The influence of spatial heterogeneity of the properties of agricultural fields on productivity

Larisa Zhuravleva[1*]

[1]Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, 127434, 49 Timiryazevskaya str.Moscow, Russian Federation

Abstract. The use of differentiated technologies in crop production ensures high yields while minimizing environmental impacts and significant resource savings. To optimize technological impacts, it is necessary to know the distribution of soil properties and their changes in space and time. The purpose of the work is to assess the variability of soil characteristics and the impact on crop yields. The article presents studies of the variability of soil properties, the unevenness of soil moisture during the operation of wide-range sprinkler equipment and the influence of spatial heterogeneity of properties and the use of differentiated technologies on crop yields.

1 Introduction

The modern concept of agriculture has long been based on the fact that all agricultural fields were considered as homogeneous territories with certain soil characteristics, and all technological impacts on them were taken on the basis of average values. The simplified approach was primarily due to the lack of technical and technological capabilities, appropriate digital technologies, and sensor systems. Nevertheless, modern domestic and foreign researchers have proven the relatively low effectiveness of this approach [1-14].

Differentiation of fertilizers, chemicals and water application allows to avoid excessive environmental impact and ensure resource savings when obtaining the maximum yield.

The purpose of the work is to assess the variability of soil characteristics and the impact on crop yields.

2 Materials and methods

To optimize technological impacts, it is necessary to know the distribution of soil properties and their variability in space and time.

When describing the spatial heterogeneity of the soil, permanent and random components can be distinguished. The influence of human activity on the variability of soil properties deserves special attention.

* Corresponding author: dfz@yandex.ru.

Three independent components are considered in geostatic models: the first characterizes the average value within a geographically allocated territory, the second is considered as spatially correlated changes and the third is a random variation.

The value of the variable Z can be represented as:

$$Z(x, y) = f(x, y) + \varepsilon'(x, y) + \varepsilon'', \quad (1)$$

where $f(x,y)$ and $\varepsilon'(x,y)$ – the first and second components, respectively; ε'' – random variation.

In general, the spatial heterogeneity of agrochemical properties depends on a number of factors, ranging from natural processes to anthropogenic impact in the process of anthropogenic impact.

There are two opposing opinions regarding anthropogenic impact. A number of scientists claim that fertilization leads to an increase in spatial heterogeneity. Moreover, it is the anthropogenic impact that determines the heterogeneity of properties to a greater extent. Other researchers describe smoothing properties during agricultural processing.

In any case, the heterogeneity of soils does not depend so much on the type of soil as on the adopted farming system and the fertilizers applied.

A review of the research shows that the change in various soil indicators occurs in a rather complex way.

For example, nitrogen, phosphorus, acidity and organic carbon content are more dependent on fertilizer application and heterogeneity increases during anthropogenic impact.

A natural question arises, how many samples should be taken, on what area and with what step. Is it possible to "scale" soil properties?

Studies [2-4] show that an optimal estimate can be obtained if the distance between sampling points is less than half the radius of action of the determined factor.

In [6], the spatial variability of soil moisture and inorganic nitrogen was studied at various scales. The rank of spatial correlation increased as the scale increased.

3 Results

Studies of the water-physical properties of the soil show that spatial variability has the ability to scale to assess the soil moisture content and water retention capacity of the soil. The researchers [7, 11, 12] concluded that up to 95% of the variability of soil properties can be explained using geostatistical methods.

Simplistically, we can say that up to 70% is accounted for by the regional factor. From up to 30% of the total variability is at the local level (the scale of a single farm). From up to 10% variability within a plot or field. In general, this suggests the expediency of creating databases and using them in predictive models of resource consumption.

With the help of the constructed cartograms of various properties, it is possible to identify areas with increased and decreased content of various chemicals, trace elements and, depending on the size and location of these zones, make a decision on their differentiated application.

Yields also vary significantly within the field. The variability of yield parameters is slightly lower than the variability of soil properties. Most yield parameters have moderate or weak spatial correlation and a significant proportion of random variability.

Of interest are not only yield cartograms, but also crop contamination cartograms.

