A Method for Evaluating and Principles for Developing a Map of the Productive Potential of Agricultural Land

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Abstract. Crop production is a highly complex process. It requires comprehensive knowledge about natural phenomena and agronomic treatments that provide plans with optimal conditions for growth and development. Crop yield is influenced by a variety of environmental factors, including availability of water, temperature and light. The main anthropogenic element in crop production is the shape of the plot which is determined by the land division plan. Farmers also have to undertake the relevant measures to ensure the appropriate soil pH, soil structure, nutrient content and microbial activity. The main objective of this study was to develop a method and principles for evaluating the productive potential of agricultural land, and to compile a map presenting the productive potential of agricultural land. The main aim was achieved through detailed goals. Model evaluation indicators and criteria, the sources of information used in the evaluation process as well as the stages of and principles for developing a map of the productive potential of agricultural land were described. The results of an evaluation performed on a selected research site were presented in graphical form in the Conclusions section.

Keywords: farmland protection, productive potential of land, agricultural land.

Conference topic: Technologies of geodesy and cadastre.

Introduction

Planning and economic policies in rural areas should rely on well-premeditated strategies. The main challenge in agriculture is to reconcile the growing demands of industrialized societies with environmental protection goals (Cymerman 1993). Land is a tradeable and limited resource which needs to be regularly evaluated (Cymerman 2010). Traditional soil cultivation systems do not fully account for the variations in the spatial and environmental characteristics of farmland. Individual fields are generally regarded as areas characterized by identical soil quality, micronutrient and macronutrient levels, soil pH and nutrient abundance. The size, shape, slope and sun exposure of agricultural fields also play a very important role in crop production. In many cases, the same sowing standards, fertilization regimes and crop protection methods are applied across the entire field. Crop yield can be improved by mapping the productive potential of agricultural land. The proposed maps would contribute to the development of cohesive farming systems that meet modern agricultural engineering standards and are well adapted to variable spatial and environmental conditions.

Conducting analyses and evaluations, and documenting the results

Land comprises distinctive spatial features with unique characteristics and distribution in space. In this study, the productive potential of agricultural land was evaluated by identifying indicators that facilitate an assessment of land use features, their mutual relations in space and variable environmental factors (Podciborski 2014). The relevant indicators were selected by identifying spatial features that can be transformed in line with the existing legal regulations, the effort required to modify those features, and whether the relevant costs outweigh the anticipated results. Based on the above criteria, spatial features can be divided into the following groups:

– features that are difficult to modify – the modification requires a legal permit. These features constitute fixed elements in space;
– features that are moderately difficult to modify – the modification does not require a legal permit, and average effort has to be invested in the modification process;
– features that are easy to modify – the modification does not require a legal permit, and little effort has to be invested in the modification process.

The following elements were evaluated based on an analysis of the relevant literature, the results of expert surveys and own experiences:

– shape of plots – according to Moszczeński, the optimal plot shape is a square or a rectangle (Moszczeński 1927), whereas Hopfer recommended rectangular plots (Hopfer 1982). According to the latter, in an ideal plot,

the longer sides of the rectangle should be parallel to facilitate field operations, whereas the shorter sides do not have to be represented by straight lines, but the angles between line segments should not deviate from a straight angle by more than 30°;

– soil conservation measures in controlling erosion – erosion leads to degradation of the soil surface and deeper soil horizons as surface runoffs generated by rain, melting snow and flood waters seep deeper into the soil;

– wind force – in extreme cases, wind (aeolian) erosion can also lead to soil degradation. Aeolian erosion involves several processes: deflation – where soil particles (humus, silt, clay, sand, rock debris) are lifted from the surface and transported across various distances; corrasion – which involves the wearing away of rock surfaces by the impact and grinding action of sand particles moving with wind; and accumulation – which is the settlement and deposition of deflation material carried by wind;

– sun exposure during the growing season – plants convert solar energy into organic matter during photosynthesis. The photosynthetic efficiency and productivity of crops are determined by exposure to photosynthetically active radiation and ambient temperature. Sunlight significantly influences temperature and, consequently, the length of the growing season. Light intensity and duration of daylight are critical factors in photosynthesis. Light intensity and photosynthetic rate are bound by a linear correlation until the achievement of an optimum point (Odum 1982);

