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Comparison of interpolated soil nutrients maps obtained with application of various approaches of ordinary kriging

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Abstract. To create maps of the available forms of nutrients in arable land for implementation of systems of mineral fertilizers differential application, various approaches of interpolation by the ordinary kriging method were used. Maps of the availability were built according to the agrochemical analysis of mixed samples compiled from elementary plots of 5 ha. In the first case, the result of the agrochemical analysis was tied to the centroids of the elementary plots, and the interpolation was carried out using point ordinary kriging. In the second case, the indicator value was attached to blocks corresponding to the area of elementary sites. In this case, the interpolated cards were obtained using block kriging. It was shown that the application of various approaches to interpolation gives similar maps of spatial distribution. At the same time, maps obtained by ordinary point kriging are characterized by a more accurate forecast compared to maps obtained using block kriging. Therefore, the construction of interpolated maps of the availability of arable lands with nutrients based on the results of agrochemical analysis of mixed samples with data binding to the centroids of the sampling cells and compiling the combined samples is more preferable.

1. Introduction

The development of digital farming technologies for needs of implementation of differential fertilizer application systems is associated with the development of new approaches in the study of spatial heterogeneity of arable land. The application of precision farming technologies requires a more detailed study of the spatial heterogeneity of soils, providing the creation of interpolated maps of the content of available nutrients that establish the necessary accuracy of differentiated fertilizer application. When applying geostatistical methods to create interpolated maps, often use the results of agrochemical analyzes with point spatial localization. Sampling points can be marked at the nodes of the systematic grid or at the center of regular sampling sites (parcels) [1-3]. Special point-sampling schemes according to a stratified randomized or route randomized scheme are also used. They provide uniform coverage of the surveyed area when placing points randomly, which allows more adequate models of spatial heterogeneity of soil properties [4-6]. At the same time, the use of the point method is associated with the need to select and analyze a large number of samples, which leads to a significant increase in the cost of agrochemical study. It is believed that for field study for the precise application of mineral fertilizers, the area of an individual parcel for obtaining a point sample should not exceed 0.5–1.0 ha, and only in this case a reliable heterogeneity of soil fertility can be obtained [7]. In study [6], using block kriging, was calculated that for accurate fertilizer application in a 20x20 m cell, point sampling of the



soil along the grid should be carried out with an interval of 20-30 m depending on the soil property, which is currently very difficult to implement.

Despite the advantages of point sampling methods for carrying out the interpolation procedure, the sampling for agrochemical studies are regulated by methods and standards, focused primarily on compiling combined (mixed) samples from individual samples selected by elementary participation [8-10]. If the natural variability significantly exceeds the analytical error, and the studied parameter is characterized by additivity in the preparation of the combined sample, the mixed samples obtaining allows us to get the necessary reliability in soil property assessment with a smaller sample size [11].

When creating interpolated maps of the content of nutrients, two approaches to the application of ordinary kriging are possible. In the first case, the value of the agrochemical index obtained in the analysis of the combined sample composed of individual samples taken along the route is attached to the centroid of the elementary section, and interpolation is carried out using ordinary point kriging. An alternative option - the value of the indicator is attached to the blocks corresponding to the area of the elementary sections, and the maps are obtained using block kriging to interpolate.

Block kriging is a type of ordinary kriging. It calculates the average for a region instead of a point value by replacing the point-to-point covariance with point-block covariance [12]. The use of block kriging instead of point kriging can be advisable if the average value of the parameter for the region is more informative than the value for a single point [6]. When forecasting average values for blocks, most of the variability (intra-block) is averaged and the block average has a smaller forecast error, preserving the spatial structure of the entire section if the block sizes are not too large [13]. Block kriging may be advantageous if point kriging shows high values of forecast errors with high variability of the observed indicator, but this approach is used in practice quite rarely and, as a rule, to solve rather specific problems [14, 15]. In [6], block kriging was used to optimize sampling and calculate the distance between sampling points.

In this study, we compared the accuracy of the spatial forecast of interpolated maps of the nutrients availability in arable land using point and block ordinary kriging according to the results of agrochemical analysis of mixed soil samples.

