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Geostatistical model evaluation for soil tillage suitability II

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Abstract

This paper presents the development of a computer model for estimation of suitability for soil tillage in eastern Croatia. Model are based on GIS geostatistical analyses of physico-chemical data of Interpretative base of soil resources of Osijek-Baranja county, which currently accounts 24 536 soil samples with over 1,000,000 soil information. As a cartographic basis, but also a source of data were used the Croatian soil map in digital form, and the data of size and position of agricultural land units (parcels) have been taken from ARKOD. Previous model of soil tillage suitability has been upgraded and now uses seven indicators of suitability of which four are determined exactly (pH, humus content, plot size and elevation), soil type and type of wetting (automorphic and hydromorphic) are taken from the Digital Soil Map of the Republic of Croatia as and the rank of general workability which is an inherent property of each pedosystemic units. Required power or *Power Index* is calculated from the 3D function whose variable concentrations of humus and soil bulk density, while the geographical position and elevation used for estimation of the plot slope, average annual temperature and rainfall. The model calculated the average relative workability of land 59.75% (min. 35.82, max. 89.78%) and the total number of samples in the interpretive basis of land resources Osijek-Baranja County, 5.82% are in the class S1; 27.57% in S2; 66.49% in S3, and only 0.11% are in class N1 or N2, which is not suitable for soil tillage.

Key words: Geostatistical model, soil tillage, soil suitability

Introduction

Methodology of evaluation of soil suitability for specific purpose as well as for its tillage, are very complex because it must take into account a number of relevant indicators that its quality can be defined as a measurable value (Vukadinović et al., 2009). The complexity of such a methodology imposed simplification and reduction on the attributes that describe the critical properties of the soil, although neither they, in many cases, can not be directly measured. Therefore, the model includes only those indicators of the relative land suitability that are measurable and sensitive to variations in soil with relatively low analytical or measurement error (MacEwan and Carter, 1996).

The proposed model generally determines the relative suitability of agricultural land as the basis for estimating the required tractor power. Further research and development model should determine the actual power required, the type and capacity of tillage equipment for a different level of land workability, easily by measuring and comparing the performance of the same or similar equipment, or agrotechnics.

Selection of tools for soil tillage and optimum power tractors are extremely important for the effectiveness of each farm. In fact, in every system of crop production machines represent the largest single item, and almost 60% of total expenditures (Dash and Sirohi, 2008). The decision on the optimal size of the machine so it is complex because it is a critical and very risky capital investment, not only because of the high initial investment, but also a significant share of the total costs and the irreversibility of such a decision. In any system of crop production soil type, the number of operations required for each crop, crop rotation, time available and other factors are very delicate and extremely important in selection of the optimal size of the tractor and tillage equipment's. On tractor market and equipment machinery, on the one hand it is a great offer considering the type, strength, capacity, cost, etc., while on the other, should take into account climate (e.g. the variability of weather conditions), land (e.g. towing strength due to the soil type, moisture, etc.) and agricultural management requirements (e.g. timeliness for soil tillage, fertilization, planting, plant protection, soil cultivation, etc.). Therefore, investment in agricultural mechanization is still more on intuitive than on scientific-expert bases.

Though the analysis, evaluation and prediction with GIS today irreplaceable, many models of land suitability assessment based on it are still imperfect, lacking the appropriate tools for data entry and data management, and have sufficiently reliable prediction of certain soil properties, and they are still with small application value. Therefore, the focus of this paper is not only just a presentation of the conceptual aspect or inventarisation land resources, but the integration of GIS, primarily geostatistical methods and mathematical-computer model for evaluation of land suitability for soil tillage in experimental model subjected for validation in the specific conditions of the eastern Croatian (Vukadinovic et al., 2008 and 2009; Vukadinovic and Jug, 2010).

The paper describes the geostatistical computer model for evaluation of soil workability in Osijek-Baranja County, and the data were analyzed and visualized by GIS tools (ArcMap v10.1). As a cartographic basis, but also as a source of information used data of Digitad Croatian Soil Map (Bogunović et al., 1997), ARKOD and online data of State Geodetic Administration, and as a source of exact physical and chemical indicators of fertility, information about the arrangement of soil, crop rotation, organic fertilization, soil biogenity, climate, etc. are used Interpretation Base of Land Resources of Osijek-Baranja County, which was created in the Department of Chemistry, Biology and Physics of soil from Faculty of Agriculture in Osijek (http://pedologija.com.hr/karte.htm).