– microclimate – the type and intensity of climate changes varies in different parts of the world, and the process can have varied consequences for food production. In warm regions exposed to prolonged drought, such as the Mediterranean region, higher temperatures decrease agricultural productivity. In the cold regions of Central Europe and Scandinavia, a rise in temperature can have positive consequences because it expands the geographic range of certain crops in the northern direction;

– availability of nutrients (phosphorus, potassium, magnesium) and organic matter in soil which are essential for the development of plants during the growing season;

– soil tilth, availability of macronutrients (carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur) and micronutrients (iron, chloride, manganese, boron, zinc, copper, molybdenum) in soil. Soil tilth is the physical condition of soil which is suitable for growing crops. Tilth is not a natural feature, and it is shaped by man during many years of planned activities (Jabłoński 1997). Tilth requires rational cultivation practices and the presence of soil particles aggregated into crumps. The following agronomic measures contribute to soil tilth: cultivation of perennial legumes, organic fertilization, liming, crop rotation and drainage. Sub-standard cultivation practices lead to the gradual loss of tilth due to the degradation of soil aggregates. Tilth is the main prerequisite for soil fertility. Soil has to be abundant in essential micronutrients and macronutrients which are required for the growth and development of plants throughout their life cycle. Essential nutrients cannot be replaced with other components, and they are directly involved in plant metabolism as constitutive compounds or enzyme activators;

– soil pH – the pH of soil is expressed by the ratio of hydrogen ions H^+ to hydroxide ions OH^- in the soil solution. The pH value is a measure of soil acidity or alkalinity. It is expressed by the concentration of hydrogen ions in moles H^+ per dm^3. In practice, the pH scale is used as a more convenient measure of hydrogen ion concentrations;

– soil permeability – is the filtration capacity of soil, which is also referred to as hydraulic conductivity. Highly permeable soils, where 10 mm of water is absorbed in less than 48 seconds, include gravel, gravel mixes, rubble, crushed rock and coarse sand. Permeable soils, where 10 mm of water is absorbed in 48 to 90 seconds, include medium sand. Medium-permeable soils, where 10 mm of water is absorbed in 1.5 to 13 minutes, include fine sand. Weakly permeable soils, where 10 mm of water is absorbed in 13 to 60 minutes, include loamy and silty sand. Non-permeable soils, where 10 mm of water is absorbed in more than 60 minutes, include sandy loam, loam and clay;

– presence of point and linear infrastructure in the analyzed area – point infrastructure comprises fixed elements in space such as drainage wells and utility poles for low-, medium- and high-voltage power lines, whereas linear infrastructure comprises elements of above-ground infrastructure, drainage canals as well as natural features such as streams and rivers (Kuciński 2000).

The applicability of selected elements was verified based on the results of a survey conducted among agriculture experts. The proposed evaluation method was developed based on the random sampling scaling technique. In this approach, the evaluated land features are expressed by a single number which denotes the overall quality of the analyzed site (Babicz-Zielińska *et al*. 2008). The proposed method supports an evaluation of 10 quality criteria. Every quality criterion is described verbally and with points on a scale of 0 to 2 (Jędryka, Kozłowski 1986). The main advantage of the proposed method is that the evaluated criteria are summed up and expressed by a single number (Babicz-Zielińska *et al*. 2008). The point scale should meet the following criteria:

– every point on the scale should adequately depict the quality of the evaluated element,

– every element should be evaluated with the same number of points on a scale of 0 to 2,

– the scale should be linked with quality classes,

– every point on the scale should have a non-ambiguous definition of quality (Baryłko-Pikielna 1975).
The reliability of the obtained results is determined by the appropriate definition of quality levels and the evaluating personnel's ability to correctly interpret the results (Gawędzka, Jędryka 2001). The proposed 4-point scale consists of the following quality levels:

– level I; highest quality ($1.500 \leq x \leq 2.000$);
– level II; high quality ($1.000 \leq x < 1.500$);
– level III; average quality ($0.500 \leq x < 1.000$);
– level IV; low quality ($0.000 \leq x < 0.500$).