2. Materials and methods

As the object of study, we used 2 fields of grain-cultivated crop rotation located in the chernozemic zone of the Republic of Tatarstan, Russia. The first field (№ 1, an area of 254 hectares) is located in the Zainsky district of the Republic of Tatarstan. The site is characterized by a rather significant elevation difference of up to 60 m, with steep slopes in the southwestern part of the field. The soil cover is represented by non-eroded, weakly eroded, and mid-eroded leached chernozems, which are quite different in fertility. The second field (№ 2, an area of 287 hectares) is located on the territory of the Sarmanovsky district of the Republic of Tatarstan. The field is confined to a gentle slope of the north-eastern exposure (elevation difference of less than 30 m). The soil cover is also represented by leached chernozems. Soil erosion has not been established. The mixed soil samples along the diagonal of elementary sites of 5 ha in accordance with the current state standard [8] were obtaining. Determination of hydrolyzable nitrogen was carried out according to the Kornfield method (N_{hyd}), available (mobile) forms of phosphorus (P_2O_5) and potassium (K_2O) according to the Chirikov method.

As the interpolation methods, we used the methods of ordinary point and block kriging. Geostatistical analysis was carried out using the *gestate* package of the program-oriented language R. Interpolation was estimated by comparing the observed values with the values of the spatial forecast, which were averaged within each elementary section. The evaluation criteria were the mean error (ME), standard error (RMSE), MSDR and RPIQ, the ratio of the variance of the predicted values to the variance of the observed values (RVar), and also the compliance coefficient (CCC).

Average error was determined by equation 1.

$$ME = \frac{1}{n} \sum_{i=1}^n (p_i - o_i) \quad (1)$$

RMSE was determined by equation 2.

$$RMSE = [\frac{1}{n} \sum_{i=1}^n (p_i - o_i)^2]^{1/2} \tag{2}$$

MSDR - the average value of the ratio of model residuals to forecast dispersion was determined by equation 3.

$$MSDR = \frac{1}{n} \sum_{i=1}^n \frac{(p_i - o_i)^2}{\sigma^2} \tag{3}$$

Ratio of model performance to inter-quarter range was determined by equation 4.

$$RPIQ = \frac{IQ}{RMSE} \tag{4}$$

The ratio of the variance of the predicted values to the variance of the observed values was determined by equation 5.

$$RVar = \frac{Var[p]}{Var[o]} \tag{5}$$

Compliance coefficient was determined by equation 6

$$CCC = \frac{2\rho\sigma_p\sigma_o}{\sigma_p^2 + \sigma_o^2 + (\mu_p - \mu_o)^2} \tag{6}$$

In the equation p_i – the predicted value, o_i – the observed value, σ^2 – is the dispersion, μ – the average value.

ME is used to determine in evaluation of bias degree, RMSE estimates the error of the mean, RVar is a measure of the variance ratio. If the ME closer to zero, and the RMSE value is less, than the model will be more accurate. If the RVar value closer to 1, than the better the model is capable of maintaining the dispersion of the studied indicator. Also, if the MSDR value is closer to 1, than better the model described the data. In general, the method that generates an assessment that coincides with the observed value at the sampling point is recognized as the most accurate method [12].

3. Results

Table 1 presents the statistical characteristics of the agrochemical properties of the examined fields.

Table 1. Descriptive statistics for agrochemical indicators.

Field	Nutrient	N _{hyd} (mg kg ⁻¹)	P ₂ O ₅ (mg kg ⁻¹)	K ₂ O (mg kg ⁻¹)
№ 1	Amount of soil samples	50	50	50
	Mean value	100.4	149.4	226.5
	Coefficient of variation, %	19.4	34.2	19.1
	Lower quartile	88.6	108.7	195.2
	Median	98.0	138.7	230.7
	Upper quartile	110.3	175.3	250.7
	Interquartile range	21.7	66.7	55.6
№ 2	Amount of soil samples	59	59	59
	Mean value	140.0	131.3	163.3
	Coefficient of variation, %	16.3	42.3	25.1
	Lower quartile	128.2	88.7	130.1
	Median	136.1	112.8	152.8
	Upper quartile	149.6	167.9	190.1
	Interquartile range	21.4	79.3	60.0

