

# Bioclimatic basement for mesoscale agricultural land use assessment in Samara region

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**Abstract**—The necessity of bioclimatic approach in the agricultural land use assessment in the Russian Federation constituents is substantiated in this paper in order to improve land use management. Mesoscale bioclimatic potential assessment using dynamic-statistical simulation of basic grains production process (winter and spring wheat, spring barley) as well as bonitet assessment have been performed for administrative districts in Samara region. GIS analysis of the results and mesoscale comprehensive assessment zoning of the territory were applied. Seven mezozones were allocated in the region with compliance of the crop productivity scales and its formation factors. The results of farmland evaluation with their accuracy and reliability analysis in comparison with other existing techniques are shown. The obtained spatial distributions of the normative productivity and bonitet are not distorted by the influence of agrotechnic; they more reliably and completely reflect the natural and economic properties of the territory in contrast to other options. This is confirmed by the high values of the spatial correlation coefficient with complex of soil and climatic indicators, especially in the forest-steppe zone of the Samara region.

**Keywords**—*bioclimatic potential, agricultural land use assessment, land evaluation, bonitet, dynamic-statistical simulation, normative productivity.*

## I. INTRODUCTION

Agricultural land sites assessment allows identify the advantages and disadvantages of land, quantitatively express the degree of their suitability in agricultural production and value in price indexes. It is a digital basis for solving problems of agricultural design and land use. A distinctive feature of organization of land use assessment in Russian Federation is a necessity of result adequacy and comparability at a very wide range of natural resources, therefore, the priority of their assessment is determined both logically and practically.

As it is known, the leading role in the structure of natural agricultural potential (NAP) is allocated to land resources [1, 2], due to their exceptional role in arable farming and depletion (with provision for incomparably slower recovery processes). However, many scientists (Dokuchaev, Tulaykov, Loiko, Zhuchenko and others) noted that the weather and climatic conditions are the most important factors of crops productivity and production risks throughout most of agricultural zone of Russia due to their large spatial and temporal variability. Their correct reflection in the NAP

assessment and taking in account when planning sown areas structure, as well as introduction of farming systems and taking other business decisions are necessary to maintain agroecosystem's stability and its sustainable functioning [3].

Mesoscale assessment of both bioclimatic potential (BCP) and farmland bonitet have been done in this study through dynamic-statistical simulation of basic grains production process in administrative districts of Samara region.

## II. LITERATURE REVIEW

Agricultural assessment of climate considers agroclimatic resources in terms of their favorability to agricultural production. Territory distribution of some climate components describes territory properties, the potential ability of agriculture in regions, but is not sufficient to assess the production resources, as it does not represent their connection with crop productivity. The necessity of geographic BCP analysis appears taking into account both climate spatiotemporal heterogeneity and comprehensiveness, and different factors having an effect on plants during their vegetation period.

BCP has a complex structure, and its form, the scale of described processes, the spatiotemporal detailing as well as the calculation methods are determined in each case individually depending on study goals and objectives [3]. Macroscale features of the BCP spatial distribution in the Russian Federation are sufficiently studied and displayed at maps of agroclimatic and nature-agricultural zoning (P.I. Koloskov, S.A. Sapozhnikova, D.I. Shashko and others). For the purpose of land sites evaluation land-assessment districts are established (in Samara region, particularly, there are three districts conforming to 1 - forest-steppe, 2 - steppe and 3 - dry-steppe nature-agricultural zones). BCP assessment in meso- and microscale levels is a more complicated task, since the interaction processes between surface air and ground are to take into account additionally and as a result to analyze the effect of wide environmental conditions variety on plants.

In order to study the impact of farming level on crop yield the reference yield method widely used, which consists of sequential calculation of potential (PP), climate-provided (CPP) and actual eventual (AEP) crop productivity [4]. De Wit [5] also dealt with several BCP categories, depending on considered factors (only radiation or with water stress, availability of mineral elements for plant nutrition). A comparison of these categories and levels characterizes the productivity reserves and economic practicability of any factors adjustment, farming system improvement, and farmland melioration application.

