DOI: 10.22616/j.balticsurveying.2023.18.006

ESTIMATION OF THE FOREST-GROWING POTENTIAL OF LANDS BY SOIL INDICATORS

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Abstract. The indirect approach is mainly used to assess the forest-growing potential of lands in the forestry of Ukraine. For these purposes, a comparative ecological (forest typological) method is used to assess soil conditions according to their forest growth effect. The species composition of the forest stand and its productivity are the main indicators of the forest growth effect. The undoubted advantages of this method are high forestry value, low labor intensity and cost, and the main disadvantages are the subjectivity of determining the types of forest conditions (especially derivatives and artificial plantations), its insufficient environmental sensitivity, and the difficulty of applying to places where there is no forest vegetation. The aim of the study was to quantify the quality of forest land and develop markers of the forest-growing potential of soils. The studies were carried out by synthesizing two methodological approaches – forest typological as the leading method for assessing the potential of habitats and direct study of soils (field and analytical). The package of markers was developed to assess forest potential of soils based on the establishment of a correlation between the productivity of forest stands (height, quality class) and soil indicators (thickness of the humus part of the profile, pH, content of clay particles, humus, total and exchange forms of N, P, K, Ca, Mg). The package of markers depends on the soil type and consists of the following soil indicators: the content of particles of physical clay (d<0.01 mm), the thickness of the humus part, as well as the content of humus, N, Ca, K, Mg. A gradual increase in their quantitative values leads to increase in the forest productivity of the soil and, as a result, the productivity of the forest stand.
Keywords: productivity of forest soils, markers, tree stand

Introduction

The phytoindication (by the species composition and productivity of native forest plantations) is the leading method for determining the forest-growing potential of lands in Ukraine, the essence of which is clearly displayed in the classification model of forests and forest plots – in edaphic grid of Alekseev – Pogrebnyak's (Table 1) (Погребняк, 1955; Остапенко, Ткач, 2005). The edaphic grid is based on two main soil properties that determine its fertility – moisture and nutrient content (trophicity). The grid is a coordinate system: the abscissa shows habitats that differ in nutrient content – trophotopes (A, B, C, D) and the ordinate shows habitats with different humidity – hygrotopes (0, 1, 2, 3, 4, 5). The intersection of a hygrotope and a trophotope results in edaphotope (edatope) – the type of forest condition (TFC) indicating overall forest area productivity (Table 1).

The value of this method, which underlies the forest cadaster of Ukraine, is beyond doubt. The absolute advantages of the method are relatively low labor intensity, cost and high forestry value. However, a number of circumstances makes it difficult to use. First of all, rapid reduction of the virgin natural forest area (according to experts, only 16-35 thousand hectares remain in Ukraine). The characteristics of these forests (composition and productivity) used as the criteria for the level of forest-growing potential of lands. At the same time, the taxation characteristics and composition of artificial forests, especially with an imperfect forest management system, often differ significantly from the characteristics of natural forests and, therefore, cannot objectively reflect the forest productivity of the habitat. In this case, we are no longer assessing the natural fertility of the soil, but its anthropogenic component. In addition, it should be noted that the forest stand capacity class is only a consequence of a certain soil fertility level and does not indicate, which soil properties determine this level. For the most part, the forest vegetation is forming on soils with a low level of fertility. The assessment of the forest soil productivity has its own specifics and differs from the assessment of agrocenosis (Ponette et. al., 2014; Hansson et. al., 2020; Legout et. al., 2020; Gao et. al., 2022). This is primarily due to the fact, that the forest is a complex multicomponent and multifunctional ecosystem with a practically closed circulation of substances, functioning for a hundred years or more. Therefore, mobile forms of nutrients are used to assess the fertility of agricultural land on which the crop is forming during one growing season, while the total forms of nutrients are often used (Gao et. al., 2022; Zhao et. al., 2023) to assess the productivity of forest soils. In addition, the productivity of forest stands depends not only on the presence of nutrients in the soil, but also largely determined by the granulometric composition of the soil.