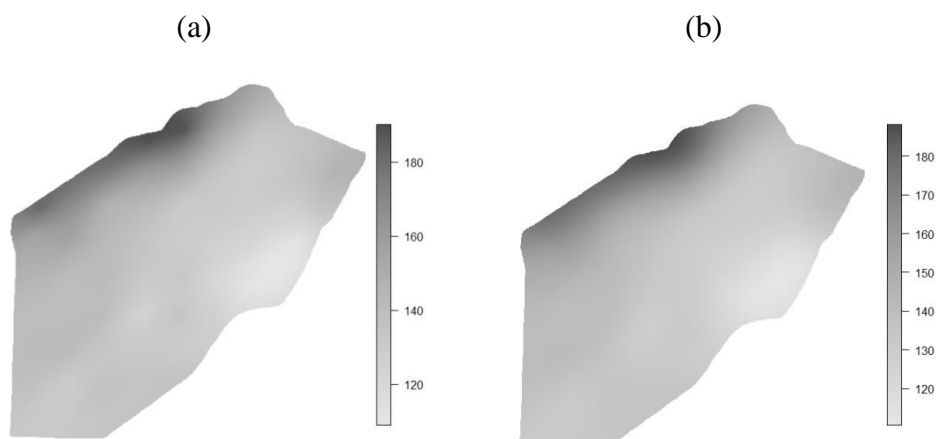
Table 2 presents the results of the semivariogram analysis for two fields. Variograms are constructed taking into account anisotropy. According to the ratio of nugget to threshold, which determines the spatial dependence, mobile potassium and hydrolyzable nitrogen in field № 1 have a strong spatial dependence. Mobile phosphorus is determined by moderate dependence, while in field № 2, mobile potassium and phosphorus also belong to moderate dependence, and hydrolyzed nitrogen to weak dependence.

Table 2. Parameters of semivariograms of agrochemical indicators.

Index (Nutrient)	Model	Correlation radius	Nugget (C ₀)	Partial threshold (C ₁)	Threshold (C ₀ +C ₁)	C ₀ /(C ₀ +C ₁)	Anisotropy	
							Direction	Coefficient
Field№ 1								
N _{hyd}	Sph	1445.73	95.22	395.82	491.04	0.19	-	-
P ₂ O ₅	Sph	763.39	898.23	1844.73	2742.96	0.33	-	-
K ₂ O	Sph	1184.89	13.17	2062.25	2075.42	0.01	315	0.8
Field№ 2								
N _{hyd}	Sph	1927.75	151.08	488.58	639.66	0.76	-	-
P ₂ O ₅	Sph	527.13	838.81	2289.43	3128.24	0.73	50	0.6
K ₂ O	Sph	3772.75	1055.93	1253.56	2309.49	0.54	-	-

Figures 1 and 2 show interpolated maps of the nutrients availability. A visual analysis of the figures shows that the application of various interpolation approaches by the ordinary kriging method gives very close maps in spatial distribution.

Table 3 presents the indicators of the criteria for the accuracy of interpolation carried out using ordinary point and block kriging. An analysis of the data in the table shows that in both fields for all three elements, interpolation by ordinary point kriging is characterized by a more accurate forecast compared to interpolation using block kriging.