Methodology

As a GIS background, and as a source of information related to pedophysical properties of soils are used Digital Croatian Soil Map (DCSM). From CSM are taken types of soils and their inherent physical and chemical properties on the basis of which is ranked general land workability. Since it contains a modest number pedophysical and chemical analysis, and basic pedosystemic units are aggregated into digital form (often on inadequate way), Digital Soil Map is enough reliable. Also, as the cartographic basis are used DOF and TK25 maps (http://geoportal.dgu.hr/viewer/) and ARKOD as source of geopositioning and size of land units (production) plots (http://preglednik.arkod.hr).

Since each model is only an approximation of reality, in the evaluation of the soil workability are involved only relevant aspects of the data available from DCSM, ARKOD and Interpretative Base of Land Resources (IBLR) of Osijek-Baranja County respectively following indicators:

1) General soil workability (5 classes based on soil types, f1),
2) Soil tillage workability in the unfavorable state of humidity (3 class based on the type of soil wetting, f2),
3) Index of the required power (3D function that combines the bulk density of soil and organic matter content, f3, Graph 1),
4) Applicability of direct seeding (3 class based on the physical properties of soil, f4),

5) Index modes of soil wetting - automorphic (includes pH) or hydromorphic soil type (4 class, logical function, f5),
6) Altitude (Six classes, f6),
7) Plot (unit) size (seven classes, f7).

Tables of ranks are adjusted relative to the first version of the evaluation of the relative workability of land (Vukadinovic and Jug, 2010), and negative values of workability indicators ranks are abandoned. Table 1 shows the value and description of the ranks (more is better) and the rules for their application:

Table 1. General soil workability

General workability (f1)	rank
1) soil suitable for tillage	15
2) soil moderately suitable for tillage	12
3) limited soil suitable for tillage	10
4) soil temporarily unsuitable for tillage	5
5) soil permanently unsuitable for tillage	2
Workability in the unfavourable soil moisture (f2)	**rang**
1) tillage possible in a wide range of moisture levels	15
2) tillage possible in optimum range of moisture	10
3) tillage possible in the narrow limits of humidity	5
The possibility of direct seeding (f4, No-tillage)	**rang**
1) without restriction	10
2) after agro- and hydro technic measures of improvements	8
3) permanently restricted	5
Altitude (f6, m)	**rang**
1) <100	10
2) 100-150	8
3) 150-200	6
4) 200-250	4
5) 250-500	2
6) >500	1
Plot size (f7, ha)	**rang**
1) <1	2
2) 1-2	3
3) 2-3	4
4) 4-5	6
5) 5-10	8
6) 10-20	9
7) >20	10

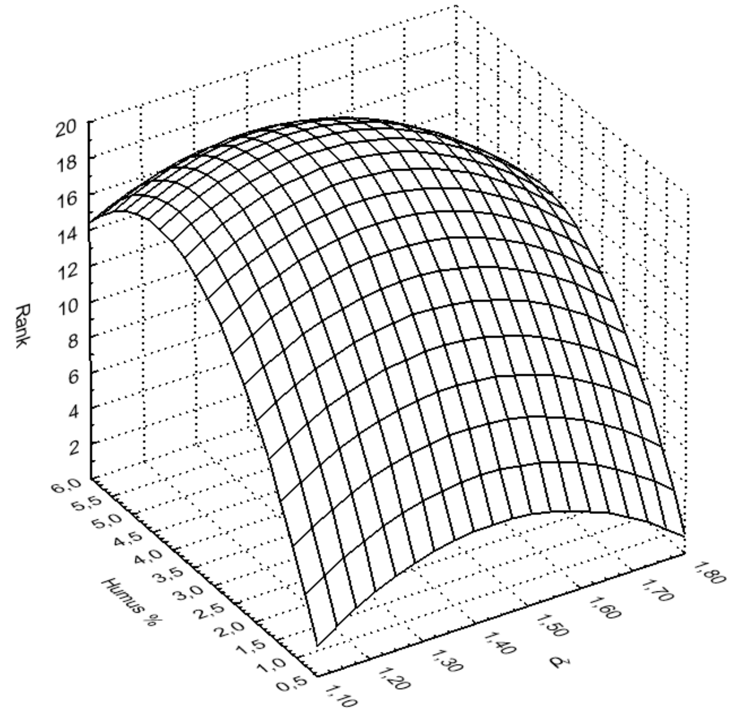
Index of the required power (*Power Index*, PwI) for soil tillage are very similar to Power Index explained in *ISPAID Database*, 2006, and is determined based on soil bulk densities (6 classes, field assessment of soil texture groups with feel method, calculated to bulk density (ρv) and exactly defined concentration of humus using 3D function (Graph 1):

$$PwI = -65.74+92.66\times\rho_v+10.54\times humus-32.14\times \rho_v^{2}-1.09\times tgr\times humus-1.08\times humus^2$$