A promising and in-demand direction is the use of cartograms of the quality of cultivated crops. For cereals, these are cartograms of the content of protein, gluten, and trace elements in the grain, Fig. 1

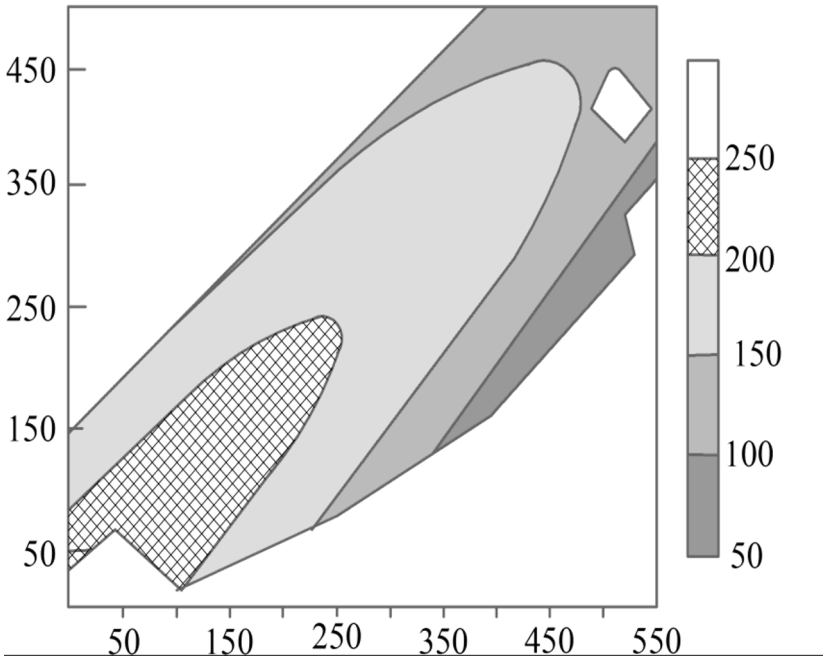


Fig. 1. Cartogram of wheat biomass distribution, g/m

Let's consider the result of differentiated technologies for cultivating winter wheat of the Moskovskaya variety. The humus content is shown in Figure 2.

Figure 3 shows the Task maps for the differentiated application of ammophos and nitrogen.

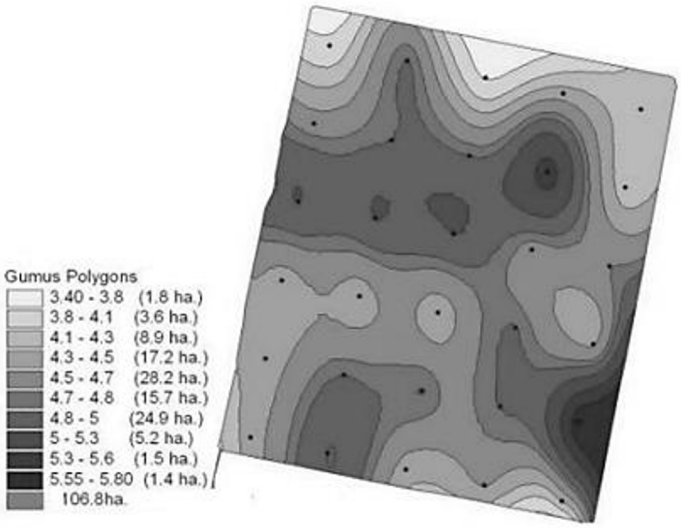
The application of fertilizers using traditional technology allowed for an increase in yield of 32% compared with the control (without fertilizers) and 82% compared with the use of differentiated technologies.

The redistribution of moisture in the soil has a significant effect on crop yields. It is known that not only a lack, but also an excess of moisture has a negative effect.

