Spatial variability of the structural state of soils in rainfed and irrigated regions of Azerbaijan

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Abstract. Regularities of spatial variability of the structural state of soils in rainfed and irrigated regions of Azerbaijan are discussed with application of classical statistics and geostatistics. The highest coefficient of variation is observed for water-stable aggregates \(>3 \text{ mm}\) (106 %), and the lowest – for 10-0.25 mm (7.9 %). The results of geostatistical analysis show a strong spatial dependence of the indicators of wet sieving at irrigation. Structural indicators are mainly approximated by spherical and exponential models in irrigated soils, but in rainfed conditions, by linear models.

1. Introduction
The spatial architecture, shape, size and strength of the aggregates determines the water, air, heat and nutrient regimes, and accordingly, the movement of moisture and nutrients, the growth and development of the root system and, in general, the productivity of agriculture crops and vital activity of the soil-plant cover. Intensive use of soil in agriculture and the systematic use of agricultural technology under various agro-ecological conditions change the initial structural and aggregate state of the soil significantly. Negative changes in the structural-aggregate state of the soil usually result in limitations on root growth, reducing the use of moisture and nutrients by plants.

Since the 90s of the last century, the attention of agronomists and agrophysicists has been focused on studying and modeling the variability of soil-physical properties at different spatial scales using geostatistics [1 – 6]. The growth of interest in the study of spatial variability is associated with the development of precision farming [7]. Therefore, the geostatistical assessment and modeling of the spatial variability of the structural-aggregate state of the soil at the agricultural field scale is of great scientific and-practical importance for agronomy, agrophysics and agriculture.

2. Materials and methods
The investigations were conducted in 2016 in the territories of Jalilabad (J) and Terter (T) Regional Experimental Stations (RES) of the Research Institute of Crop Husbandry of the Ministry of Agriculture of the Azerbaijan Republic. Territories J (rainfed conditions) and T (irrigated soils), respectively, belong to the Jalilabad and Mil-Garabagh agro-ecological regions of the republic. Soil cover of J and T, mainly consists of rainfed and old irrigated light chestnut soils (WRB, 2006 [8]). Investigations were conducted under production conditions for the arable (0-30 cm) layer of the soil. Sampling of the soil cover in J was carried out on a plot of 4.05 hectares (150x270 m) area (39°13.002'-39°14.043' N, 48°27.070'-48°27.280' E) on a regular grid with a spacing of 30 m (\(n = 60\)), 3 days after the winter wheat harvest. In T, the selected plot was in the area left for growing winter grain crops in the next vegetation season. In this area (40°20.532'-40°20.590' N, 47°00.007'-47°00.993' E), testing was also conducted in an
appropriate manner with a spacing of 30 m (n = 76). The area of the soil contour was 4.86 ha (90x540 m).

Definitions and calculations of indicators of structural-aggregate composition were carried out by standard agrophysical methods [9]. The statistical parameters of the structural-aggregate composition of soils at 5% significance level were obtained using the Minitab 14 software package. Geostatistical data analysis was done by using the Vesper 1.6 and Surfer 8.0 software packages. The theoretical base of geostatistics and its practical application are well presented in the scientific literature [10 – 12].

3. Results and discussion
The statistical characteristics of the structural-aggregate composition of the soil are presented in table 1. The results of statistical analyzes show that, in addition to agronomically valuable aggregates (10–0.25 mm) (CV <15%), all other indicators have moderate (15% <CV <50%) and strong (CV> 50%) spatial variability according to value of the coefficient of variation. The highest coefficient of variation was observed for water-stable aggregates >3 mm (105–106%), which indicates to the high variability of this indicator in the agricultural field scale.

