GIS Modeling of Site-Specific Fertilization Requirements

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Abstract

Application of Geographic Informatic System (GIS) in land-planning management has been well known among researchers for over 40 years, and for site-specific fertilization, it started to be recognized in the early 90s. GIS modeling in agriculture helps to identify site-specific distribution of a certain characteristics, and by creating theme maps associated with a database, a visual display of numerical information for a certain field site can be created. Present study of GIS modeling of sustainable crop selection and optimization of fertilization used the database from AGRI-CONTO-CLEEN project and decision making support systems (DSS) based on agronomists expertise. The aim of our study was to determine and visually display soil properties, needs for liming and fertilization recommendations on two family farms (Vinogradci and Berak). The soils of two investigated farms differ significantly in soil properties as well as in needs for nutrient application. GIS modeling identified liming requirement only on Vinogradci site. The same site was characterized by more intensive fertilization requirement, indicating lower soil quality and lower suitability for agricultural production at Vinogradci site. Proposed fertilizing recommendations considered application of farm yard manure to decrees the application of mineral fertilizers and cost of fertilizers and to improve the soil quality, particularly on the Vinogradci farm. GIS modeling in sustainable crop selection and optimization of fertilization contribute to easier, faster and accurate decisions within agricultural production and helps to reduce negative impact on the environment.

Keywords: GIS modeling, fertilization, crop production planning

Introduction

Precision Agriculture (PA) is a whole-farm management approach that uses information technology, satellite positioning (GNSS) data, remote sensing and proximal data gathering. These technologies have the goal of optimising returns on inputs whilst potentially reducing environmental impacts (European Parliament, 2014; Buick, 1997; Pierce and Clay, 2015; Yousefi, et al., 2015; Lee, 1997). At a very basic level, precision agriculture can include simple practices such as field scouting and the spot application of fertilizers or pesticides. However, precision agriculture usually brings to mind complex, intensely managed production systems using global positioning system (GPS) technology to spatially reference soil, water, yield, and other data for the variable rate application of agricultural inputs within a field. Research is ongoing to develop or improve yield monitoring methods and equipment, determine economic and environmental impacts of variable rate application of agricultural inputs, and use remotely sensed data to make management recommendations (Nemenyi et al., 2003; Buick, 1997).

Precision Agriculture is a method of agriculture that considers changes in the land and the technology of cultivation, fertilization, spraying, and other agro-technical practices are used according to these changes. Also, they are used in local applications in a particular land. Global Positioning System (GPS) provides the possibility to attribute the spatial coordinates of the farm data. Also, it is possible to determine and record the correct position continuously. Such technology provides readily available data and a larger database for agricultural users. Geographic information system (GIS) is essential to the storage and handling of data (Buick, 1997; Lee, 1997). Stored GIS satellite images are used as a reference backgrounds to the relevant database in GIS which are being generated during field investigations. Combining the data from the field with GIS satellite images, we are able to produce theme maps. In theme maps, each data is georeferenced and stored on a specific data layer which overlaps with other layers creating a theme map. Each layer represents a unique database for a specific group of data (eg. rivers and other water surfaces are part of a one unique layer in GIS). With multiple layer combination theme maps can be created whit spatial presentation of attributes in question in addition modelling provides a logical procedure for predicting process outcomes in circumstances other than those observed. The overall impact of a farming system can be understood better, and management decisions that address both economic and environmental issues can be presented (May et al., 2007; Tayari et al., 2015; Pinter et al., 2003).

The aim of present study was to determine and visually display optimal fertilization and liming requirements in crop production at two different family farms (Vinogradci and Berak) based on soil properties. The additional goal was to determine possible connection of spatial distribution of the soil agrochemical properties, agronomic practice at farms and other land properties.

I.
Materials and methods

Soil properties Data used in present study are soil data from an EU crossboarder Croatia-Serbia project „Agriculture Contribution Towards Clean Environment and Healthy Food – AGRI-CONTO-CLEEN“. Database of the project consists of agrochemical properties of soil for many farms in Osijek Baranja County. In our study we investigated two farms with different soil properties - Vinogradci and Berak. Soil data included agrochemical properties such as: pH, hydrolytic acidity, soil organic matter content (humus), available phosphorus (AL-P_2O_5) and available potassium (AL-K_2O) determined by ammonium-lactate extraction method (AL-method).

GIS layers The GIS modelling was conducted using Arc-GIS 9.3 software (2006). We used a WMS map, a ortophoto images of Croatia from 2011 which is available on the Geoportal of State Geodetic Department Republic of Croatia. On this layer, using Arkod – system of records of land parcels in Croatia, we drew the field sites of the two observed farms and joined this polygon layer with the soil properties data layer, and by that we were obtained the georeferenced data.