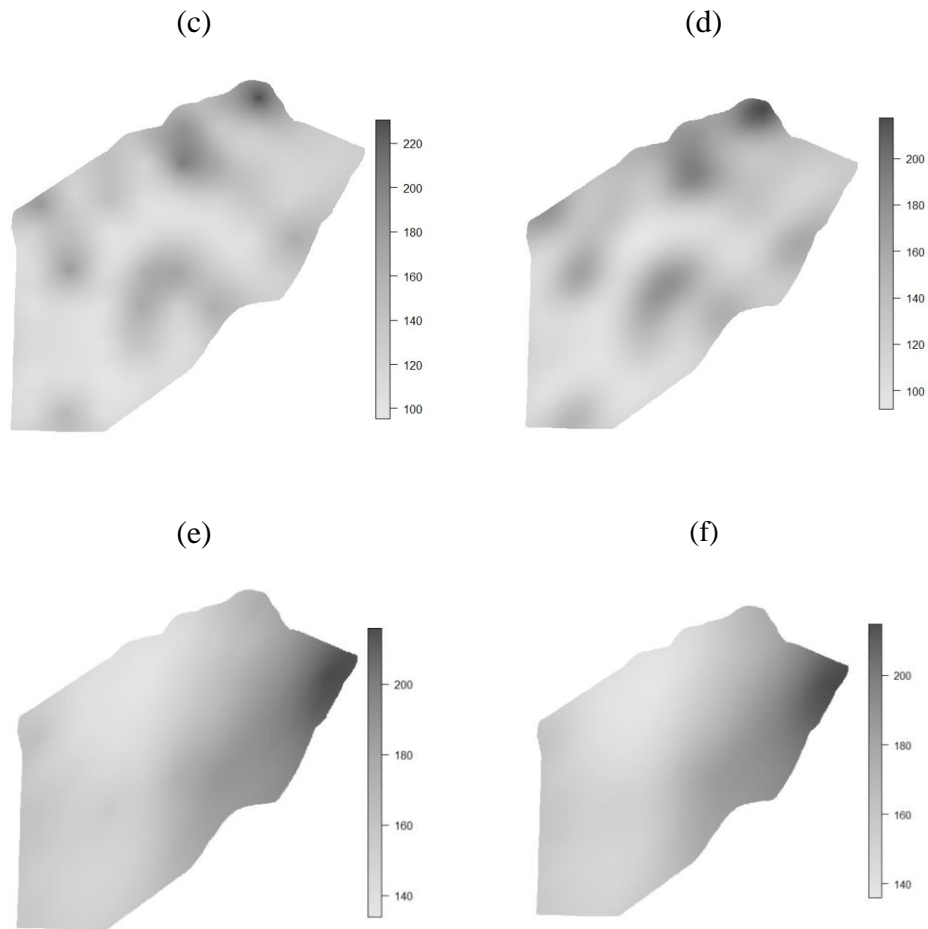
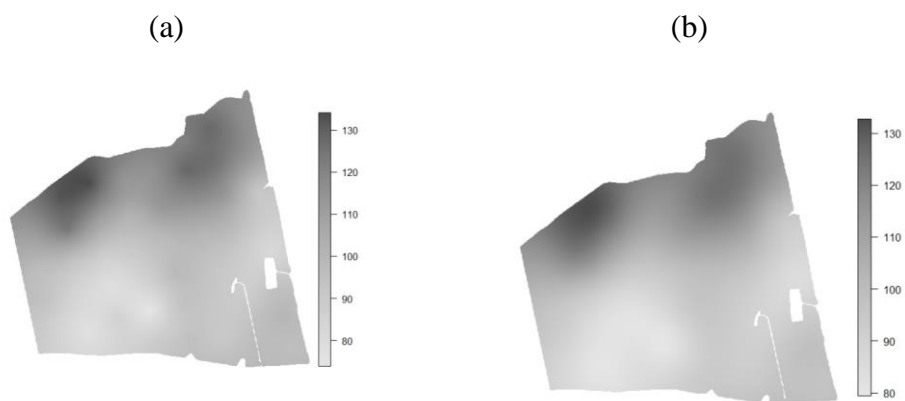


Figure 1. Interpolation maps of the nutrients availability at the field №1: (a), (c), (e) - ordinary point kriging; (b), (d), (f) - block kriging; (a), (b) - hydrolyzable nitrogen; (c), (d) - available forms of phosphorus; (e), (f) - available forms of potassium.



