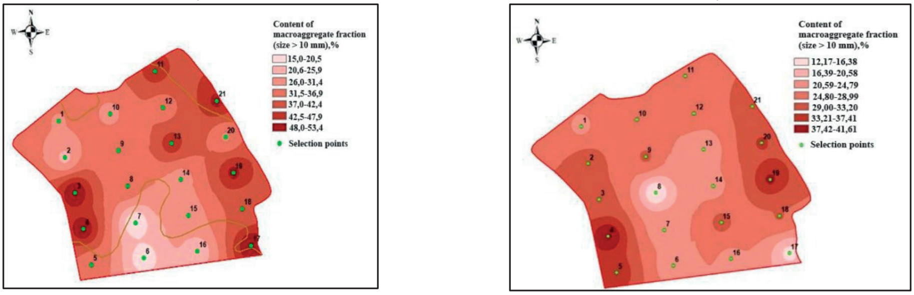
Where:
Z - soil bulk density, g/cm^3;
x - physical clay content (particle size < 0.01 mm), %;
y - humus content, %.

The productivity of cultivated crops was assessed by grain (winter wheat) and seed (sunflower) yields. Harvesting was carried out in the phase of full crop maturity by the meter method (on an area of 1m^2 in a radius of 1m from each point), which was then calculated in hundreds kg/ha.
Mathematical-statistical methods were used to establish the reliability of the obtained data and the relationships between productivity and the studied agrophysical parameters of the soil, which were implemented with the help of Excel and Statistica 10. The geostatistical method was used to evaluate the spatial analysis of the data. This analysis was carried out using the ArcGIS 10.4.1 program, which made it possible to single out the most informative sections of the field for local improvement of their parameters using such a measure of precision agriculture as differential tillage.

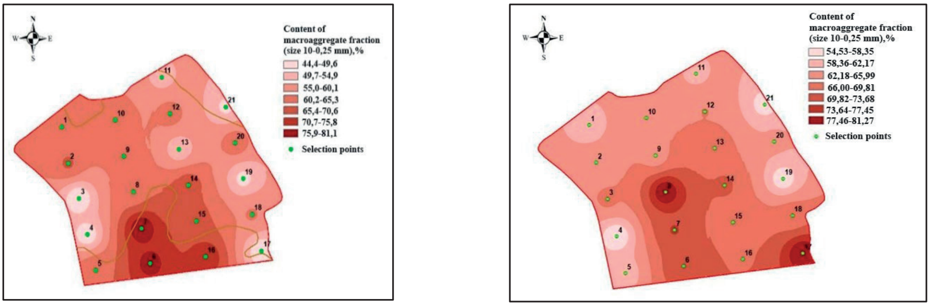
RESULTS AND DISCUSSIONS

Assessment of the heterogeneity of indicators of the structural and aggregate composition of soils. The spatial distribution of indicators of the structural-aggregate composition (Figure 2) shows that the majority of the studied soils in 2020 were characterized by favorable indicators of the structural-aggregate composition: 61.9% of the total area of the territory was characterized as good, 33.3% - sufficient, 4.8% - excellent structural condition. According to the results of 2021, it was established that almost half of the area of the object was characterized by a good structure, the other half by a sufficient structure, that is, there was a decrease in the lumpy and an increase in the dusty fractions of the soil.
The obtained statistical indicators confirmed that the content of the lumpy and dusty fractions was characterized by the greatest heterogeneity, the values of the correlation coefficients (Kv) for which were 0.33 and 0.55, respectively.