Table 1. Statistical characteristics of the soil structural-aggregate composition.

| Parameters | Aggregate content, %; size of aggregate, mm |
|------------|---------------------------------------------|
|            | Dry sieving | Wet sieving |
|            | >10  | <0.25 | 10-0.25 | Kstr | >3 | >0.25 | KAFI |
| Teter (irrigated soils) | | | | | | |
| X̄ | 13.5 | 17.3 | 69.1 | 2.3 | 0.9 | 25.0 | 128.7 |
| CV (%) | 62.7 | 39.6 | 7.9 | 24.1 | 104.6 | 23.3 | 51.6 |
| Xmin | 1.2 | 4.1 | 50.7 | 1.0 | 0.1 | 14.8 | 49.7 |
| X0.25 | 7.0 | 12.1 | 66.5 | 2.0 | 0.4 | 20.8 | 88.6 |
| Xmed | 12.3 | 15.9 | 69.8 | 2.3 | 0.6 | 24.6 | 109.6 |
| X0.75 | 17.6 | 22.9 | 73.1 | 2.7 | 1.1 | 27.5 | 150.0 |
| Xmax | 42.1 | 36.9 | 79.0 | 3.7 | 6.0 | 50.5 | 429.2 |
| KStr | 1.3 | 0.5 | -0.9 | 0.3 | 5.8 | 1.2 | 2.4 |
| KAFI | 1.9 | -0.4 | 1.5 | 0.3 | 12.9 | 3.8 | 7.3 |
| Jalilabad (rainfed condition) | | | | | | |
| X̄ | 20.9 | 10.2 | 68.9 | 2.4 | 0.7 | 16.4 | 146.6 |
| CV (%) | 42.2 | 30.4 | 10.3 | 34.0 | 106.4 | 40.0 | 55.8 |
| Xmin | 4.9 | 4.3 | 53.4 | 1.1 | 0.0 | 4.6 | 32.0 |
| X0.25 | 12.8 | 7.8 | 64.0 | 1.8 | 0.2 | 10.9 | 73.2 |
| Xmed | 21.3 | 9.8 | 69.0 | 2.2 | 0.4 | 16.1 | 131.0 |
| X0.75 | 28.0 | 12.4 | 74.6 | 2.9 | 0.9 | 21.2 | 205.2 |
| Xmax | 38.1 | 21.7 | 81.1 | 4.3 | 3.5 | 32.8 | 352.4 |
| Kskew | 0.1 | 1.1 | -0.1 | 0.6 | 1.8 | 0.4 | 0.6 |
| Kkurt | -1.0 | 2.0 | -0.9 | -0.6 | 3.2 | -0.4 | -0.5 |

aaverage 
bcoefficient of variation 
cminimum 
dlower quartile 
emedian 
fupper quartile 
gmaximum 
hasymmetry coefficient 
i(coefficient of kurtosis 
jstructural coefficient 
kwater-stability index of AFI
Geostatistical methods are based on the statistical interpretation of spatial data and allow assessment and prediction of values at the points where sampling was not performed. The geostatistical analysis was carried out for all the studied parameters, experimental variograms were constructed and approximated with their corresponding theoretic models.

![Semi-variograms of indicators of the structural-aggregate state of Irragric Kastanozems (Terter, irrigated soils).](image)

**Figure 1.** Semivariograms of indicators of the structural-aggregate state of Irragric Kastanozems (Terter, irrigated soils).

Experimental variograms and model approximation parameters are presented in figures 1 and 2, and in table 2. Variogram analysis of the structural-aggregate composition of the soil shows that different theoretical models are applicable in different agro-ecological conditions. Thus, in irrigated conditions, structural indicators are mainly approximated by spherical and exponential models, and in rainfed conditions, by linear models. Some indicators do not have a spatial structure and demonstrate a net
nugget effect. In general, the radius of influence (range) varies from 22.8 m to 479.3 m. Relatively low values (22.8–40.0 m) of this geostatistical indicator are observed with data on wet sieving under irrigated conditions. In rainfed conditions, at the same sieving procedure, this indicator shows much higher values (212.4–479.4 m).

\[ \gamma(h) \]

Dry aggregate >10 mm

\[ \gamma(h) \]

Dry aggregate <0.25 mm

\[ \gamma(h) \]

