Methodological approaches to constructing 3D models of soil in potato farming

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Abstract. Uniformity of potato tubers for a number of parameters (size, form, composition) is an important quality indicator of potato as marketable products. In production, this issue is resolved by selecting a variety. Conditions for a good plant development are primarily provision with nutrition, optimal moisture, soil density, microbiological activity. This study generalizes research in 3D organization of soddy podzols on the basis of spatial variation in fertility, moisture, density, hardness, microbiological activity and provides methodological approaches to preparing design specification for creation of functional spatial model of soil for potato growing using the methods of 3D geostatistics. A methodology has been developed for constructing a multilayer functional spatial soil model using the methods of 3D geostatistics for fertility, moisture, density, hardness, biological activity of the soil. The research showed a high degree of dispersion among the soils as for nutrient content, moisture, density, hardness and biological activity of the soil. Correlation was analyzed between soil density and moisture content, as well as influence of soil compaction onto its physical structure, bulk density, hardness and aeration. Tubers, their diameter, length and morphology were analyzed as plant characteristics that change under the influence of soil compaction.

1. Introduction
Uniformity of potato tubers for a number of parameters (size, form, composition) is an important quality indicator of potato as marketable products. In production, this issue is resolved by selecting a potato variety that corresponds to given quality criteria and subsequent creation of optimal field conditions for their actualization.

It is known that conditions for a good plant development are primarily provision with nutrition, optimal moisture, soil density, microbiological activity and some other characteristics. [2].

The purpose of the study is to generalize research in 3D organization of soddy podzols on the basis of spatial variation in fertility, moisture, density, hardness, microbiological activity and develop methodological approaches to preparing design specification for creation of imitation spatial model of soil for potato growing using the methods of 3D geostatistics.
2. Research methods
The testing area is represented by 8 transects, each consisting of 20 sampling points. The transects are located in a west-east direction, spaced at intervals of 1.5 m. Sampling points are spaced similarly. Thus, the testing area is a regular grid with a grid node width of 1.5 m. The long side of the testing area is 285 m, the short side is 12.0 m.

Soil density and hardness values were measured in the field with a cylinder and a manual penetrometer (made by Eijkelkamp), to a depth of up to 25 cm with a 5 cm interval.

Mean measurement error of the instrument is ±8 %. A cone with a cross-section of 1 cm² was used in measurements. Within each node, soil hardness was measured with single replication. Statistical processing was performed with the Statistica 7.0 software package, 2D mapping and evaluation of geostatistical indicators were performed with Surfer 8.0; Moran’s I value was evaluated with the GeoDa software. 3-D variogram is represented by two nested structures.

3. Research Results
Our research has shown that there is a high degree of dispersion in soil as for nutrient content, as it may be seen, for example, in distribution of exchangeable potassium (Figure 1) [1].

Figure 2 presents soil moisture dynamics (% of field moisture capacity) and soil density (g/cm³) in the tuber bunch area depending on preplanting soil treatment, three-year average.

Figure 1. Exchangeable potassium content (mg/kg) according to Kirsanov (GOST 26207-91) for testing areas of VNIIKKh where 1 – ≤ 63; 2 – 64–100; 3 – 101–137; 4 – 138–174; 5 – 175–211; 6 – 212–248; 7 – 249–285; 8 – ≥286
Figure 2. Soil moisture and density as a function of pre-planting soil loosening

Data on biological activity of the soil are shown in Figure 3.

Summarizing the above, general stratified soil model (SSM) for potato farming may be described with the following multidimensional matrix $W(x, y, z, t)$, which may be represented in the following way:

Abstraction levels

|        | 0 | 1 | 2 | n |
|--------|---|---|---|---|
| F      |   |   |   |   |
| D      |   |   |   |   |
| M      |   |   |   |   |
| P      |   |   |   |   |

$W(x, y, z, t) = \begin{bmatrix}
F_U & F_{1U} & F_{2U} & F_n \\
D_U & D_{1U} & D_{2U} & D_n \\
M_U & M_{1U} & M_{2U} & M_n \\
P_U & P_{1U} & P_{2U} & P_n
\end{bmatrix}$

Layer 1 – nutrients
Layer 2 – density
Layer 3 – moisture
Layer 4 – biological activity

Figure 3. Biological activity of soil, %
where \( \subseteq \), \( \subseteq \) are containment and inclusion symbols, respectively, \( W \) is a soil model matrix; \( x, y, z, t \) are spatial and temporal parameters; \( F \) is soil fertility; \( D \) is soil density; \( M \) is soil moisture; \( P \) is soil biological activity.