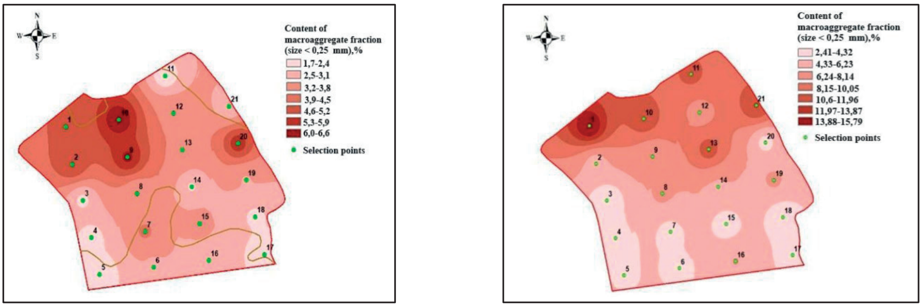
2020 year | 2021 year



a) content of macroaggregate fraction (size > 10 mm), %



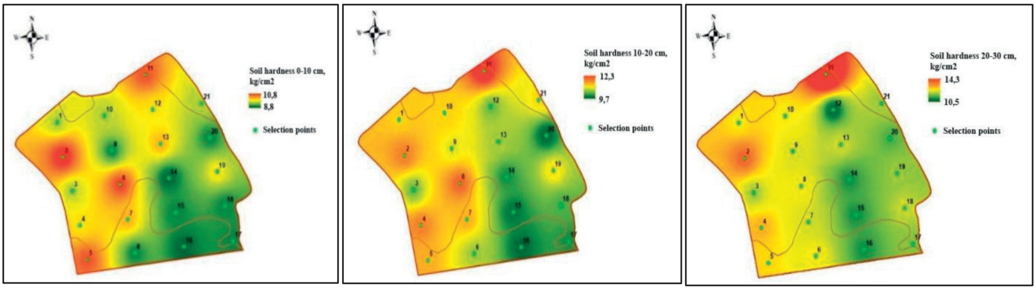
b) content of agronomical-valuable fraction (size 10-0.25 mm), %



c) content of macroaggregate fraction (size < 0.25 mm), %

Figure 2. 2-D diagrams of the spatial distribution of the structural and aggregate composition of soils

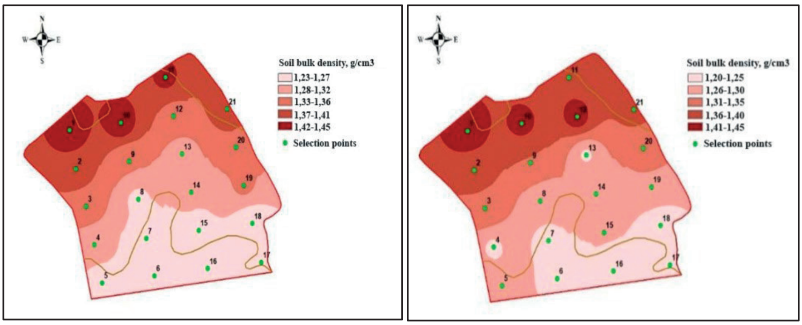
Assessment of heterogeneity of soil hardness. Indicators of soil hardness during the research period ranged from 8.8 kg/cm^2 to 14.3 kg/cm^2 (Figure 3). The standard deviation of the sample for a depth of 0-10 cm was 0.63 kgf/cm^2, for a depth of 10-20 cm - 0.65 kgf/cm^2, for a depth of 20-30 cm - 0.78 kgf/cm^2. Despite the fact that the hardness of the studied soils of the site was no more than 14.3 kgf/cm^2, it is important to emphasize that for successful seed germination and the development of first-order roots, it is recommended that the hardness does not exceed 10 kgf/cm^2, and for small-seeded crops (such as sugar beet) - even 5-7 kgf/cm^2. (Medvedev, 2009; Medvedev, 2010b).



a) layer 0-10 cm b) layer 10-20 cm c) layer 20-30 cm

Figure 3. 2-D diagrams of the spatial distribution of soil hardness within the territorial object of the study

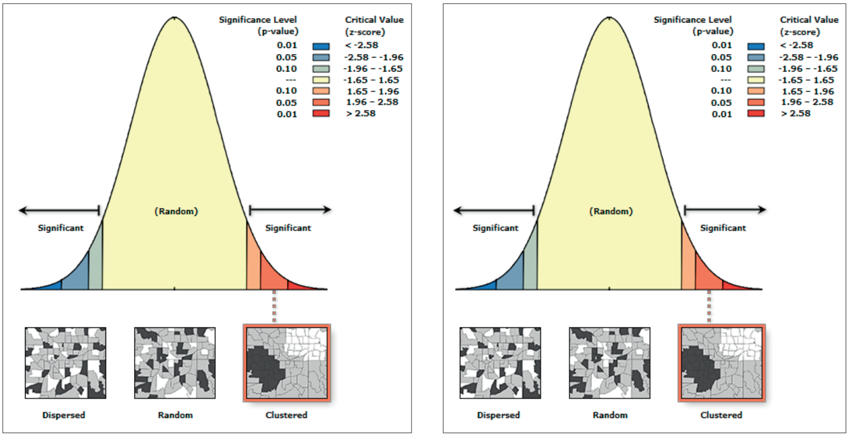
Evaluation of the heterogeneity of the density of the soil structure. The obtained data indicate the variability of the structure density within the study object (Figure 4). The range of changes in the indicator was from 1.20 g/cm^3 to 1.45 g/cm^3, which potentially substantiates the feasibility of differentiating agricultural measures from soil cultivation in those parts of the field where the permissible parameters of structure density were exceeded (> 1.3 g/cm^3). This trend was observed during two years of research.