Table 1

The edaphic grid with indicator-species and their quality class, which indicates the forest lands productivity

Humidity types (Hygrotopes)		**Fertility types (Trophotopes)** Increasing fertility levels →			
		A (poor habitats) *Bir*	B (relatively poor habitats) *Subir*	C (relatively rich habitats) *Sugrud*	D (rich habitats) *Grud*
0 (very dry)	Increasing humidity level ↓	*P – IV-V* A_0	*P – III/IV* B_0	*P– III* C_0	*Q–IV-V* D_0
1 (dry)		*P – III-IV* A_1	*P – II/IV ; Q –V* B_1	*P– II/I ;Q –III-V* C_1	*Q– III-IV* D_1
2 (moderately humid)		*P – II-I/III* A_2	*P– I-I^a ; Q, Pc – III-IV, B–I* B_2	*P –I^a-I^b ;Q –I-III; F, Pc –II* C_2	*Q, Fr –I-II; F-II-I; Pc– I-I^a* D_2
3 (humid)		*P – III/IV; Q -V; Pc-IV-V* A_3	*P –I-II; B – I; F, Q, Pc – IV-III* B_3	*P–I-I^a; Q, F– I-II ; Pc –I -II* C_3	*Q, Fr – I-I^a; F– I-II, Pc– I^a-I^b* D_3
4 (very humid)		*P – IV* A_4	*P –II-IV; B–II; Pc – IV-V* B_4	*P–I; B, Pp–I-II; Al–II; Q, Pc –II-III* C_4	*Q–I-II; B, Pp–I; Pc–I-II* D_4
5 (marshy ground)		*P– V* A_5	*P, B – IV-V; Al -IV-III* B_5	*P–II-IV; B-III-II; Al-I-III* C_5	*Al I-I^a ;·Pp-I* D_5

Note: *P– Pinus sylvestris, Q – Quercus robur, Pc – Picea abies, B – Betula pendula, Fr – Fráxinus excelsior, Al – Alnus glutinosa, F – Fagus sylvatica, Pp – Populus tremula*.

Determining the marker system for the level of forest soil fertility and their quantitative parameters has a particular importance in the context of the prioritized tasks of forestry such as increasing the forest cover of Ukraine to a scientifically substantiated optimal level (20%). The planned increase of the forest cover is due to expanded afforestation, i.e. large-scale afforestation of lands previously unoccupied by forest vegetation. At the same time, it is planned to increase the level of forest cover in Ukraine in the short term (until 2035) up to 18% (Державна стратегія, 2021). It is impossible to determine the forest-growing potential of these soils by the productivity of forest vegetation. Under such conditions, the soil properties is the most objective criteria for the forest growth potential of lands and their forest suitability.

The purpose of the study is to quantify the main properties of forest soils in the flat part of Ukraine and develop a set of diagnostic indicators of the forest-growing potential of soils. The study is based on two methodological approaches - forest typological (phytoindication method), as the main method for assessing the productivity of Ukrainian forest lands, and assessment based on the soil research.

Methodology of research and materials

The study of the forest-growing potential of lands based on the principles of forest typology, comparative ecology, soil science, agrochemistry, and mathematical statistics and carried out in several stages. The first stage of research included experimental plots, which were laid in middle-aged primary (mostly natural) plantations in various types of growth, of natural and climatic zones of Ukraine (Polissya, Forest-Steppe, and Steppe), where the forest stand productivity (quality class) and soil covering were determined. There were at least 30 trees on the sample plot. A total of 170 sample plots were established. On the each sample plot, the soil profiles were laid, described (the depth depended on the type of soil and varied from 0.5 m to 2 m) and the samples were taken for the chemical analysis.