Index modes of soil wetting (f5) including pH_{KCl} soil reaction, and is defined by the logical expression:

IF (soil tipe = automorphic and pH-KCl > 5)
THEN rank = 20
ELSE rank = 10
ELSEIF (soil tipe = hydromorpfic AND pH-KCL > 5)
THEN rank = 5
ELSE rank = 2
ENDIF

Index modes of soil wetting (automorphic ili hydromorphic) are determined according Škorić (1986).



Graph 1. Function of Index of the required power for soil tillage

Model of evaluation for soil tillage suitability has been created based on 24,536 soil samples taken in the eastern Croatian in period from 2003 to 2012 year, of which 17,681 samples from Osijek-Baranja County. Since each sample exactly geopositioning in WGS 1984 projection (lat, long, alt), with the DCSM (Bogunović et al., 1997) were obtained by overlapping layers (*intersect layer*, ArcMap v10.1) data about pedosystemic units on which they are automatically ranked general workability and other indicators of inherent soil type (type of wetting).

Thus, the geographical position, altitude, humus and pH-KCl were determined to exact laboratory analysis; the texture class is given by *"feeling method"* on the field when taking soil samples and in laboratory. *"feeling method"* are used because the DCSM of Osijek-Baranja County contains only 20 soil profiles with the needed information.

Geoposition and each plot site are taken from ARKOD which are overlapping with GIS layers. Average annual precipitation and average annual temperature for each location (plot) are calculated with regression model (Zaninović et al., 2005; Gajić-Čapka et al., 2004.). Soil type is defined with overlapping layers from DCSM and Workability model. Rankings are fitted so that the sum of the greatest value of all indicators is 100 and the expression of soil suitability for processing is always in the range 0-100, or a percentage (relative suitability).

Results and discussion

Basic statistics indicators of evaluation of relative soil workability are shown in Table 2. Results of analyses are indicate on predominantly lowland character of Osijek-Baranja County with average altitude of all analyzed samples (locations-plots) of 91.86 m. A small number of samples from the mountainous area Krndija not significantly affect the average altitude. The average size of the analyzed plots was 17.2 ha (median 5.2 ha), which clearly indicates that larger farmers often analyze their own soil and participate in the control of fertility. In fact, the situation is very bad because the ARKOD in Osijek Baranja County has a total of 113,652 plots with an average size 2,175 ha (median = 0.479 ha). Fragmentation of agricultural land in the whole territory of Croatia is much worse, so the total of 2,285,638 plots their average size are only 0.800 ha, and the median only 0.286 ha.

Table 2. Basic statistical data of modeling suitability for soil tillage

	Lat.	Long.	Alt. (m)	Temp. (ºC yr^{-1})	Precip. (mm yr^{-1})	pH_{KCl}	Humus %	ρ_v g cm^{-3}	Area (ha)	Rel. suitab. crops (%)	Rel. work. (%)
Average	45.4895	18.511	91.86	10.55	835.03	5.67	2.13	1.43	17.20	65.04	59.75
Sd	0.23	0.33	17.94	0.36	151.25	1.21	0.74	0.10	25.82	10.39	9.36
Median	45.52	18.53	87.10	10.50	856.33	5.56	1.95	1.40	5.20	66.30	57.50
Kv%	0.50	1.79	19.52	3.37	18.11	21.26	34.61	6.77	150.11	15.97	15.67
Max.	46.32	19.24	428.20	11.59	1376.27	8.23	7.70	1.70	383.21	87.34	89.78
Min.	44.87	16.86	74.70	8.09	413.16	3.16	0.32	1.20	0.00	2.50	35.82