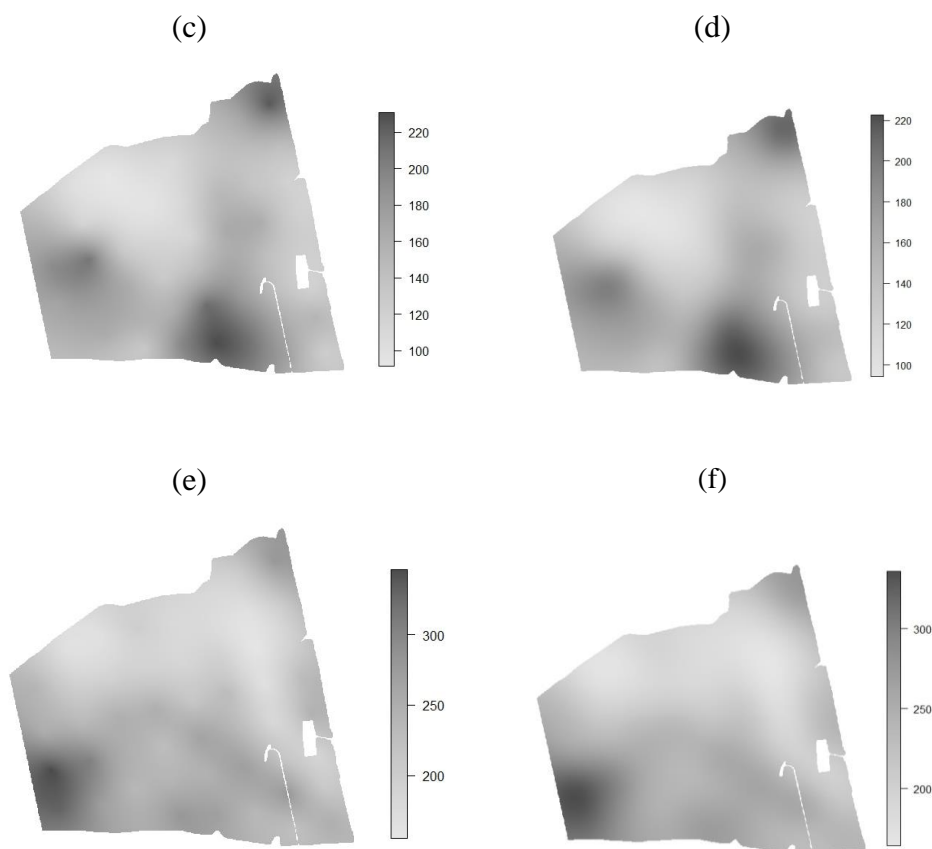


Figure 2. Interpolation maps of the nutrients availability at the field №2: (a), (c), (e) - ordinary point kriging; (b), (d), (f) - block kriging; (a), (b) - hydrolyzable nitrogen; (c), (d) - available forms of phosphorus; (e), (f) - available forms of potassium.

Table 3. Indicators of criteria for accuracy of interpolation.

Index (Nutrient)	ME	RMSE	MSDR	RVar	CCC
<u>Field № 1</u>					
Ordinary point kriging					
^a N _{hyd}	0.01	9.10	0.41	0.54	0.84
^a P ₂ O ₅	-0.14	28.70	0.96	0.33	0.74
^a K ₂ O	0.12	10.83	0.08	0.74	0.94
Block kriging					
N _{hyd}	0.02	9.75	0.49	0.51	0.81
P ₂ O ₅	-0.11	30.75	1.25	0.29	0.70
K ₂ O	0.34	13.65	0.14	0.67	0.92
<u>Field № 2</u>					
Ordinary point kriging					
^a N _{hyd}	0.15	11.70	0.54	0.49	0.81
^a P ₂ O ₅	0.28	37.34	3.16	0.14	0.59
^a K ₂ O	0.03	31.55	2.54	0.23	0.50

	Block kriging				
N _{hyd}	0.17	12.41	0.65	0.46	0.78
P ₂ O ₅	0.31	38.03	2.90	0.16	0.58
K ₂ O	0.09	31.95	2.69	0.23	0.49

^a Interpolation results characterized by a more accurate forecast.

4. Conclusion

From an analysis of the work, we can conclude that the application of various approaches to interpolation by the ordinary kriging method gives very close maps of the available forms of nutrients. Despite this, in the surveyed fields for all three nutrients the interpolation by ordinary point kriging is characterized by a more accurate prediction than the interpolation using block kriging. Therefore, the construction of interpolated maps of the availability of arable land with nutrients based on the results of agrochemical analysis of mixed samples with data binding to the centroids of sampling cells and compiling the combined samples is still more preferable than binding to blocks corresponding to the average cell size.

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