A New Method for Determining Appropriate Sites for Growing Perennial Crops

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Abstract

A new quantitative multi-level method for assessing land suitability has been developed, which is intended for evaluation activities for specific goals - mainly when selecting sites for creating new orchards and vineyards, agro-ecological zoning and preparing specific programs/projects. It represents a complex assessment of biophysical conditions (soil, relief and climatic conditions) and is based on the interrelationship "soil - plant - climate", reflecting the biological characteristics of the respective perennial crop and its requirements for the specified conditions. This method suggests possibilities for selecting the areas with the most suitable conditions, where the risks associated with the expected desired quantity and quality of production, the costs of creating and operating the plantations would be minimized. On its basis, an application in GIS can be developed, which allows work automation, as well as creation of thematic maps for the purposes of zoning of perennial plantations and when implementing large investment projects in the field of agriculture. It can also serve as a basis for sustainable land management and sustainable land use planning.

Key words: sustainable land use planning, assessment of land suitability, soil, relief and climatic conditions

Introduction

The selection of new sites for the creation of permanent plantations requires in-depth preliminary studies and is associated with significant financial costs and time (Beatty, et al., 1979; FAO, 1995; FAO, 1999). Errors or insufficiently good decisions in such cases appear relatively late (when fruiting begins) and are impossible to eliminate or limit (Bouma, et al., 1996) The soil and landscape requirements comprise both internal soil properties and external site qualities. An agro-climatic land adaptability matches each crop with climate and soil resources (Bouma, 1989). A key concept is the length of growing period, which is based on rainfall and temperature regimes (Penkov, 1997; Penkov & Staneva, 2004; Ivanov, et al., 1981). The growing period forms the basis for a quantitative climatic classification for each chosen crop, assuming rain-fed agriculture. At present, a fact complicating this process is the global unfavorable climate changes, which further increase the risk of such an investment

intention. Taking measures to adapt to the changing climate can already be defined as imperative, and this applies particularly strongly to the field of agriculture (Bacelar, et al., 2012). Global climate changes, expressed in increasingly higher average annual temperatures and increasingly frequent droughts, including soil and atmospheric (Alexandrov, 2011). Most perennial crops require available moisture within root range throughout the year (Bacelar,et al., 2012). This is why soil and climate conditions should be the focus of preliminary studies when choosing sites for their plantations.

The aim of this work is to create and present a multi-level model for assessing the biophysical conditions (soil, relief and climatic conditions) for choosing sites for planting perennial crops (orchards and vineyards) based on the soil-plant-climate relationship, reflecting the biological characteristics of the respective crop and its requirements for the specified conditions. This method suggests possibilities for selecting the regions with the most suitable conditions, where the risks associated with the expected desired quantity and quality of production, diseases, pest damage, costs for the creation and maintenance of the orchards and vineyards, erosion and soil degradation processes would be minimized.

Material and Methods

The research method involves the application of a model for multi-level assessment of an impact or process, which is currently used in the field of natural disaster risk assessment, as well as for environmental protection (Mondeshka, 2012). In the present work, this method is adapted and further developed for the purposes of planning sustainable land management within the framework of preliminary studies in determining the land use structure at the regional level. The model includes a comprehensive study/assessment of three groups of indicators (Fig. 1) regarding the mandatory natural and climatic conditions for the creation of permanent plantations and the subsequent obtaining of optimal results, namely: soil, climatic, terrain/topographic (relief and exposure).

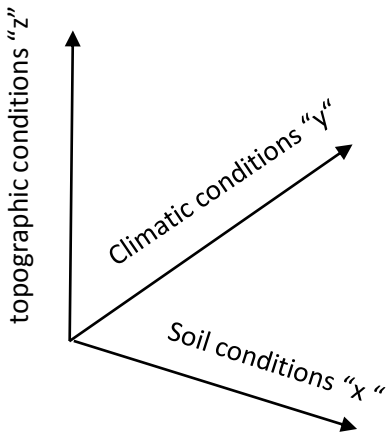


Figure 1. *Model for assessing the site (growing area)*

The model includes the following stages:

Stage I - Determination of the indicators (by groups - soil, climatic, topographic conditions) that to the maximum extent (fully and unambiguously) determine the optimal biophysical environment for the development and fruiting of the plant;

Stage II - Determination of the intervals in terms of indicators that determine different degrees of satisfaction of the biological requirements of the respective perennial crop;

Stage III – Determining the weight of the indicators by groups (the weight of each individual indicator for forming the assessment by each indicators group (soil, climatic, orographic);

Stage IV – Obtaining a summary (final assessment) from the application of the model –this allows to jointly assess the three groups of conditions.

The assessment model is based on a three-dimensional matrix, along the x, y, z axes, to which correspond respectively: assessment of soil conditions (i =1 - 4), assessment of climatic conditions (j = 1 - 4) and assessment of topographic conditions (f = 1 - 4), (Fig. 2).
For each of the condition's groups (x, y, z) four grades are applied for assessing the relevant situations, within this the highest score "4" corresponding to optimal conditions, and the lowest "1" corresponding to unfavorable conditions.