An evaluation chart (Table 1) was developed to facilitate the assessment and maximize its reliability. The chart contains the evaluated indicators, the relevant criteria and the assigned weights calculated based on the results of a survey. The results are expressed by a number which is included in all observations of the evaluated site to demonstrate differences in the significance of every observation.

Table 1. Evaluation chart (Source: own study)

A	B	C	D	E	F
Indicator	Weight	Criteria	Points	Score	Weight * Score
Plot shape	0.1058	Regular square shape	2	1	0.1058
		Regular rectangular shape	1		
		Irregular shape	0		
Soil conservation measures in controlling erosion	0.1042	No soil erosion	2	1	0.1042
		Soil erosion contributes to gradual land degradation	1		
		Soil erosion contributes to accelerated land degradation	0		
Wind force	0.1038	Plot screened by coniferous forests, deciduous forests or elevated land	2	2	0.2076
		Wind contributes to soil drying, but only in spring	1		
		Wind erosion leads to the loss of soil particles	0		
Sun exposure during the growing season	0.1032	Sun exposure for more than 7 hours daily	2	2	0.2064
		Sun exposure for 6 to 7 hours daily	1		
		Sun exposure for less than 6 hours daily	0		
Microclimate	0.0999	No cold-air pools	2	1	0.0999
		Cold-air pools cover less than 10% of plot area	1		
		Cold-air pools cover more than 10% of plot area	0		
Availability of nutrients and organic matter in soil	0.0994	Soil supplied with organic fertilizers	2	2	0.1988
		Soil supplied with mineral fertilizers	1		
		Monoculture / unfertilized and nutrient-deficient soil	0		
Soil tilth, availability of micronutrients and macronutrients	0.0989	The arable layer retains good structural properties over long periods of time, soil is abundant in micronutrients and macronutrients	2	2	0.1978
		The arable layer can be quickly and easily restored for productive use, soil is abundant only in micronutrients or only in macronutrients	1		
		Nutrient-deficient, degraded or devastated soil, absence of micronutrients and macronutrients	0		
Soil pH	0.0960	Neutral, pH 6.6 – 7.2, optimal cation-anion balance	2	2	0.1920
		Acidic, pH < 6.6, predominance of hydrogen and aluminum ions (liming required)	1		
		Basic, pH > 7.2, predominance of hydroxide ions	0		
Soil permeability	0.0949	Very high or high: rock debris, gravel, coarse sand, compact rock mass, variously grained sand,	2	1	0.0949

End of Table 1

A	B	C		D	E	F
Indicator	Weight	Criteria		Points	Score	Weight * Score
		Average and low: fine-grained sand, silty sand, loamy sand, alluvial-muck soil, sandstone, compact rock with minor fractures, loess-like clay		1		
		Semi-permeable and impermeable rock: loam, sediment/silt, mudstone, sandy clay, clumps, silty loam, silty marls, solid rock		0		
Point and linear infrastructure	0.0939	No point or linear infrastructure		2	2	0.0939
		Point and linear infrastructure along plot boundaries		1		
		Point and linear infrastructure inside plot		0		
4-point scale				Total		1,5013
Level I. Highest quality (1.500 ≤ x ≤ 2.000)				Evaluation class: I		
Level II. High quality (1.000 ≤ x < 1.500)				Highest quality		
Level III. Average quality (0.500 ≤ x < 1.000)				Date of evaluation: 10.06.2016		
Level IV. Low quality (0.000 ≤ x < 0.500)				Developed by: T. Podciborski		

Evaluations should be performed in line with the following principles:

− during field surveys, local variations should be determined with the use of one of the following methods: dispersed points method (based on observations of soil parameters, terrain and detail mapping), dynamic mesh model (based on the location of the main and auxiliary test pits along lines parallel to boundary strips), or the method of sequences or lines created by successive test pits (open and closed polygonal chains),
− test pits should be dug at the main or auxiliary measurement points, samples should be collected with soil sampling tubes, and the groundwater table should be determined,
− a field sketch should be developed,
− the points along boundaries separating local variation zones should be measured to the nearest 0.5 m (boundaries should be determined with a GPS device),
− the required data should be registered separately for every soil variation in the simplified evaluation chart (Table 1),
− the geodetic coordinates (X, Y, Z) of points along boundaries separating local variation zones should be determined,
− the results of land surveys and the measured data should be used to generate a map of the productive potential of agricultural land with 10 thematic layers.

