Spatial variability of soil properties and its effect on meadow productivity

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Abstract. The spatial heterogeneity of the yield of perennial grasses was studied to identify soil factors that most affect the productivity of sown meadows in South Karelia. Soil variability was studied using various statistical and geostatistical methods. In the course of research, it was found that the best conditions for the growth of perennial grasses are created on soils with a carbon content of about 8% and a slightly acidic or close to neutral reaction environment. It is noted that the type of soil affects the organic carbon content and change in the yield of perennial grasses. In the diagnostic range of peat soils, as the transition from peat-mineral soils to peat soils the organic carbon content in the soil increases and the yield of grasses decreases. The acidity distribution is rather anthropogenic in nature.

1 Introduction

Soil resources are the basis of food security, including in areas of risky farming. The Republic of Karelia belongs to the regions where agricultural production is limited by climatic conditions and low natural soil fertility. The specialization of Karelia is dairy cattle breeding, for which the sustainability of feed production, primarily perennial grasses on sown meadows, is of paramount importance. The productivity of meadows depends to a large extent on the properties of soils, including their spatial heterogeneity, which makes it difficult to process soils, fertilize, and leads to a decrease in the productivity of meadows. To increase yields, it is necessary to identify the factors that most affect the productivity of meadows, as well as to assess the spatial heterogeneity of each soil parameter affecting the growth of perennial grasses.

Crop yields may vary over time, due to agro-climatic conditions. But even within the same field, the yield varies greatly in space. The main reasons can be both natural and anthropogenic - imperfection of agricultural technologies and errors in measuring yields [1-5]. Nevertheless, among the factors affecting the productivity of crops, one of the key roles is played by soil properties.

Significant heterogeneity of the soil cover within individual agricultural lands, in addition to natural causes, can also be the result of anthropogenic impact (uneven application of lime, fertilizers, agricultural activity intensity). Heterogeneity due to

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anthropogenic impact can be eliminated with proper organization of measures. This may be land reclamation or change in the fertilizer application system.

To ensure highly effective yield management, it is necessary to have information about the scale of variation of properties, about the main patterns of observed spatial changes, and the correlation of the values of the studied indicators. In case of low variability of properties, it is possible to plan agrotechnical measures on the scale of the entire farm or one specific field. In case of high variability of properties, it is possible to use elements of "precision agriculture" technology, that is, soil treatment and fertilization based on pre-prepared cartograms [6, 7]. For example, it can be agrochemical cartograms. Such cartograms give an idea of the availability of soils with various nutrients [8-10]. Yield cartograms are also useful. With their help, it is possible to identify areas of reduced yield, information about the location of these plots in space and their size, the degree of crops contamination [11-13].

The purpose of the presented work is to identify factors affecting the yield of perennial grasses and to assess the contribution of these factors to the overall variation level.

2 Objects and Methods

Studies of soil properties affecting yields were carried out on the Olonets plain in the area of the village Rypushkalitsy (Olonetsky district, Rep. Karelia). The plot is an old-sown agrocenosis. For a long time, the plot was used as a haymaking ground.

The total area of the plot is 25 hectares. The community is dominated by *Elytrigia repens* (L.), *Deschampsia cespitosa* (L.). The following soils are allocated on the plot: 1 – Umbric Albeluvisols (loamic), 2 – Histi-Gleyic podzols (clayic), 3 – Histic Gleysols (loamic) (Fig. 1).

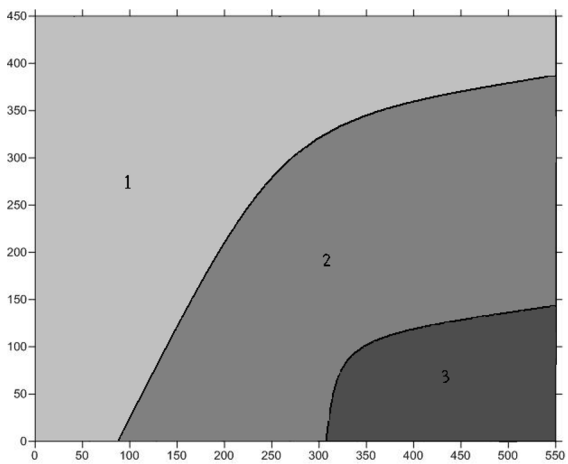


Fig. 1. Plot soil map: 1 – Umbric Albeluvisols (loamic), 2 – Histi-Gleyic podzols (clayic), 3 – Histic Gleysols (loamic)

The variability of soils within soil contours was studied using various statistical and geostatistical methods. The selection of soil samples in the arable horizon was carried out according to a randomly regular grid. The sampling interval is on average 50 m. A total of 80 samples were selected. The obtained samples were analyzed for the organic carbon content in the soil by the method of high-temperature catalytic combustion on the analyzer TOC-L CPN and pH(KCl) values potentiometrically. At the same points, the yield value of herbage green mass was determined. The yield was calculated within the size of 50x50 cm, followed by recalculation in t/ha.