Fertilizing recommendations We used Decision Support System (DSS) calculator to determine the fertilizing and liming requirements for the two farms, Vinogradci and Berak. The fertilizing calculator is available on the AGRI-CONTO-CLEEN projects webpage (www.agroekologija.com, Faculty of Agriculture in Osijek, Agroecology Department). Required input data for the DSS calculator are: planed crops, planed yields, pre-crop, properties of the soil (pH_{H2O}, pH_{KCl}, SOM content (%), AL-P_2O_5 (mg/100g), AL-K_2O (mg/100g) and hydrolytic acidity (cmol/kg)), mean values for the region were included for the texture class of the soil, organic fertilizing of the pre-crops, planed organic fertilizing and available mineral fertilizers. Data collected by the DSS were further combined with the database of the AGRI-CONTO-CLEEN project and the orthophoto map of Croatia from 2011, by which we were able to visually project fertilizing and liming requirements on a map for these two farms.

Statistics The results were processed in statistical program Minitab® Statistical Software version 15 (2007). We determined correlation, analysis of variance (ANOVA) and Tukey test to show significant differences.

Results and discussion

The two observed family farms, Vinogradci and Berak, showed significantly different soil properties. The first one, Vinogradci, was determined as acid soil and the second one, Berak had mainly alkaline soil (Table 1).

On the Vinogradci farm, 30 fields were analysed which ranged in size from 0,28 ha to 35,09 ha, with mean size of 3,6 ha. These plots were further separated into 52 field sites for more clear spatial analysis and they ranged in size from 0,28 ha to 17,95 with the mean size of 2,1 ha. Total area of the Vinogradci farm covered 109 ha.

On the Berak farm, 29 fields were analysed, ranged in size from 0,6 to 12,97 ha, with mean size 3,1 ha. For more precise spatial analysis the plots were further separated into 50 field sites ranged from 0,6 ha to 4 ha, with mean size 1,7 ha. Total area of the Berak farm covered 85 ha.

Table 1. Descriptive statistics of the investigated field sites

	Site	n	mean	StDev	Min.	Max.	p
pH(H_2O)	Vinogradci	52	5.8	0.6967	4.4	7.6	***
	Berak	50	7.2	0.972	5.7	8.6	
pH(KCl)	Vinogradci	52	4.9	0.722	3.9	7.1	***
	Berak	50	6.4	1.06	4.7	7.7	
Humus	Vinogradci	52	1.7	0.3376	1.1	2.7	***
	Berak	50	2.1	0.2515	1.6	2.8	
AL P_2O_5	Vinogradci	52	11.2	7.145	4.9	47.2	***
	Berak	50	21.2	24.89	5.6	100.0	
AL K_2O	Vinogradci	52	17.5	6.699	9.1	44.1	***
	Berak	50	24.3	4.619	15.7	35.6	

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; ns – no significant differences

For both farms and their field sites, soil properties analysis included soil pH (pH_{H2O} and pH_{KCl}), SOM (soil organic matter) content, phosphorus and potassium content determined by ammonium lactate (AL) method (Table 1).

For both farms and their field sites, fertilizing and liming recommendations were generated and significant differences in fertilizing and liming requirements were detected between the two farms. The recommendation are calculated for applying only mineral fertilizer (without farm yard manure application) and for applying both mineral and organic fertilizer (FYM).

Table 2. Descriptive statistic for the fertilizing recommendations of the two farms

	Site	n	mean	StDev	Min.	Max.	p
N kg/ha	Berak	50	93	3.642	85	105	***
	Vinogradci	52	97	4.345	90	105	
P_2O_5 kg/ha	Berak	50	74	38.59	0	130	**
	Vinogradci	52	94	27.87	0	130	
K_2O kg/ha	Berak	50	36	27.07	0	95	***
	Vinogradci	52	82	34.06	0	125	
FYM t/ha	Berak	50	33	3.607	20	40	*
	Vinogradci	52	35	3.093	22.5	50	
N kg/ha after FYM	Berak	50	42	5.345	35	65	ns
	Vinogradci	51	44	5.833	35	75	
P_2O_5 kg/ha after FYM	Berak	50	35	27.9	0	95	*
	Vinogradci	51	48	30.09	0	90	
K_2O kg/ha after FYM	Berak	50	1	4.482	0	25	***
	Vinogradci	51	20	21.64	0	60	