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In addition to this, layered BCP structure formation is caused by scale and spatiotemporal variability of the factors considered. In circumstances where interrelated soil fertility and climate unidirectionally and jointly form landscape zones, macroscale territory variability of climate can be expressed as PP or CPP (in other terminology, as radiation-thermal potential). However, within zones connection of soil type and landscape with climate is disturbed due to variousazonal factors influence (topography, vegetation cover, water objects location and parameters and others), causing meso- and micro-climatic perturbations [6]. Therefore, productivity modelling should be done with sufficient territory detailing and according to physical characteristics and soil fertility effect on plants, i.e. at AEP level (or as soil-climatic potential).

### III. RESEARCH METHODOLOGY

More than 60% of sown areas in Middle Volga region are traditionally allocated to grain crops, including barley, winter and spring wheat, that cover about 80% of area. Therefore, their common productivity largely characterizes grain group as a whole, the conditionality with natural resources and territory bioclimatic potential value.

To calculate the productivity, we used the dynamic model of plants production process [7], which describes in detail processes of soil water block, and can be applied, to dry conditions of the middle Volga region. The model was adapted to soil conditions of Samara region, set the appropriate parameters, as a result of specially organized field observations a number of biological parameters of crops have been carried out [8].

During the research the structure of the model was sequentially complicated by including assessment of crops germination capacity, reduction of winter crops during overwintering and additional variables, reflecting the conditions of conformity for the plants elements formation (tillering, the number of grains per ear, grain filling, and others) [9, 10]. All these predetermined accuracy of the productivity calculation on sample of 1983-2012 up to 90-95% with about 90% assurance.

Using software complex "Agrometeorological Information Territory System" (SP AMITS) [11] crops productivity was calculated in points of notional spatial grid for Samara and surrounding areas in 400 weather conditions cases. For the calculation preparatory works were carried out on collection and formation of the information base. Climatic data in spatial grid points were determined with the use of data interpolation, method of meteorological values stochastic modeling being applied for lots of weather conditions variants generating [12]. Other required information (soil characteristics, topography parameters, administrative territory division and other data) was taken from maps with combined layers.

### IV. RESULTS AND DISCUSSION

The spatiotemporal distributions of actual eventual crop productivity, creating information base for the territory features analysis, its BCP and farmland evaluation are obtained. Fig. 1 shows the maps of territorial index of natural resources agricultural productivity, based on average productivity distribution in relation to the corresponding average for region.

The zone of the highest index values (over 1.4) naturally extends to north-eastern part of the territory, characterized by the most fertile soils with a high water-holding capacity (mainly leached argillaceous and heavy-loamy medium-humus chernozems) and rather favorable combination of heat and moisture conditions (annual rainfall of 370-450 mm, active temperatures sum 2200-2500°S, hydrothermal coefficient 0.8-1.0). To south and southwest the index value is reduced to 0.4-0.8, reaching a minimum in the most arid regions to south of the River Great Irgiz (precipitation sum 310-380 mm per year, active temperatures sum 2600-2800°S, hydrothermal coefficient 0.5-0.6) and in some areas along the eastern border of the territory and on the right Volga bank, which are characterized with the spread of low-humus soils with a low water-holding capacity and varying degrees of salinization.