Further under laboratory conditions the following soil indicators were determined according to generally accepted methods: granulometric composition (pipette method in modification of N.A. Kachinskiy); humus

content (method of Tjurin in Kononova and Belchikova's updating); content of total forms N, P, K, Ca, Mg (in concentrated sulfate extract); permanent wilting of plants (calculation method); content of exchange forms Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} (in acetic-ammonia extract); acidity level (potentiometric method).
At the final stage, a correlation analysis of the dependence between the values of soil indicators and the height of the forest stand were carried out. Thus, those soil characteristics that have the greatest influence on the height of the stand were determined. This methodological approach made it possible to determine the indicators of the forest-growing potential of soils, as well as quantitatively characterize various types of habitats (Bir, Subir, Sugrud, Grud).
The studies covered sandy lands under pine forests in the main natural and climatic zones of Ukraine, in particular, in Polissya (within the Zhytomyr and Chernihiv regions), Forest-Steppe (Kharkiv region) and Northern Steppe (Kharkiv and Luhansk regions). The types of forest conditions for these lands are A_1, A_2, B_1, B_2, C_1, C_2. Trial plots were also laid on clay lands, on which broad-leaved, mainly oak, forests had been formed (Eastern Forest-Steppe, Kharkiv region). The type of forest conditions of these lands is D_2.

Discussions and results
The development of a diagnostic indicators system for assessing the forest growth potential of sandy lands was carried out for a consolidated group of sandy soils in Ukraine, which includes:
1) Soddy-podzolized (Leptic podzols) clayey-sandy and sandy loamy soils on rocks of various genesis, mainly on ancient alluvial pseudofibre sand (Fig. 2a). The soils of this group are not subject to deflation, as they are fixed by vegetation. They predominate in the Forest-Steppe, but also can be found in Polissya and Northern Steppe.
2) Soddy-slightly podzolic (hidden podzolic) sandy, clayey-sandy, sandy loamy soils on the fluvioglacial, moraine and ancient alluvial sands (Fig. 2b). Soil names are given in accordance to the Ukrainian soil classification and the FAO classification (Полупан et.al., 2005; World Reference Base, 2006).

a Leptic podzols on ancient alluvial pseudofibre sands	b Soddy-slightly podzolic soil on fluvioglacial

Fig. 1. Typical forest soil profiles under pine forests in Ukraine

These types of soils were combined into groups based on the significant homogeneity of the basic properties (water-physical, nutritional, etc.), which is due to their sandy granulometric composition (Table 2, Fig. 2.). This similarity of soil properties, in turn, determined their identical forest growth effect (forest stand productivity). The sandy soils characterized by a very low level of fertility relatively to agricultural crops, but forest plantations, pine in particular, reach high productivity on such soils.

Table 2

Average values of the main indicators for sandy soils under pine forests

Clay %	Humus horizon thickness, cm	pH (H_2O)	pH (KCl)	Humus	N	P	K
				%			
7.0±0.25 (n = 489)	24±2.7 (n = 145)	5.2±0.06 (n = 495)	4.3±0.07 (n = 245)	0.51±0.06 (n = 377)	0.04±0.003 (n = 449)	0.03±0.003 (n = 449)	0.06±0.005 (n = 449)

Note: Clay – total content of particles with a diameter of <0.01 mm; Humus, N, P, K – total content (significant difference, $p < 0.05$)

The fertility of forest soils under conditions of sufficient moisture is closely correlated with their granulometric composition. A straight-line correlation (significant difference, $p < 0.05$) was established between the height of pine stands and the content of physical clay particles in the upper (up to 50 cm) soil horizon. An increase in the content of clay particles in the soil enhances its ability to accumulate moisture and nutrients, which in turn leads to an increase of the forest stands productivity.