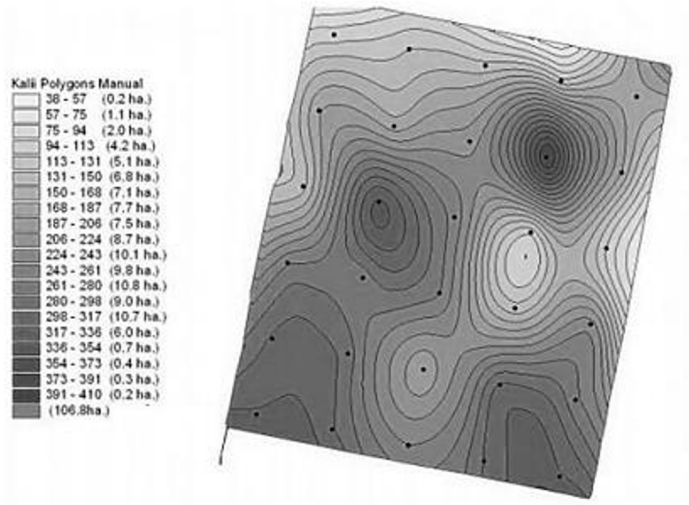
The graphical dependencies in Figure 4 demonstrate the relationship between soil moisture and yield, even at microlevels. When variations in the precipitation layer produced by a wide-range frontal sprinkler machine "Kuban" has a clear effect on productivity.

Field studies were conducted on light chestnut medium loamy soils with the lowest moisture content of 20%. The coefficient of effective irrigation is 0.7. Culture is alfalfa.

The maximum precipitation layer of almost 50 mm was obtained under the right console and decreased along the length of the machine to 30 mm. Accordingly, the humidity is from 25% to 17%. The decrease in the yield of alfalfa green mass reaches 40 c/ha [13-14].



a)



b)

Fig. 2. Field characteristics: a) Humus content, b) Exchangeable potassium content

Crop shortages will be more serious if irrigation is accompanied by a surface redistribution of irrigation water. When irrigation norms exceed those of sufficient (about 300 m3 /ha), the presence of surface waters causes a noticeable difference in soil moisture reserves in elevated and lowered areas of microrelief.

New farming technologies are based on yield management, taking into account knowledge of the spatial and temporal variability of the environment and, based on this, optimization of technological impacts, which minimize the impact on the environment and ensure resource savings.