Statistical data analysis, as well as correlation and regression analysis were carried out according to standard methods [14]. The evaluation of the patterns of spatial variability of soil properties and yields was carried out using variography methods [15].

Regression kriging was used to construct cartograms, which is a combination of the standard model of multiple linear regression and the geostatistical method of conventional kriging. [16].

3 Results and Discussion

Table 1 presents the data of statistical processing of the obtained results.

Table 1. Statistical characteristics of soil properties and yields.

Property	Yield, t/ha	pH(KCl)	C, %
minimum	2,00	3,70	1,30
lower quartile	8,80	4,33	3,66
median	11,20	4,73	6,07
upper quartile	15,30	5,31	14,53
maximum	24,40	7,52	38,68
spread	22,40	3,82	37,38
mean	12,19	4,90	11,99
variance	35,54	0,62	137,18
variation coefficient, %	48,89	16,09	97,65
excess	-0,58	1,63	-0,28
asymmetry	0,25	1,15	1,15

The results of the analysis showed that the studied plot is highly heterogeneous in yield and organic carbon content in the soil (variation coefficient is more than 25%). This value is a threshold value when dividing plots according to heterogeneity degree [17], but it does not allow to determine what causes this heterogeneity. Therefore, in addition, a joint analysis of yield and soil characteristics was carried out.

Regression analysis methods have established that a polynomial (quadratic) regression model can be used to describe the ratio between yield and acidity level, as well as the organic carbon content (Fig. 2). The highest yield was observed on slightly acidic and close to neutral soils (pH_{KCl} from 5.3 to 5.7) and with organic carbon content of about 8%. Such indicators are usually observed on agro-peat-mineral soils.

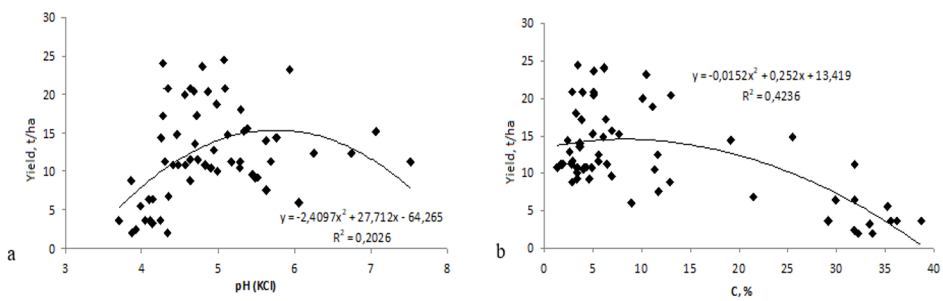
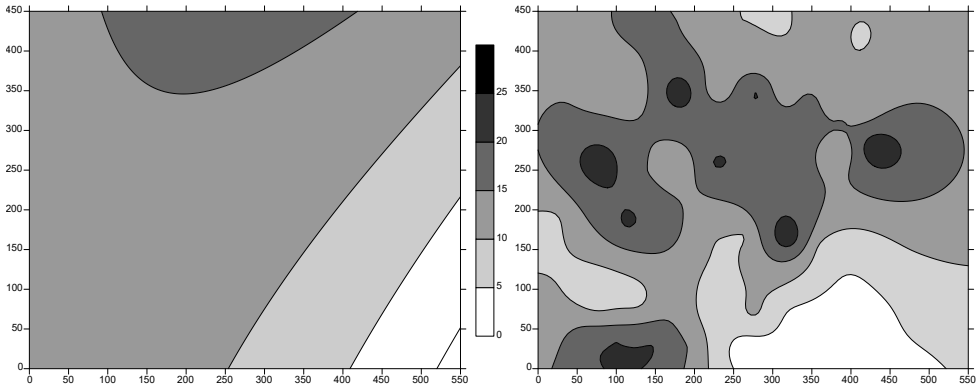


Fig. 2. The dependence of the yield of perennial grasses (t/ha) on soil properties: pH(KCl) (a) and organic carbon content, % (b).