The humus content in the studied soils was on average 2.13% (0.32 do 7.70%) with a high variability of 34.61%. Average soil bulk density (ρv) are 1.43 g cm^{-3} (medium heavy soils) with small variability, what considering the number of 30 pedosystemic units indicates unreliability of *"Feeling method"* and the needed for introduction more reliable methods for mechanical soil analysis (classical sedimentation method or fast laser method). Statistical analysis of data showed that 48.75% of the samples (11,962 out of 24,536) has a pH in KCl less than 5.5, and even 21.98% or 5,394 samples less than 4.5. Since the 7,110 soil samples (or 28.98%) have hydrolytic acidity (Hy) higher than 4.0 $cmol^{(+)}$ kg^{-1}, it is a reliable indicator for the implementation of liming, especially in the western part of the Osijek-Baranja County. In fact, reduction conditions in the soil promotes eluviation of clay in the deeper layers and deteriorate workability due to poor structure of "leached" soils, as well as the formation of impermeable barrier for water in the subsoil layer with a high risk of compacting in use of machinery, but also the formation of tillage pan (plow pan and / or disk pan).

Table 3. Distribution workability according to the number of analyzed samples

Relative workability	Number of soil samples	Percent in total (%)
S1	1.428	5.82
S2	6.765	27.57
S3	16.315	66.49
N1/N2	28	0.11

Average workability of soil in the study area was estimated by the model on 59.75%, which is between S3 and S2 class of suitability (limited to moderate suitability) with a moderate coefficient of variation (CV = 15.67%, Table 3). This estimate is significantly higher than the original, but also more realistic in relation to the initial research(Vukadinović and Jug, 2010). Specifically, negative ranking is further lowered assessment of workability hydromorphic soils that already have much lower rank to automorphic soils. It was found that in the Osijek-Baranja County has very few permanent and temporary unsuitable soils (0.11% N1 and N2), while the S3 (limited suitable) represents 66.49% of the samples, the S2 (moderately suitable), one sixth (27.57%), and excellent soil for tillage (S1, very suitable), only 5.82% (Table 3).

Osijek-Baranja County is a typical agricultural area with 59.72% percent of the agricultural area (arable land on 50.70%), a quarter are covered with forest (27.34%) and 87.06% of its area are under primary organic production. Therefore, a reliable estimation of the required traction for soil tillage, transport, the choice of tillage implements, as well as adequate tillage systems are very important from agrotechnical, and economic aspects. Geostatistical interpolation by kriging (Malvić, 2005) is limited only to the Osijek-Baranja County (Figure 1) where it is the largest number of analyzed soil samples, and all available data are very useful for the elimination of border effect. Also, the evaluation of workability was performed on all plots from which soil samples were taken for physical and chemical analysis and presented on maps of ARKOD, DOF and TK25 (Figure 2).

Table 4. Distribution of workability of land to the surface in ha

Class of workability	Area (ha)	Area (%)
< 50.0	1.723	0.42
50.1-55.0	76.178	18.40
55.1-60.0	200.924	48.53
60.1-65.0	55.717	13.46
65.1-70.0	52.639	12.71
70.1-75.0	19.695	4.76
75.1-80.0	6.814	1.65
> 80.0	320	77.29
Total	414.011	100.00
Forest	113.198	27.34
Arable land	209.886	50.70
Agricultural land	247.243	59.72
Other	53.57	12.94

Finally, it should be noted that in the paper describes an experimental version of the geostatistical computer model to estimate benefits of soil tillage suitability. Our intention is to develop a model incorporating more analytical data, especially indicators of physical-mechanical properties of the soil as well as its direct validation for specific soil conditions in smaller production areas.

Conclusions

Results of the evaluation of workability of land resources in the Osijek-Baranja County, carried out on 24,356 samples according Geostatistical-computer development model, suggest the following conclusions:

1 The model is fast and easy to use due to the implementation of the GIS, and taking the necessary indicators of the benefits of digital soil maps, ARKOD, Interpretative base land resources in Osijek-Baranja County, as well as mapping layers from the internet is automated (*intersect layer*) and enables:
   a) calculation of the relative soil workability,
   b) visualization benefits for soil tillage with thematic maps,
   c) prediction of workability with geostatistical interpolation methods and the use of other indicators of soil productivity as well as the relative suitability for crops, the expected amount of crop yield, the need for fertilization, soil conditioning, etc.,
   d) outline planning for supply of adequate machinery due to the demands of the size of the plots and power required,

2. Practical application of computer model evaluation workability of land, due to the still insufficient reliability "input" must be gradual and cautious, limited to areas where the model will be tested and then calibrated (measured) to model parameters were adjusted so that the prediction is closest reality and within acceptable error and risk.
3. Because the model is spatially oriented, comparing estimates workability of different plots (parcels) by the same machinery and the same tillage systems will probably give very good support to make the right decisions in supply and completing the tools for soil tillage.