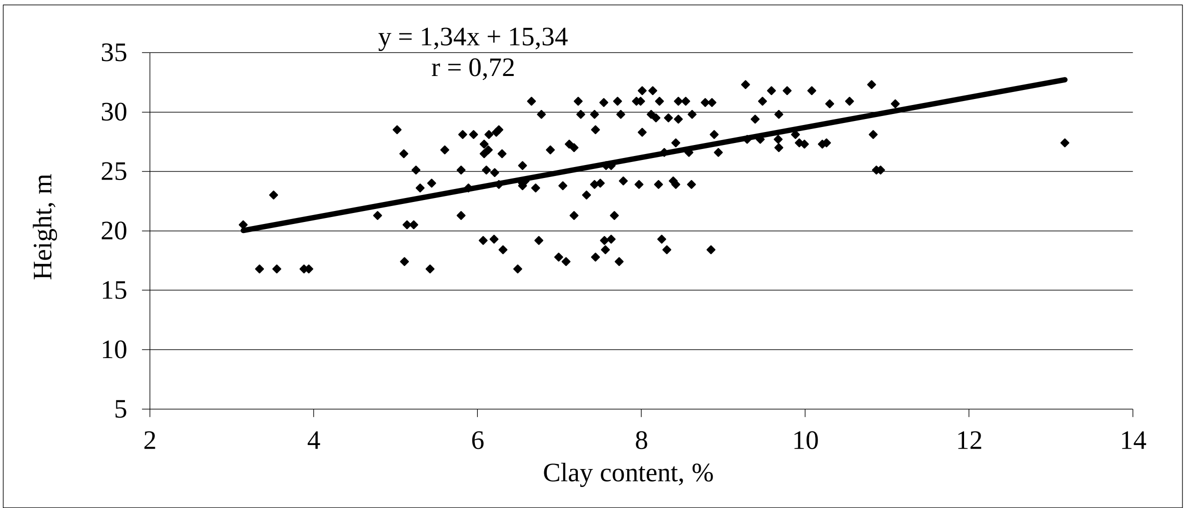

Fig. 2. Dependence of the height of pine stands on the clay particles content in the soil

The studied sandy soils of Ukraine are characterized by an acid reaction of the solution (pH_{H2O} –5.2), very low total content of nutrients (N – 0.04%, P – 0.03%, K – 0.06%), exchange bases (4 meq/ 100 g of soil) and humus (0.51%) with a gradual increase in values from Bir to Sugrud conditions (significant difference, $p < 0.05$). Among these indicators, the best indicator of the forest productivity of sandy soil is the content of total Potassium. Noted that the content of Potassium and exchange bases completely determined by the mineralogical composition of the parent rocks and the degree of the soil solid part dispersion, i.e., the granulometric composition.

In addition to the content of clay particles and total Potassium, the productivity of pine plantations is significantly ($p < 0.05$) affected by the thickness of the humus horizon. Other studied indicators had a lesser effect on productivity. Thus, content of silt particles, thickness of the humus horizon, and content of total Potassium are the markers of the forest growth potential of sandy soils and pine habitats. A gradual increase in their quantitative values leads to an increase in the forest lands productivity in the group Bir – Subir – Sugrud trophotopes (Table 3).

The forests of Ukraine formed by more than 30 types of trees dominated by pine (*Pinus silvestris* L.) – 33% and oak (*Quercus robur* L.) – 24%. In the Eastern Forest-Steppe of Ukraine, the main arrays of oak forests formed on watersheds, right side of river banks covered with significant thickness of loess. Oak forests in the vast majority are represented by D_2 conditions, which are replaced by D_1 conditions on the top of slopes and on the southern slopes, and in lowering are replaced by D_3 conditions.

Table 3

The markers of forest-growing potential of sandy soils by the types of forest-growing conditions

Soil type	Clay %	Humus horizon thickness, cm	K_2O, %
A			
Soddy-podzolized	4,9	11	0,03
Soddy-slightly podzolic	5,0	13	0,04
Average values	4,9	12	0,03
B			
Soddy-podzolized	6,5	18	0,04
Soddy-slightly podzolic	6,8	25	0,06
Average values	6,6	21	0,05
LSD_{05} (A_2–B_2)	0,5	3	0,01
C			
Soddy-podzolized	8,4	23	0,06
Soddy-slightly podzolic	9,8	71	0,12
Average values	9,2	39	0,09
LSD_{05} (B_2–C_2)	0,8	9	0,02

LSD_{05} – Least significant difference

The oak forests of the region are quite sparse with a developed grassy cover and formed on dark gray podzolized soils on loess (Greyic Phaeozems Albic) almost everywhere (Fig. 3).