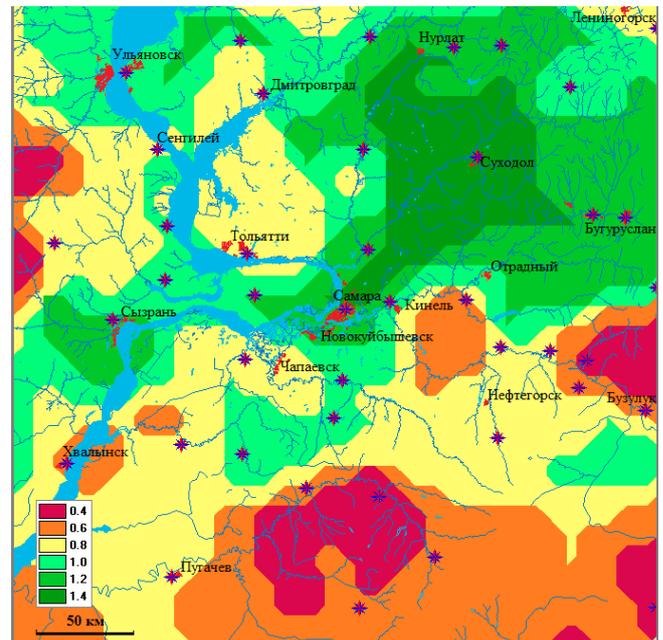


Fig. 1. Spatial distribution of the index of agricultural productivity natural resources (stars – meteorological stations)

These spatial distributions correspond to the allocation of agro-meteorological factors affecting plants. It is confirmed both visually and statistically (correlation coefficients with some meteorological values reach up to 0.78).

The spatial distribution of simulated crop productivity is the basis of mesoscale complex zoning of the territory. The analysis was carried out by maximizing its correlation with a set of indicators of the soil and climatic resources of the territory. As a result, the boundaries of seven natural-agricultural mesozones were determined on the territory of the Samara region (Fig. 2). Four of them are allocated within the boundaries of the forest-steppe natural zone, two - within the dry-steppe zone, and steppe zone is represented as a whole. Their position is completely consistent with the characteristics of the landscape of the territory. The spatial correlation coefficients of the average normative yield in the mesozones with many soil-climatic indicators turned out to be higher than 0.7.

The characteristics of the formed mesozones are given in Table 1. However, the dispersion of indicators in the 1st and 5th estimated mesozones remains significant. And further,

their additional division into areas in which conditions will be more uniform is required in accordance with this or that principle.

In accordance with methodological guidelines [13], we have calculated the farmland bonitet for administrative districts of Samara region (Fig. 2), taking the simulated productivity as the normative. For comparison, a similar calculation was made for a comparable normal grain yield, valued using regression equations according to the production yield for 5-10 years [14], the actual average yield of grain crops in agricultural enterprises for 1971-2012 [13], and on the basis of the physico-statistical assessment of the normative productivity at the agrotechnology level of the National Sorts Test Network [15]. In all variants bonitet varies over a wide range of values, and distributions are not entirely consistent with each other (correlation coefficients 0.40-0.74).

TABLE I. MULTIPLE CORRELATION COEFFICIENT OF FARMLAND BONITET WITH SOIL AND CLIMATE VALUES IN LAND ASSESSMENT DISTRICTS (LAD) IN SAMARA REGION

Farmland bonitet assessment technique, according to	Correlation coefficient <sup>a</sup>	
	1 LAD	2 & 3 LAD
Comparable normal average district yield based on a regression equation [14]	0.91±0.08	0.88±0.10
Average district production yield [13]	0.78±0.13	0.82±0.11
Normative average district productivity based on the physico-statistical equation [15]	0.82±0.13	<b>0.93±0.07</b>
Normative average district productivity based on dynamic statistical modeling	<b>0.94±0.10</b>	0.85±0.15

<sup>a</sup>. Significance level 0,05

The dependence of bonitet spatial variability on natural factors, taking into consideration their complex effect on plants, is studied. The following soil characteristics are taken into account: humus content, bulk density and the lowest moisture content in 0-100 cm soil layer. Climatic characteristics complex include: temperatures sum above +10 and below -10°C, precipitation amount at warm (April to October) and cool (November to March) periods, humidity deficits sum.

The distribution obtained on the basis of actual productivity in agricultural enterprises are strongly enough caused by soil-climatic territory resources – multiple correlation coefficients in land assessment districts are 0,91 and 0,88 at first and 0,78 and 0,82 at second variants (Table 2). However, errors caused with production data heterogeneity (due to the influence of socio-economic factors), distort bonitet results, and make them impossible to rely on in land assessing.