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Figure 1. Kriging of relative land workability in Osijek-Baranja County (M 1:350.000)

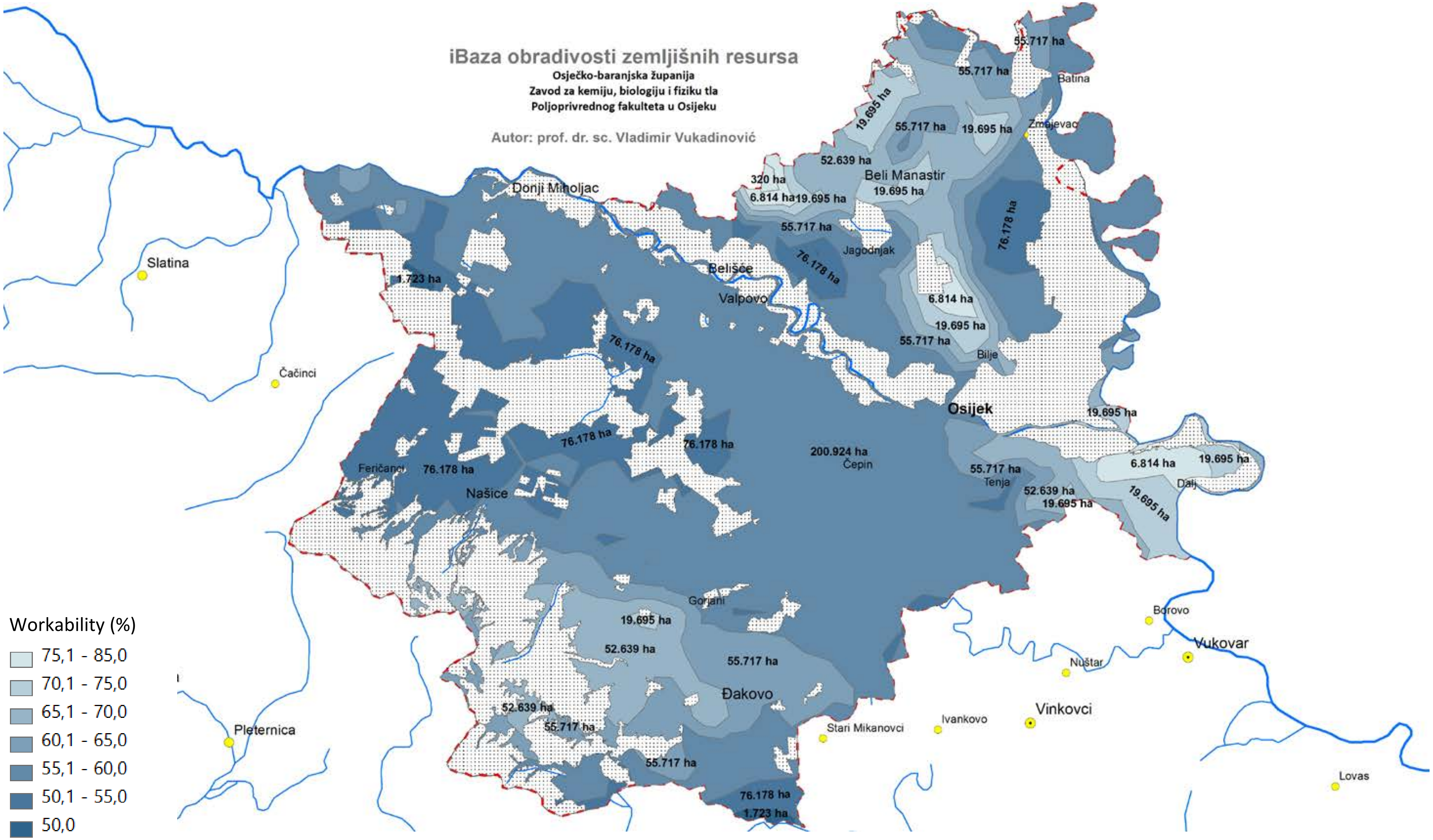

Figure 2. Relative plots workability based on ARKOD and TK25 (M 1:15.000)