The assessment intervals for the groups of indicators x, y, z are:

- 1 – corresponds to a score from 1.00 to 1.99;
- 2 – corresponds to a score from the tables from 2.00 to 2.99;
- 3 – corresponds to a score from the tables from 3.00 to 3.99;
- 4 – corresponds to a score from the tables from 4.00 to 5.00;

For example, if the thickness of the soil profile from a given studied site is 115 cm, then this indicator will receive a score of 4 (Table 1[1]).

The overall assessment for each group of conditions is the sum of the score for the individual indicators, corrected by the corresponding correction coefficient (Results and discussion) – Kxn/ Kyn/ Kzn, where n = 1 – 4:
Assessment for a group of indicators "x" = Σ Vn . Kn (Table 1)

Table 1. *Scheme for determining the assessment for groups of indicators – on the example of indicators group "x"*

indicators	X_1	X_2	X_3	.. X_n	
Score of the indicators xi	V_1	V_2	V_3	V_n	
Corrected score	$V_1 . k_1$	$V_2 . k_2$	$V_3 . k3$	$V_n . k_n$	
Overall score for soil conditions	$\sum_{n=1}^{7}$ Vn. kn ..... (….= 3.65*)				→ i = 3

*example

In the matrix (Fig. 2) the estimates are formed following the relationship: the first digit represents the assessment of soil conditions, the second – the assessment of climatic conditions and the third – the assessment of topographic conditions.

[1] The proposed rating scale is conditional and is applied for illustrative purposes.

i.	**j.**	**f.**
↓	↓	↓
assessment of soil conditions	assessment of climatic conditions	assessment of topographic conditions

The scores for "j" and "f" are determined accordingly. For example, if i=3, j=4 f=2, then the aggregate score is (3, 4, 2). This, as will be shown later, corresponds to an "excellent suitability" score.

Assessment of topographic conditions (z)		Assessment of soil conditions (x)							
		1		2		3		4	
Assessment of the climatic conditions (y)	1	1.1.1.	1.1.3.	2.1.1.	2.1.3.	3.1.1.	3.1.3.	4.1.1.	4.1.3.
		1.1.2.	1.1.4.	2.1.2.	2.1.4.	3.1.2.	3.1.4.	4.1.2.	4.1.4.
	2	1.2.1.	1.2.3.	2.2.1.	2.2.3.	3.2.1.	3.2.3.	4.2.1.	4.2.3.
		1.2.2.	1.2.4.	2.2.2.	2.2.4.	3.2.2.	3.2.4.	4.2.2.	4.2.4.
	3	1.3.1.	1.3.3.	2.3.1.	2.3.3.	3.3.1.	3.3.3.	4.3.1.	4.3.3.
		1.3.2.	1.3.4.	2.3.2.	2.3.4.	3.3.2.	3.3.4.	4.3.2.	4.3.4.
	4	1.4.1.	1.4.3.	2.4.1.	2.4.3.	3.4.1.	3.4.3.	4.4.1.	4.4.3.
		1.4.2.	1.4.4.	2.4.2.	2.4.4.	3.4.2.	3.4.4.	4.4.2.	4.4.4.

Figure 2. *Multilevel baseline model for assessment of the site conditions*

In order to optimize the work on the model, the estimates in each area of the three-dimensional matrix are summarized by summing the corresponding numbers – i, j, f (Fig. 2 and Fig. 4). This makes it possible to give an assessment of the summarized information from the various possible combinations of natural conditions. The resulting summary values ($\Sigma = i + j + f$) are in the range from 3 to 12 (Fig. 2 and Fig. 4). From the final assessment of the various combinations of the assessments of soil, climatic and topographic conditions, five types of suitability are formed:

For the values of Σ = 3, 4, 5, 6 is assigned suitability – ***unfavorable conditions***. For values of Σ = 7 and 8, when "1" is involved in their formation, suitability is assigned as ***conditionally good*** (7), and in cases when the sum is formed with assessments other than "1", their suitability is – ***good***. When "1" is included for the formation of the value 9, the suitability is defined as ***conditionally excellent*** (9). For values of Σ = 9, 10, 11, 12 the site suitability is ***excellent*** (Fig. 2, Fig. 3 and Fig. 4).