4. Discussion

Excessive fertilization is one of the ways to reduce the influence from soil dispersion and provide plants with uniform nutrition. It allows plateauing in providing all the plants with a necessary dose of nutrients in such a way that soil non-uniformity in humus, macro- and micro-elements is no longer important, however it involves high doses of fertilizers and influences soil microbiology and product quality. The second way is using precision fertilizing systems [1].

Studies of spatial and temporal distribution of moisture conducted on VNIIKKh potato farming testing fields showed high degree of dispersion in soil moisture (Figure 2).

It is evident that plants experienced moisture deficiency during the most critical stages of tuber formation and harvest buildup. It is also evident that various soil treatment methods applied pre-planting allow to a certain degree influencing soil moisture throughout the vegetation period up to harvest.

It is known that surface and subsurface watering are used to reduce soil non-uniformity and achieve optimal soil humidity [3, 4]. Under conditions of hydrologic equilibrium complicated with short-term abrupt dry periods, it is possible to use water-absorbing biopolymers that hold water in the soil and release it when a water deficiency arises [1].

There is a correlation between soil density and soil moisture.

Soil compaction may arise as a result of anthropogenic impact (vehicle traffic on the soil surface) or due to natural causes, e.g., in alkaline soils [5]. Compaction influences physical structure, bulk density, hardness and aeration of the soil. All these characteristics influence plant growth [6, 7]. Tubers, their diameter, length and morphology, change under the influence of soil compaction [8]. Determining a scale of soil compaction within a field in an important task. Useful tools for its completion are moisture analyzer, density analyzer and penetrometer, used to measure moisture, density and hardness of soil through relatively large territory. It is generally thought that the hardness value obtained with a penetrometer reflects the resistive action experienced by a plant root during its growth [5].

Maximum root pressure onto the soil is in a range of 0.9–1.3 MPa [9]. According to other researchers, root growth stopped at a resistance of 0.8–5.0 MPa [10]. Thus, penetrometer measurements over 5 MPa are witnessing to soil compaction impeding root growth, thus influencing primary productivity of the plants [5].

Soil is a three-dimensional body, whose properties may vary in any direction within its spatial and temporal limits. However, soils are usually studied only in the horizontal plane; if a 3D characteristic of spatial variance is sought after, it is usually described as a set of horizontal layers of various depths. The main disadvantage of layered 2D representation is a possibility of mismatch between the layers when they are placed one over another [11].

Quite accurate representation of impact from various agrotechnical approaches to the intensity of plant material destruction is given by methods that take into account biological activity of soil analyzing decay of straw and linen fiber as natural cellulose sources. Technically, the easiest way to determine activity of cellulose-decomposing microorganisms is by degree and rate of decay of linen cloth (linen canvas stripes). Our research has shown that dispersion of biological activity of soil through a plot with dimensions 40 x 100 m was from 5.8 to 61.7 % (Figure 3).

From the point of view of agronomy, it is very important that the linen canvas method not only shows activity of cellulose-decomposing microorganisms, but nitrogen mobilization in the soil as well [1]. Besides, the linen cloth decomposition often gives a more objective reflection of the state and activity of soil microbiome in vivo than laboratory-based plating procedures.

Studying soil activity layer by layer allows obtaining a complete picture of the soil biological activity.
Such characteristics of plants as tubers, their diameter, length and morphology, are susceptible to soil compaction, which, in its own turn, depends on moisture and microbiological activity. Thus, the task of reducing dispersion in potato tubers may be resolved by reducing soil dispersion in fertility, moisture, density and microbiological activity within a given plot.

Methods of 3D geostatistics were used to compile a spatial map of a plot with a thickness of 5–25 cm, depending on arable layer thickness. The next stage is to obtain layer-by-layer information taking into account spatial and temporal data of the model W (x, y, z, t), analysis of research results in the form of 3D images for practical application in potato farming.

5. Conclusions and recommendations
1. A methodological approach was developed to compiling a technical assignment for construction of spatial functional model of potato farming soil using methods of 3D geostatistics.
2. The research showed a high degree of dispersion among the soils as for nutrient content, humidity, density, hardness and biological activity of the soil.
3. The task of reducing dispersion in potato tubers and increasing yield was formulated as one involving reducing soil dispersion in fertility, moisture, density and microbiological activity within a given plot.
4. The proposed approach allows summarizing research in multidimensional organization of soddy podzols from the data of spatial variability in fertility, density, moisture, hardness, microbiological activity, using them as separate layers in the model.

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