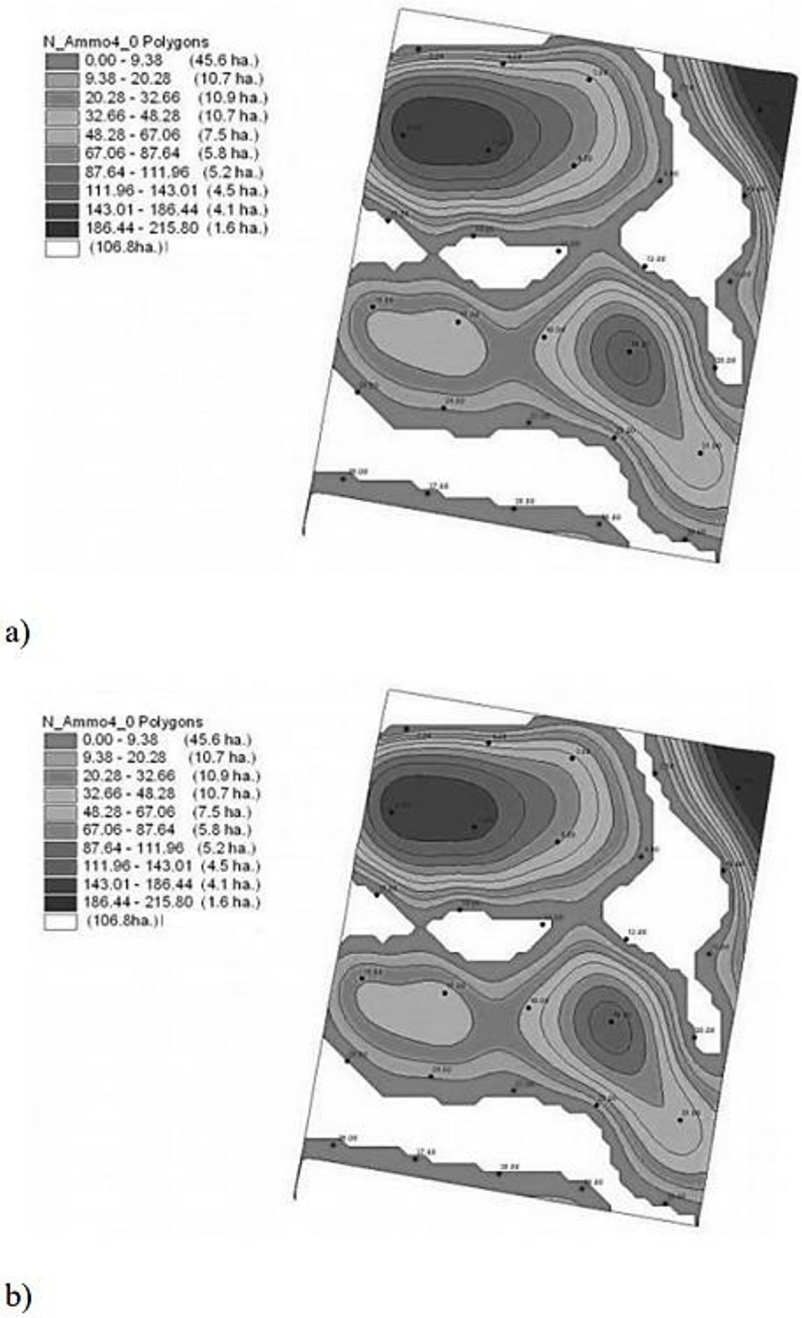


Fig. 3. Task maps for differentiated application of: a) ammophos, b) nitrogen

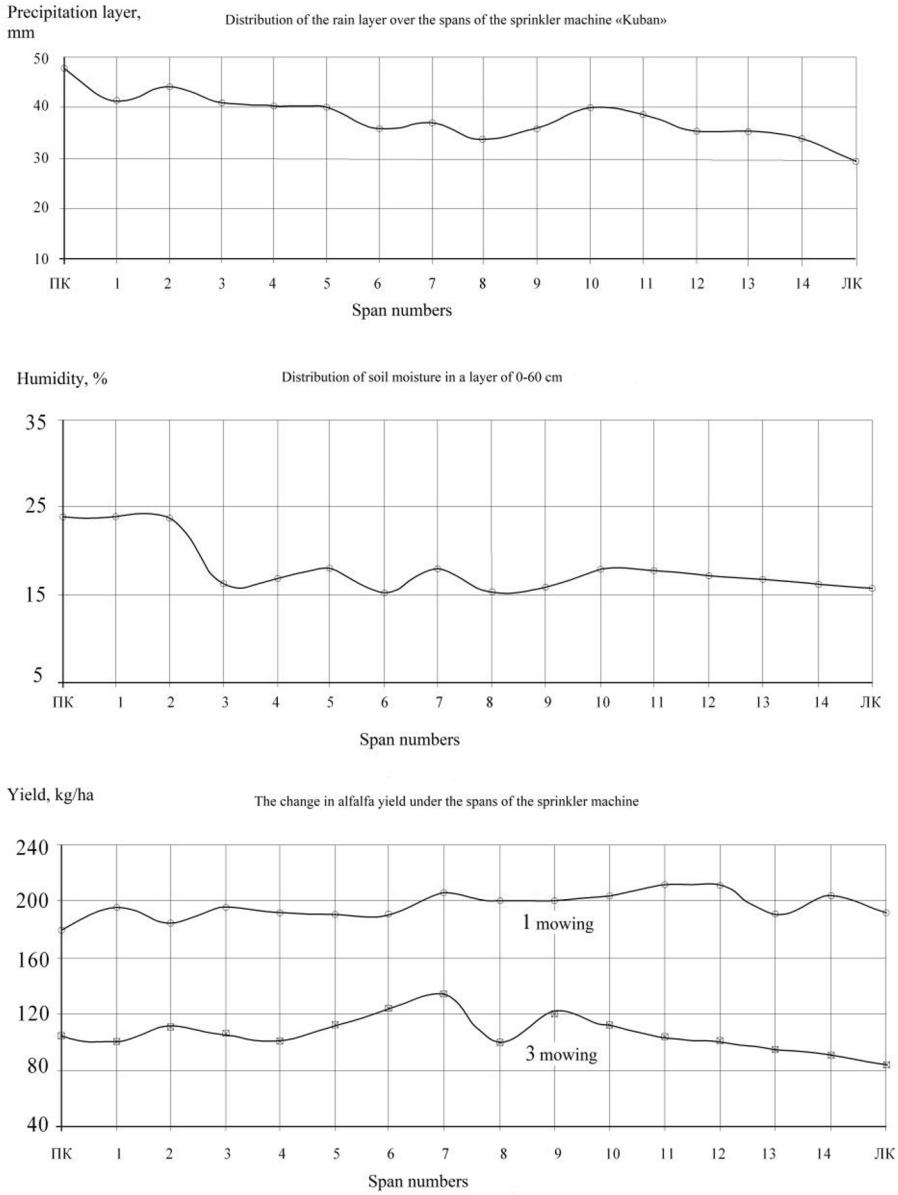


Fig. 4. The effect of moisture uniformity on crop yields

4 Conclusions

New farming technologies are based on yield management, taking into account knowledge of the spatial and temporal variability of the environment and, based on this, optimization of technological impacts, which minimize the impact on the environment and ensure resource savings.

The work was carried out on the topic of the Ministry of Agriculture of the Russian Federation and at the expense of the federal budget.

References

1. F.K. Abdrazakov, D.A. Solovev, L.A. Zhuravleva, D.A. Kolganov, V.A. Soloviev. *The Studies of Water Flow Characteristics in the Water Conducting Belt of Wide-coverage sprinkling Machines*. **8.** (2018)
2. O. Adeyemi, I. Grove, S. Peets, T. Norton. *Advanced monitoring and management systems for improving sustainability in precision irrigation.* Sustainability, **9** (2017)
3. L. Anselin, R. Bongiovanni, J. A Lowenberg-DeBoer. Spatial econometric approach to the economics of site-specific nitrogen management in corn production. American Journal of Agricultural Economics **86** (2004)
4. R. Bongiovanni, J. Lowenberg-DeBoer. *Precision agriculture and sustainability.* Precision Agriculture. **5** (2004)
5. D. Bullock, J. Lowenberg-DeBoer. *Using Spatial Analysis to Study the Values of Variable Rate Technology and Information*. Journal of Agricultural Economics, **58** (2007)