Exemplary map of the productive potential of agricultural land

The research site was selected based on the presence of variations in the evaluated land parameters. This criterion was fulfilled by three plots in the municipality of Nowa Karczma in the Region of Pomorze/Pomerania (Poland). According to the Strategy for Social and Economic Development of the Kościerzyna County for 2010–2025, Nowa Karczma has diverse landforms that were created in the last glacial period, and it features terminal moraines, outwash plains and a large number of lakes spanning a total area of nearly 300 ha. Nowa Karczma is part of the Pomorze Lakeland with has a temperate climate and is characterized by rapid movement of barometric pressure areas and high variability in weather conditions. The analyzed area is situated in the proximity of the Baltic Sea which has a stabilizing effect on the differences between winter and summer temperatures. However, the effects of the maritime climate are limited, and Nowa Karczma has a more continental climate than the northern and eastern parts of the Pomorze Region. The mean winter temperature is 2 °C, and it is somewhat below the regional average. The average annual temperature is 7 °C, the average temperature in January is 3.5° and in July – 17 °C. The average annual number of hot and very hot days is 15–30, and the average number of cold and very cold days is 20–45. Seasonal differences in temperature in the Pomorze Lakeland are estimated at 20–22 °C. Total annual precipitation ranges from 400–450 mm in the eastern part of the county to more than 600 mm in the western part and the moraine upland in the northern part of the county. The number of snow cover days exceeds the regional average and is estimated at 70 days in the northern part of the county, which creates favorable conditions for winter sports. The risk of sudden storms and hail storms, and the number of foggy days, in particular in areas with no water outflow and in depressed

areas, is also higher than the regional average. The predominant winds are NW, W and SW. The average length of the growing season is 200 to 225 days. The evaluated plots have the same owner and are part of an organic farm. Farmland is ploughed. Soil tilth is average, mainly due to sloping landform. Production takes place in a crop rotation system. The plots are regularly fertilized with manure, liquid manure and slurry from organic farms. An exemplary map of the productive potential of agricultural land, developed with the use of the described indicators and criteria, is presented below. The analyzed plots were divided into 5 highest-quality segments, 4 high-quality segments, 3 average-quality segments and 10 low-quality segments. Segments characterized by high land quality had the largest share of the analyzed plots.
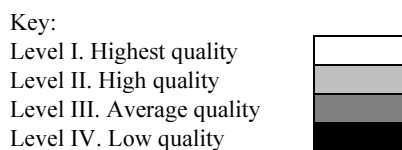

Key:
Level I. Highest quality
Level II. High quality
Level III. Average quality
Level IV. Low quality

Fig. 1. Map of the productive value of agricultural land (Source: own study)

Conclusions

Arable land is characterized by original attributes and properties that have been shaped by a regular sequence of events (Liżewska, Kecner 2003), which is why sustainable management of modern farms requires a multi-faceted approach that accounts for all aspects of bioproductive space. Modern solutions improve productivity and profitability, facilitate agricultural operations and lower costs. The proposed method facilitates an evaluation of the spatial parameters of agricultural land, and the generated maps with thematic layers can be used to:
- identify spatial elements that exert an adverse influence on land ownership/management and land use structure,
- identify the required soil conservation measures to control erosion,
- identify strongly eroded agricultural land that should excluded from agricultural production and zoned for afforestation,
- manage production processes and coordinate the use of farm machinery during field operations,
- determine the coordinates of points along boundaries separating local variation zones, which can be used in precision agriculture to change the operating parameters of farm machines and cultivation units,
- determine the direction of movement of agricultural machines and program their routes based on the identified geodetic coordinates,
- determine fertilization requirements,
- select optimal crop rotation schemes,
- determine crop protection requirements,
- develop databases and record changes in a given farm.

Disclosure statement

The authors declare that they have no competing financial, professional, or personal interests.

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