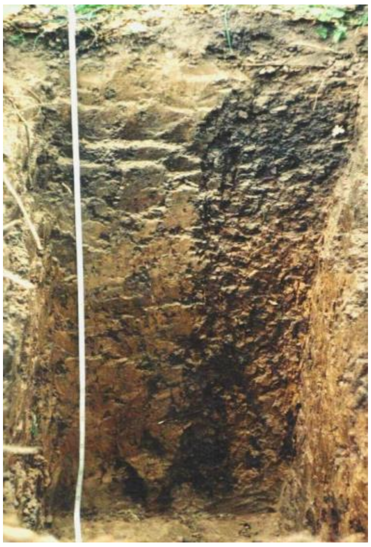

Fig. 3. Dark gray forest soil on loess

These soils characterized by an accumulative type of profile (with accumulation of humus in the upper part), which is superimposed by an illimerization process. The soils contain carbonates, which are usually concentrated in the parent rock.

According to the granulometric composition, the soils are classified as light clay soils with a high content of silt particles (diameter <0.001 mm). The average content of silt particles is 37.17±1.77% with a range of values from 13.68 to 62.83%. The content of particles with a diameter <0.01 mm averages 58.68±1.63% and ranges from 28.88% (light loam) to 90.5% (heavy clay). The ability of silty particles to absorb vaporous moisture, which becomes inaccessible to plants, is well known. In soils with a high content of clay fraction, a significant part of the moisture is in a bound state, which negatively affects the productivity of forest stands. This pattern is typical for the Eastern Forest-Steppe of Ukraine, where during the growing season there is a shortage of precipitation at high air temperatures. The productivity of oak stands is limited not only by the high (>31%) content of the clay fraction in the rhizosphere soil layer, but also by the salinization of loess rocks with Magnesium compounds (average content of Mg 1.7%).

An increase in the forest growth potential of dark gray podzolized soils, which leads to an increase in the productivity of oak stands by an average of one capacity class (from class II to class I), correlates with an increase in the thickness of the humus part of the profile (from 34 to 45 cm), of Ca^{2+} content (from 4.18 to 18.85 meq/100 g soil) and the ratio of Ca and Mg (Ca/Mg) (from 1:4 to 3:1) ($p<0.05$).

Conclusions and proposals

The content of physical clay, the thickness of the humus part of the profile, and the content of total Potassium are main diagnostic indicators in assessing the forest growth potential of sandy soils in Ukraine. Changes in parameters of the indicators determines the type of forest conditions and the productivity of pine plantations.

The granulometric and chemical composition of the parent rock are main diagnostic indicators of the forest growth potential of soils under the oak forests of the Eastern Forest-Steppe of Ukraine. Soils formed on light and medium clay loess, saturated with Calcium compounds characterized by the highest forest growth potential compared to soils formed on the heavy clay loess saturated with Magnesium.

The proposed markers characterize types of forest conditions of Alekseev – Pogrebnyak's edaphic grid providing a theoretical basis for assessing the forest growth potential of various soil types.

To increase the level of forest cover to a scientifically substantiated level (20%) on the territory of Ukraine, it is necessary to create forest plantations on an area of about 2 million hectares. To do this, it is planned to withdraw soils with a low level of fertility from agricultural circulation. It is impossible to determine the forest growth potential of these soils using the phytoindication method, i.e. according to the composition and productivity of the stand. Using the proposed package of markers, one can accurately assess both the forest suitability of lands transferred for afforestation and make a forecast of the productivity of the created forests.

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