a) 2020 year b) 2021 year

Figure 4. 2-D diagrams of the spatial distribution of the soil bulk density in the 0-30 cm layer within the territorial object

A geostatistical analysis was carried out on the example of the density of the soil structure. We used a geostatistical method, in particular spatial autocorrelation (Moran's Index). Moran's Index (MI) indicates the spatial dependence of a variable and is a correlation coefficient between the value of a feature at a given point in space and the average value of this feature in its immediate surroundings (Webster, 2023; Moran, 1950). According to the results of the autocorrelation analysis (Figure 5), it was established that the variation of the density of the soil structure of the studied object has a regular character, the MI was 0.48 and 0.45, respectively, in 2020 and 2021 with a significant Z-score (2.17 in 2020 and 2.05 in 2021) and insignificant p-value (0.029 in 2020 and 0.039 in 2021). That is, the probability is less than 5% that the analyzed attributes of the spatial object may be the result of a random distribution: the heterogeneity of the density of the soil structure within the object is not random. A positive MI value indicates clustering tendencies.



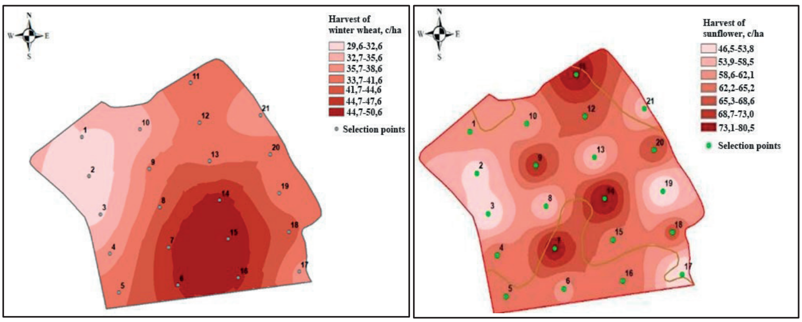
2020 year
Moran's index: 0.481387
expected index: -0.05
variance: 0.059520
z-score: 2.178110
p-value: 0.029398

2021 year
Moran's index: 0.454613
expected index: -0.05
variance: 0.060165
z-score: 2.057242
p-value: 0.039663

Figure 5. Spatial Autocorrelation Report based on Moran's index

Assessment of crop yield heterogeneity. Within the boundaries of the territorial object, the variety of yield data was noted (Figure 6).

The yield of winter wheat in 2020 ranged from 29.6 t/ha to 50.6 t/ha. Comparing the maps of yield distribution (Figure 6a) and physical properties, we came to the conclusion that the productivity of wheat increased with a decrease in the density of the structure (Figure 4), as well as a decrease in the content of lumpy fractions (Figure 2a), but an increase in fractions of agronomically valuable size (Figure 2b). The same trend was observed in 2021 (Figure 6b), where the cultivated crop was sunflower. In general, the yield of sunflower was quite high and ranged from 46.5 t/ha to 80.5 t/ha. The highest yields of both crops were obtained on gray podzolized soils, slightly lower - on their washed varieties and light gray podzolized soils. The decrease in productivity is explained by the fact that the podzolized soils are located on slopes of different steepness, in connection with this the loss of part of the moisture with surface runoff and the development of erosion processes is observed.