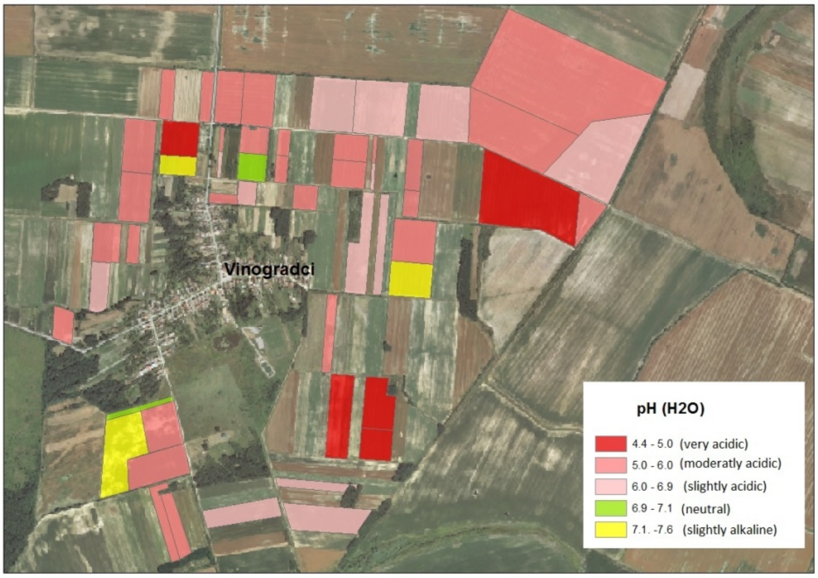
$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; ns – no significant differences; FYM: Farm yard manure

Soil analysis on farm Berak has determined the current range of acidity that varies from moderately acid to moderately alkaline soil. A total of 50 soil samples for the farm Berak, out of the 29 field sites divided into 50 plots; 6 plots belong to the category of moderately acid soils, 18 slightly acid, 2 neutral, 8 have a slightly alkaline reaction, and 16 moderately alkaline pH reaction.

Soil analysis on farm Vinogradci (52 soil samples) has determined the current range of acidity that varies from very acid to slightly alkaline soil. Out of these 52 soil samples 5 of them were very acid, 29 was moderately acid, 13 slightly acid, 2 neutral and 3 had a slightly alkaline pH reaction.

From the results of soil analysis it can be seen that Vinogradci site require liming of some sites in order to increase the pH value to an optimum and in addition they require higher dosage of fertilizers due to poor soils and lower content of main nutrients (Table 2). Therefore in the following figures are represented maps that indicate the lime and fertilizer requirement at Vinogradci location.

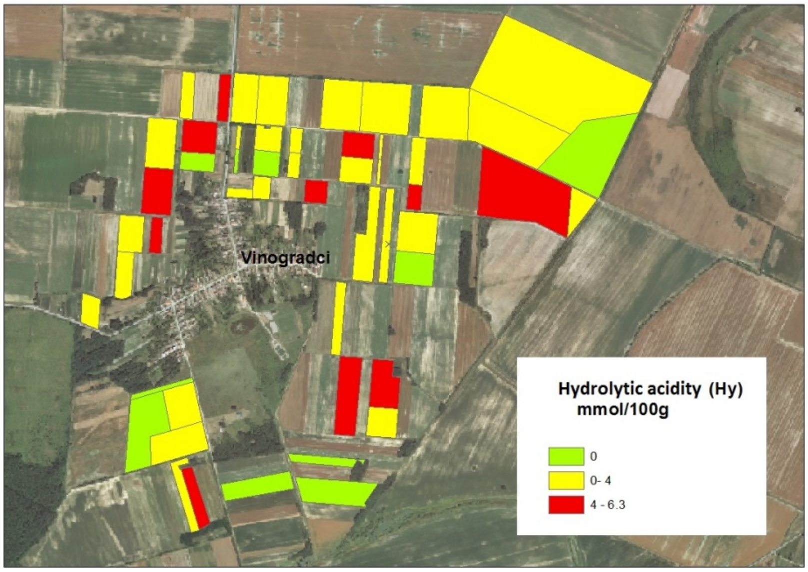
Figure 1. pH value of the field sites on the Vinogradci farm



pH reaction of the Vinogradci farm plots range from 4.4 to 7.6

Based on the results of hydrolytic acidity (Figure 2) and DSS, required amounts of liming are shown in Figure 3. The map displays the need for liming on this farm, where 5 plots out of total 52, need liming in the range of 0-10 t/ha, and 5 plots need liming in the range of 10 to 17,6 t/ha. The other 42 plots have no need for liming (Figure 3).

Figure 2. Hydrolytic acidity of the field sites on the Vinogradci farm



Hydrolytic acidity on the Vinogradci farm range from 0 to 6.3

Soil analysis determined that on Berak farm out of total 50 plots 6 of them are poor in potassium, 36 are well supplied and 8 are rich in potassium. On the other hand, on the farm Vinogradci with total of 52 plots, 6 plots were very poor, 38 were poor, 5 were well-supplied and 3 plots were rich in potassium (Figure 4).