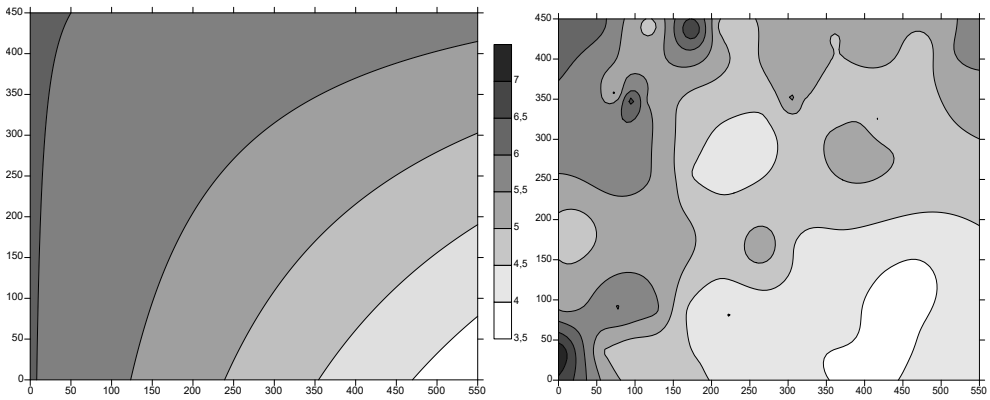
A significant (significance level 0.05; multiple determination coefficient 28.9%) dependence of yield on sampling point position was established (Fig. 3a). At the same time, there was no significant correlation between the yield and the height of the sampling point (topographic features).

A significant (significance level 0.05; multiple determination coefficient 43.0%) dependence of the soil acidity level on sampling points position was also established. The constructed cartogram (Fig. 3b) shows that such a distribution of acidity corresponds to anthropogenic impact and is associated with uneven application of lime: increased pH values are marked along the western border of the plot, which corresponds to a dirt road between fields.

The strongest dependence on sampling point position (significance level 0.01; multiple determination coefficient 72.5%) was noted for organic carbon content in the arable layer. Correlation analysis showed that there is a statistically significant correlation between yield and organic carbon content. The correlation coefficient is -0.54. Comparing the soil map of the plot (Fig. 1) and the cartograms of yield and organic carbon content (Fig. 3a, c), it can be assumed that changes in yield and organic carbon content are associated with changes in soil type: the organic carbon content in the soil increases and the yield of grasses decreases in the direction from peat-mineral soils to peat soils.



a



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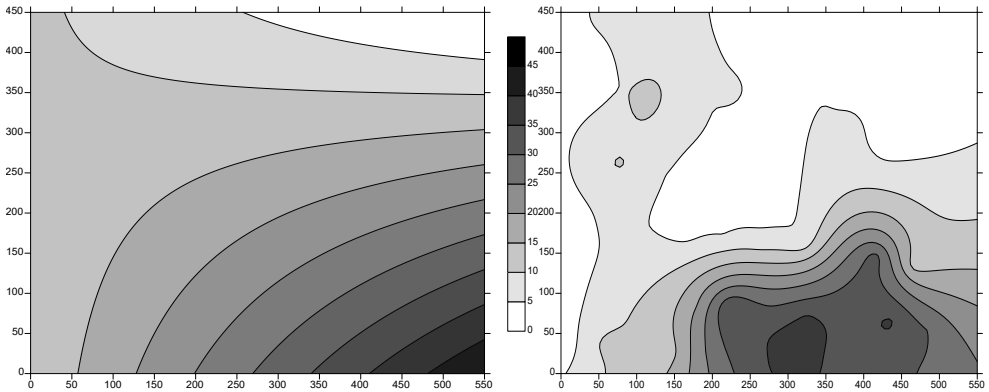

Fig. 3. Cartograms of yield, t/ha (a), pH(KCl) (b), and organic carbon content, % (c). On the left – quadratic trend surface, on the right – regression kriging result. Axes – distance, m

4 Conclusions

In the course of studies of spatial heterogeneity of the yield of perennial grasses and soil properties affecting the productivity of sown meadows, it was found:

1. the main edaphic factor responsible for the productivity of perennial grasses is the organic carbon content
2. the best conditions for the growth of perennial grasses are created on soils with a carbon content of about 8% and a pH (Kcl) level of about 5.5
3. the variation coefficient for the organic carbon content was about 98% and is explained by natural causes — change in the soil type and degree of peat formation
4. the variation in the soil acidity level largely depends on the uniformity of lime application.

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