a) winter wheat b) sunflower

Figure 6. Cartogram of crop yield distribution

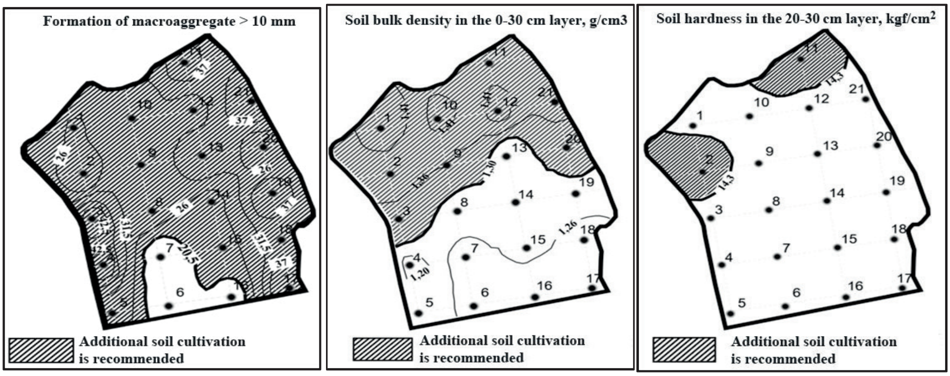
Correlation analysis was used to assess the dependence of crop yield separately on each of the studied agrophysical soil parameters. The yield of winter wheat showed an average correlation with the content of aggregates > 10 mm (r = 0.53) and the content of agronomically valuable aggregates (r = 0.59); moderate correlation was observed with hardness in the 0-10 cm layer (r = 0.36). The correlation with other investigated indicators was weak. Similar results were obtained for sunflower: an average correlation was established between sunflower productivity and the content of agronomically valuable aggregates (r = 0.52) and a moderate correlation with the content of structural aggregates > 10 mm (r = 0.47). The rest of the indicators were weakly correlated with crop productivity.

The significance of the relationships between individual investigated indicators was noted, in particular, an inverse correlation was obtained between the content of lumps and the content of agronomically valuable aggregates (r = -0.99), hardness in the 0-10 cm and 10- 20 cm layers (r = -0.82) and a positive correlation between hardness in the 10-20 cm and 20-30 cm layers (r = 0.81).

Rationale of the implementation of precision soil cultivation measures. The assessment of the heterogeneity of agrophysical soil indicators and productivity made it possible to divide the area of the research object into separate parts (Figure 7) for the differentiated management of agrotechnological operations, in particular, the application of measures of precise soil cultivation, which involves soil cultivation of different intensities and depths, aimed at leveling fertility within a specific area.

Characterizing the spatial distribution of the content of lumps, we came to the conclusion that within the scope of the study, 19.7 hectares need additional surface treatment, which is about 90 % of the total area of the field (Figure 7a). Such an operation will ensure a reduction in the content of blocks exactly on the part of the field that needs it. Exceeding the upper limit of the permissible values of the density of the soil structure in the 0-30 cm layer during the cultivation of grain crops was noted on an area of 10.8 hectares (49.6% of the total field area), which substantiates the need for additional surface tillage (Figure 7b). According to some research (Vizitiu & Calciu, 2022) in order to mitigate the subsoil compaction, the best solution with positive effects on soil quality is to use a combination of the two tillage treatments, namely the application of the mould board ploughing annually and of the subsoiling periodically at 3-4 years. In this way is prevented the formation of the hard pan layer at the base of tillage depth.

A significant area of the studied soils is characterized by loose hardness, especially in the upper 0-10 cm layer - from 8.8 to 10.8 kgf/cm^2, which is not an obstacle for the germination of seeds of most agricultural crops. In turn, in the 20-30 cm layer, an increase in hardness values was established to 14.3 kgf/cm^2, where the plow sole is located. In this regard, these areas within the object require a continuous reduction of hardness in the seed and arable (this is mandatory) layers. In advance, it is possible to assert the expediency of deeper loosening without turning over the formation (for example, with the help of a chisel or a rotary loosener), while the depth of chiseling must be differentiated. If we rely on the measurement of the density of the structure, then the best chiselling depth is at least 30 cm and it is desirable to carry it out on the entire area of over-compacted areas within the field. But we tend to give preference to determining the hardness of the soil as a more correct indicator for choosing one or another tillage and, therefore, in order to reduce the cost of the technological operation, we recommend chiseling only to a depth of 20-22 cm. These are relatively small parts of the field (about 3.5 hectares, which is 16 % of the total area of the field), which is also shown in Figure 7 c.



a) b) c)

Figure 7. Recommendations for precise tillage within the limits of the experimental field (a - by the content of macroaggregate fraction > 10 mm; b - by soil bulk density in the 0-30 cm layer; c - by soil hardness in the 20-30 cm) layer)

CONCLUSIONS

According to the results of the determination of agrophysical indicators within the territorial object of the Left Bank Forest Steppe of Ukraine, it was established that the arable (0-30 cm) layer of the studied soils was characterized by the following indicators: the content of the lumpy fraction was from 14.97% to 53.40%, the content of aggregates of agronomically valuable size ranged from 44.37% to 81.07%, the content of the dusty fraction - from 1.73% to 6.60%. The hardness of the soil varied from 8.8 kgf/cm^2 to 14.3 kgf/cm^2 depending on the depth of determination, while its highest values were recorded at the depth of the location of the plow sole (in a layer of 20-30 cm). The density of the soil structure varied from 1.23 g/cm^3 to 1.45 g/cm^3.