Dry aggregate 10-0.25 mm

\[ \gamma(h) \]

Coefficient of structure (K_{str})

\[ \gamma(h) \]

Wet aggregate >3 mm

\[ \gamma(h) \]

Water-stability index of AFI (K_{AFI})

**Figure 2.** Semivariograms of indicators of the structural-aggregate state of rainfed Calcic Kastanozems (Jalilabad).

The sill is the variance, which the variogram model gives at the radius of influence. In general, the values of this indicator for aggregate fractions, structural coefficient, and water-stability index of AFI vary in a very large range – 0.31-7530.0. The highest values show K_{AFI}, and the lowest – K_{str}.

The ratio of nugget variance to sill makes it possible to estimate the degree of spatial dependence (SDG). When the value of SDG is 0-25%, there is a high spatial dependence, at a value of 25-75% - an average dependence, at a value of 75-100% - low [13].

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The wet sieving parameters demonstrate a strong (1.3-7.2%) and medium and low (54.9-100.0%) spatial dependence at irrigation, and at rainfed respectively. In both cases, the structural compositions of the soils show moderate and weak spatial dependence. The spatial heterogeneity of the structural-aggregate composition is the result of dynamical soil-forming processes.

**Table 2. Parameters of approximation of variogram models of soil structural-aggregate composition.**

| Procedure      | Indicator | Model | $A_0^a$ (m) | $C_0^b$ | $C_1^c$ | $C_0/(C_0+C_1)^c$-100 |
|----------------|-----------|-------|-------------|---------|---------|-----------------------|
| Terter (irrigated soils) | >10 | Sph$^e$ | 241.9 | 63.13 | 12.97 | 82.9 |
| Wet sieving | <0.25 | Sph | 409.4 | 22.50 | 42.85 | 34.4 |
| Wet sieving | 10-0.25 | Nugget$^h$ | - | 31.18 | - | 100.0 |
| Wet sieving | $K_{AFI}$ | Nugget | - | 0.31 | - | 100.0 |
| Wet sieving | >3 | Exp$^g$ | 40.0 | 0.07 | 0.90 | 7.2 |
| Jalilabad (rainfed condition) | >0.25 | Exp | 35.9 | 0.50 | 37.88 | 1.3 |
| Dry sieving | $K_{str}$ | Lis | 221.0 | 56.83 | 37.79 | 60.1 |
| Dry sieving | <0.25 | Lis | 233.2 | 6.78 | 5.08 | 57.2 |
| Dry sieving | 10-0.25 | Lis | 223.1 | 42.56 | 14.97 | 74.0 |
| Wet sieving | $K_{AFI}$ | Lis | 210.0 | 0.61 | 0.12 | 83.6 |
| Wet sieving | >3 | Exp | 479.3 | 0.50 | 0.41 | 54.9 |
| Wet sieving | >0.25 | Nugget | - | 38.87 | - | 100.0 |
| Wet sieving | $K_{AFI}$ | Lis | 212.4 | 4796.3 | 2733.7 | 63.7 |

$^a$radius of influence (range)  
$^b$nugget variance  
$^c$spatial (structural) variance  
$^d$sill  
$^e$spherical model  
$^f$nugget effect  
$^g$exponential model  
$^h$linear model

Probably, this may indicate the existence of different mechanisms affecting the spatial heterogeneity of soil structural indicators.

**4. Conclusions**

The study of the geostatistical regularity of the spatial variability of indicators of the structural-aggregate state of the soil, the statistical evaluation of the components of variability and the identification of the parameters of variability models makes it possible to accurately quantify and map the structural state of the soil cover.

Variograms of indicators of the structural-aggregate state of arable soils in irrigated and rainfed conditions can be approximated an exponential, spherical and linear model. The degree of spatial dependence of the indicators of the water-stability of the aggregates under irrigation is stronger than in rainfed condition. In both conditions, mechanically strong aggregates show medium and low degree of spatial dependence.
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