The suitability types are indicated as follows:

Unfavorable conditions - 3, 4, 5, 6

Conditionally excellent – (9)

Conditionally good – (7) и (8)

Excellent - 9, 10, 11, 12

Good - 7 и 8

Figure 3. Types of land suitability

Assessment of topographic conditions (z)		Assessment of soil conditions (x)							
		1		2		3		4	
Assessment of climatic conditions (y)	1	3	5	4	6	5	7	6	8
		4	6	5	7	6	8	7	9
	2	4	6	5	7	6	8	7	9
		5	7	6	8	7	9	8	10
	3	5	7	6	8	7	9	8	10
		6	8	7	9	8	10	9	11
	4	6	8	7	9	8	10	9	11
		7	9	8	10	9	11	10	12

Figure 4. *Matrix for the multi-level model for assessing soil, climatic and orographic conditions*

Results and Discussion

Stage I The group's indicators are selected on the base of established biological characteristics and requirements of the respective crop to the climate, soils and topography of the growing site and are in fact those that have the greatest impact on the growth, development, productivity and quality of the production. The indicators may vary in number and type, but the numerous studies on various agricultural crops show that the most significant among them are (Penkov, 1997; Valev & Georgiev, 2004; Teoharov et al., 2019; Teoharov et al., 2014; Petrov, et al., 1988):

1. Indicators forming the assessment of soil conditions:

1.1. Thickness of the soil profile (Table 2);

1.2. Texture;

1.3. Coefficient of textural differentiation;

1.4. Total porosity;
1.5. Humus content;
1.6. Soil reaction (pH);
1.7. Groundwater level;

2. Indicators forming the assessment of climatic conditions:
2.1 average monthly air temperature;
2.2 average monthly air temperature during the months of flowering;
2.3 average monthly air temperature during the months of fruit setting;
2.4 average monthly air temperature during the month of fruit ripening;
2.5 average annual amount of precipitation;
2.6 average of monthly precipitation amount for the months that are determined as particularly important for the growth and development of the crop;

3. Indicators forming the assessment of the topography of the growing site:
3.1 altitude;
3.2 exposure;
3.3 slope of the terrain;

Stage II For each crop, for each indicator, corresponding assessment scales are developed that determine the optimal biophysical environment for the development and fruiting of the plant.

Table 2. *Soil profile thickness rating scale*

Thickness of the soil profile (cm)	Scope
below 30	1
30 - 60	2
60 - 100	3
more than 100	4

Stage III The weight of each individual indicator (stage III) for forming the assessment by group of indicators (soil, climatic, orographic) is determined depending on its significance for the growth, development and fruiting of the respective crop. For this purpose, correction coefficients are used, the sum of which for each indicator's group is equal to 1 or corresponding in total to 100%: for example, if it is established that the pH of the soil has a weight of 30% for the assessment of soil conditions, then a correction coefficient of 0.3 should be applied. The correction coefficients are determined depending on their significance in relation to the productive conditions - quantity and quality of production. They may have the following distribution:

- concerning soil indicators
  - soil profile thickness (the sum of thickness of A and B horizons or up to the solid/massive soil-forming rock) - 0.1;
  - soil texture - 0.15;
  - texture differentiation coefficient - 0.15;
  - total porosity – 0.1;
  - humus content – 0.1;
  - soil reaction – 0.3;

- groundwater level – 0.1;

❖ concerning climatic indicators
- average annual air temperature – 0.15;
- average annual temperature sum for the vegetation period – 0.2;
- average monthly air temperature in a certain month/months, which are important for the quantity and quality of plant production - 0.2;
- average annual precipitation amount – 0.1
- average monthly precipitation amount for a certain month/months, which are important for the quantity and quality of plant production – 0.15;
- average monthly air humidity for a certain month/months, which are important for the quantity and quality of plant production (for example, the months May, June and July) – 0.2;

❖ concerning the indicators forming the assessment of the topography of the planting site
- altitude – 0.4;
- exposure – 0.4;
- slope of the terrain – 0.2;

The proposal regarding the weighting coefficients is basic and reflects the generalizing correlation of the individual indicators, and therefore tolerates certain deviations for the different plants.

Stage IV – Obtaining a generalizing (final) assessment from the application of the model – it makes it possible to assess both the three groups of conditions together and the different combinations by the assessments for the individual indicators.

Conclusion

The developed model provides an opportunity for a complex assessment of the suitability of certain groups of conditions for sites for of new perennial crops plantation, including three components - assessment of soil, climatic and topographic conditions. In this way, it provides an opportunity to obtain an objective assessment, approaching to a significant extent the real conditions, as it includes the most important components of the necessary habitat for the cultivation of a given crop, corresponding to its biological requirements.

The model is applicable for particular areas investigations, making it possible to take into account the diversity of soil, climatic and relief conditions in them. On its basis, an application in GIS can be developed, which allows for work automation as well as the creation of thematic maps for the purposes of zoning perennial crops in a certain part of the territory.

The application of the developed methodology is suitable for the implementation of large investment projects in the field of agriculture and, in particular, for the creation of perennial plantations, as it would reduce the risk of such investment intentions in cases of inappropriately selected location, further financial and other losses. It can also serve as a basis for sustainable land management and sustainable land use planning.

It can also be applied for determining the Ecosystem Services Assessment (ESSA) and their mapping, which have recently been increasingly used in the development of strategies for sectoral policies (agriculture, environmental protection, etc.), SDPs (Spatial Development Plans) and their respective ERAs (Environmental Risk Assessments), Municipal Development Plans (MDPs) and other strategic documents.

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