Mathematically, the greatest variability of the content of the lumpy fraction (Kv = 0.33) and the content of the dusty fraction (Kv = 0.42) with insignificant variability of density and hardness was proved. Autocorrelation analysis based on the Moran`s Index confirmed the fact that the heterogeneity of the density of the soil structure within the site is not random - MI was 0.48 (2020) and 0.45 (2021)).

Correlation analysis was used to assess the dependence of crop yield separately on each of the studied agrophysical soil parameters.

The dimensions of individual working areas are substantiated for the introduction of precise tillage, which provides for the possibility of local, and not continuous (as was the case with conventional technologies) correction of inhomogeneities. It was determined that within the boundaries of the territorial object, in the presence of an excessive content of lumps in the arable layer of the soil, 19.7 hectares, which is about 90 % of the total area of the field, need additional surface treatment. Exceeding the upper limit of the permissible values of the density of the soil structure in the 0-30 cm layer was noted on an area of 10.8 ha, which substantiates the expediency of chiselling to a depth of at least 20-22 cm.

ACKNOWLEDGEMENTS

We gratefully acknowledge the researcher of Soil Geoecophysics Laboratory named after academician of the National Academy of Sciences of Ukraine Vitaliy Medvedev, Svitlana Nakisko for their assistance during the statistical and geostatistical data processing.

REFERENCES

Bertici, R., Dicu, D., Herbei, M. & Sala, F. (2022) Qualitative evaluation of agricultural land by methods based on gis techniques. lenauheim case study, Timis County, Romania. *Scientific Papers. Series A. Agronomy*, *LXV,1*, 30–39.

Beuschel, R., Piepho, H.P., & Joergensen, R.G. (2019). Similar spatial patterns of soil quality indicators in three poplar-based silvo-arable alley cropping systems in Germany. *Biology and Fertility of Soils*, 55. 1–14. doi: 10.1007/s00374-018-1324-3.

Burliai, A.P., & Okhrymenko, B.O. (2021). Precision Agriculture as a Direction of Modernization of Agricultural Production. *Modern Economics*, 29. 29-34. doi: 10.31521/modecon.V29(2021)-05.

Castrignanò, A., Buttafuoco, G., Quarto, R., Parisi, D., Viscarra Rossel, R.A., Terribile, F. … Venezia, A. (2018). A geostatistical sensor data fusion approach for delineating homogeneous management zones in Precision Agriculture. *Catena*, 167. 293–304. doi: 10.1016/j.catena.2018.05.011.

Călina, J., Călina, A., Miluț, M., Bădescu, G. & Cioboată, M. (2021). Study on the use of land scanning in soil erosion inventory works for sustainable agriculture in agritouristic farms. *Scientific Papers. Series A. Agronomy*, *LXIV, 1*, 659–668.

Chen, S., Du, T., Wang, S., Parsons, D., Wu, D., Guo, X., & Li, D. (2020). Evaluation and simulation of spatial variability of soil property effects on deep percolation and nitrate leaching within a large-scale field in arid Northwest China. *Science of the Total Environment*, 732. 139324. doi: 10.1016/j.scitotenv.2020.139324.

Medvedev, V.V. (2009). *Soil Penetration Resistance*. Kharkov: 13 Press.

Medvedev, V.V. (2010a). Heterogeneity as natural display of horizontal structure of a soil cover. *Gruntoznavstvo,* 11(1-2), 6–5.

Medvedev, V.V. (2010b). Soil hardness as a criterion for justifying technologies and technical means for its cultivation. *Bulletin of Agricultural Science,* 4. 14–18.

Metwally, M.S., Shaddad, S.M., Liu, M., Yao, R.-J., Abdo, A.I., Li, P., … Chen. X. (2019). Soil Properties Spatial Variability and Delineation of Site-Specific Management Zones Based on Soil Fertility Using Fuzzy Clustering in a Hilly Field in Jianyang, Sichuan, China. *Sustainability*, 11(24), 7084. doi: 10.3390/su11247084.