In the variant with productivity calculation by Karmanov's method on base of the physico-statistical equation, coefficients of bonitet linear correlation with soil-climatic factors justifiably turned out to be high (0.82 and 0.93). But the procedure is rather formalized (simplified), because it provides land evaluation only at the level of agroclimatic sub-zones, and does not provide information about the process of formation and temporal variability of the crop productivity.

Productivity determination based on simulation of the plant production process helps to avoid these drawbacks and to increase the reliability of bonitet results. In the first land-assessment district (1 LAD), characterized by quite favorable conditions and relatively weak spatial variability (spatial variation 11-13%), the coefficient of multiple correlation was 0.94, which indicates a higher naturecoherence of the results.

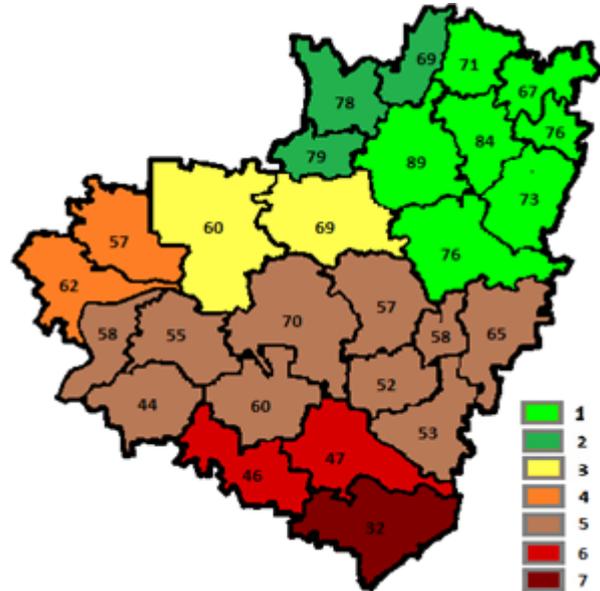


Fig. 2. Farmland bonitet, score (1-7 natural agricultural mezozones)

## V. CONCLUSION

The results of zoning in contrast to the previously proposed reflect spatial mesoscale distribution features of soil cover and climatic factors in the complex, taking into account the assurance of plants growth with environmental factors during the vegetative season.

The zoning is performed in the contours of the territory administrative division and thus forms the information basis for solving agricultural production issues and organizing land use of the relevant management objects.

The comparison of farmland bonitets obtained in this work by different ways has resulted in the following conclusions.

Crops productivity spatial analysis in order to evaluate the land as a natural object is meaningful only at a leveled agricultural background, high enough for a larger information content, which leads to the necessity of its calculation using the bioclimatic approach.

Farmland bonitet values, obtained with physical-statistical assessment of normative productivity, provide fair information on territory resources at the level of land assessment districts. On mesoscale (for administrative districts) and further on microscale level, this approach is too simplify and does not reveal the structure of productivity dependence on external factors and their spatial variability.

**TABLE II. GENERALIZED CHARACTERISTICS OF ASSESSED MESOZONES OF THE SAMARA REGION**

Nature zone	Mesozone	Normative crop productivity, c/ha	Soil humus content, %	Soil productive moisture stock (August), mm	Sum of the temperatures, C		Rainfall for April-October, mm
					Below +10C	Under -10C	
Forest-steppe	1	25.4	5.5	111	2229	1153	329
	2	24.7	6.0	108	2167	1200	317
	3	21.6	4.7	100	2350	1010	325
	4	19.3	3.7	75	2400	1001	300
Steppe	5	19.3	4.1	85	2460	1126	320
Dry steppe	6	15.8	3.6	50	2500	1137	275
	7	11.3	2.8	50	2600	1125	250

Advantages of the method of dynamical-statistical simulation of production process are provided with the possibility to analyze the territory properties at mesoscale level. Thus obtained distributions of the normative grain productivity and farmland bonitet are not distorted by the influence of agrotechnical factor, more valid and complete unlike other variants in reflection of natural-economic territory properties in land assessment districts of the Samara region.

Physical validity and naturecoherence of simulation results establish the basis for their practical use in the procedur of land price valuation.

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