6. K. Dammer, R. Adamek, Sensor-Based Insecticide Spraying to Control Cereal Aphids and Preserve Lady Beetles, Agron. J. **104(6)** (2012)
7. European Commission. Precision agriculture – An opportunity for EU farmers – Potential support with the CAP 2014-2020. European Union (2014)
8. J. Lowenberg-DeBoer. Precision Farming and the New Information Technology: Implications for Farm Management, Policy, and Research: Discussion. American Journal of Agricultural Economics (1996)
9. A. A. Skvortsov, L.A. Zhuravleva. *Theoretical Foundations of Water-Conducting Belt Design for Wide Coverage Sprinklers Using Numerical Simulation.* Materials Science and Engineering (2021)
10. D. A. Soloviev, S. M. Bakirov, L.A. Zhuravleva. *Robotic Irrigative Complex with Intellectual Control System "CASCADE".* XVIII International Scientific and Practical Conference (2019)
11. M. Yemefack, R. Njomgang. Multi-scale characterization of soil variability within an agricultural landscape mosaic system in southern Cameroon (2005)
12. Li. Zizhong. Spatial variability of soil water and inorganic nitrogen at the different scales (2002)
13. L.A. Zhuravleva, I.A. Popkov. *Improving the Patency of Sprinkler Machines on Moistened soil on the basis of experimental and theoretical studies of the system "Irrigation rate-soil-sprinkler Machine".* IOP Conference Series: Earth and Environmental Science (2022)
14. L.A. Zhuravleva. *Technological solutions are environmentally friendly safe watering with wide-ranging sprinkler machines* BIO Web of Conferences (2023)