Moran, P.A.P. (1950). Notes on Continuous Stochastic Phenomena. *Biometrika,* 37(1/2), 17–23. doi: 10.2307/2332142.

Myslyva, T., Nadtochiy, P., Bilyavskyi, Y. & Trofymenko, P. (2023) Intra-field spatial heterogeneity prediction for the purposes of precision farming: comparison of frequency ratio and shannon's entropy models. *Scientific Papers. Series A. Agronomy*, *LXVI, 1*, 138–147.

Nawar, S., Corstanje, R., Halcro, G., Mulla, D., & Mouazen, A.M. (2017). Delineation of soil management zones for variable-rate fertilization: A review. In D.L. Sparks (Ed), *Advances in Agronomy. Book series.* (pp. 175-245). Newark, DE, United States: Academic Press. doi: 10.1016/bs.agron.2017.01.003.

Patent 123878 UA (2018). Patent for utility model 123878 UA, IPC: G01N 33/24 (2006/01). *Method of determining bulk density of soil* / Medvedev, V.V., Bigun, O.M., & Plisko, I.V. Ukrainian National Office for Intellectual Property and Innovations: publ. 12.03.2018, Bull. № 5.

Plisko, I. & Byndych, T. (2020) Theoretical and applied basis for creation of spatiallydifferentiated systems of soil quality management based on space scanning data. *Scientific Papers. Series A. Agronomy*, *LXIII, 1*, 125-133.

Poffenbarger, H.J., Olk, D.C., Cambardella, C., Kersey, J., Liebman, M., Mallarino, A. … Castellano, M.J. (2020). Whole-profile soil organic matter content, composition, and stability under cropping systems that differ in belowground inputs. *Agriculture, Ecosystems & Environment,* 291. 106810. doi: 10.1016/j.agee.2019.106810.

Popescu, C.A., Herbei, M.V. & Sala, F. (2020). Remote sensing in the analysis and characterization of spatial variability of the territory. A study case in Timis County, Romania. *Scientific Papers: Management, Economic Engineering in Agriculture & Rural Development*, 20(1). 505–514.

Precision Agriculture Definition. (2024, January*). International Society for Precision Agriculture*. Retrieved from: https://www.ispag.org/about/definition.

Savytskyi, E.E. (2017). Precision farming as a result of informatization of management systems in agribusiness. *Economics and enterprise: a collection of scientific papers*, 38. 174–181.

Širáň, M., & Makovníková, J. (2021). Monitoring of Soil Bulk Density in Context with Its Small-Scale Spatial Heterogeneity. *Journal of Geoscience and Environment Protection,* 9. 138-151. doi: 10.4236/gep.2021.95010.

Soil heterogeneity and precision farming. Part 2. Research results. (2009). In V.V. Medvedev (Ed.). Kharkiv: City Printing House.

Techen, A.K., Helming, K., Brüggemann, N., Veldkamp, E., Reinhold-Hurek, B., Lorenzet, M. ... Vogel, H.-J. (2020). Soil research challenges in response to emerging agricultural soil management practices. *Advances in Agronomy,* 161. 179-240. doi: 10.1016/bs.agron.2020.01.002.

Vizitiu, O. & Calciu, I. (2022) Mitigation of soil compaction by applying different tillage systems. *Scientific Papers. Series A. Agronomy*, LXV. (1), 183-190.

Webster, R.A. (2023). Statistics in soil science. In M. J. Goss, & M. Oliver (Ed.), *Encyclopedia of Soils in the Environment (Second Edition)*. (pp. 486-498). Harpenden, United Kingdom: Academic Press. doi: 10.1016/B978-0-12-822974-3.00002-1.

Yakovenko, V.M., Dubinina, J.J., & Zhukova, Y.O. (2019). Spatial heterogeneity of the physical properties of the soil in the floodplain of the small river. *Agrology*, 2(4), 219–228. doi: 10.32819/019031.

Yao, R.J., Yang, J.S., Zhang, T.J., Gao, P., Wang, X.P., Hong, L.Z., & Wanget, M.W. (2014). Determination of site-specific management zones using soil physico-chemical properties and crop yields in coastal reclaimed farmland. *Geoderma*, 232–234. 381–393. doi: 10.1016/j.geoderma.2014.06.006.

Zukov, A.V., & Zadorojhnaya, G.A. (2016). Spatio-temporal changes of the recultivated soil penetration resistance of Nikopol manganese mining basin. *Biological systems*, 8(1), 127-137.