Figure 3. Lime requierment on the farm Vinogradci (lime t/ha)

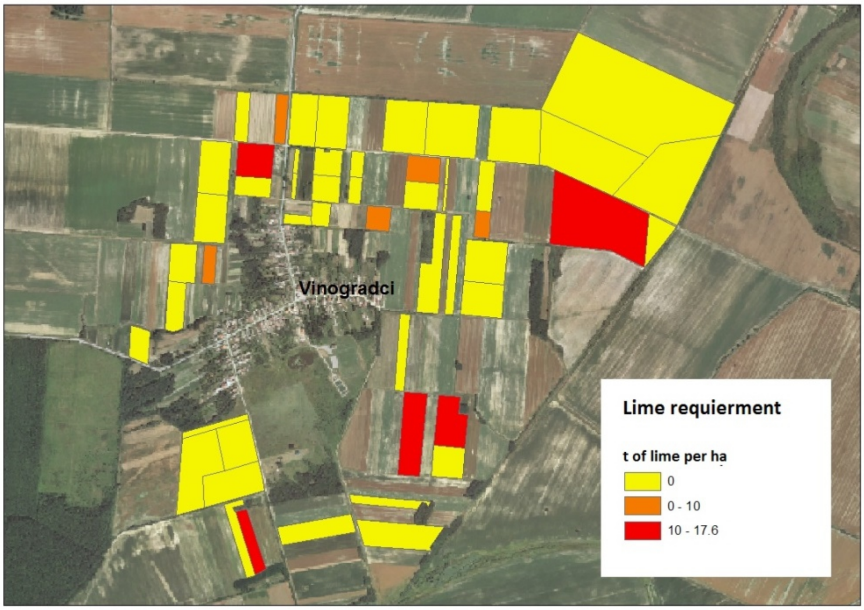
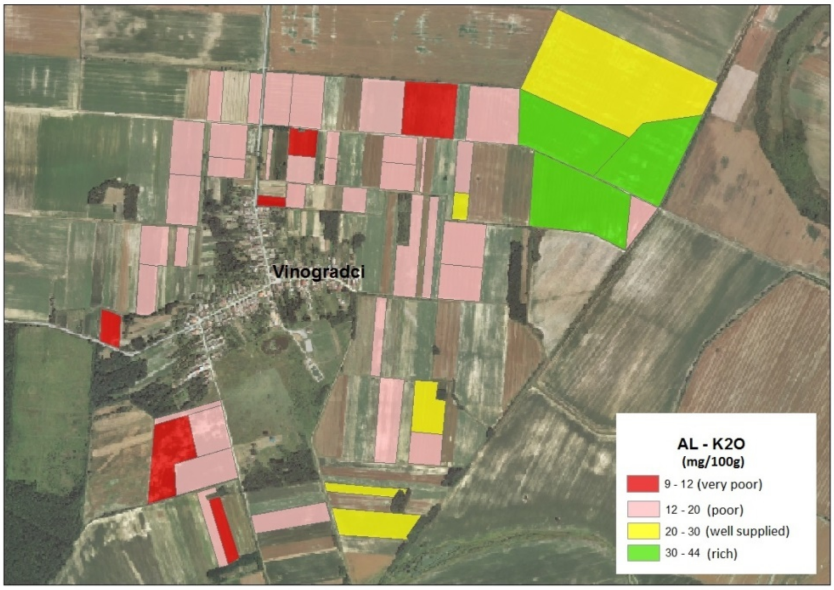


Figure 4. Potassium content (mg of K_2O per 100g of soil) on the field sites for the farm Vinogradci



According to the results of DSS, required potassium fertilization, without applying farm yard manure (FYM), on the farm Vinogradci is visualized in figure 5. The cartographic display of the need for mineral potassium fertilizer with previously applying the optimal dose of FYM is shown in figure 6. It is evident that from the total of 52 plots, without applying FYM, only 5 plots were sufficient in pottasium and only these 5 had no need for K fertilization. The recommendations for potassium fertilization for other 47 plots ranged from 35 to 125 kg/ha K_2O. These requirements are significantly lower if applying FYM was planned (Figure 6). If we apply FYM, 24 plots out of 52, so almost half of them have no need for additional mineral application of fertilizer.

According to the results of DSS calculated amounts of potassium fertilization on farm Vinogradci, combined with planned application of FYM are shown in Figure 6. The recommendations for mineral potassium fertilization were quite low. As mentioned earlier 24 of the plots needed no application of mineral fertilizer, 26 needed small amounts (20 – 55 kg/ha) and only 2 plots needed 60 kg/ha of mineral fertilization after applying FMY.

Figure 5. Need for potassium fertilization without organic fertilization

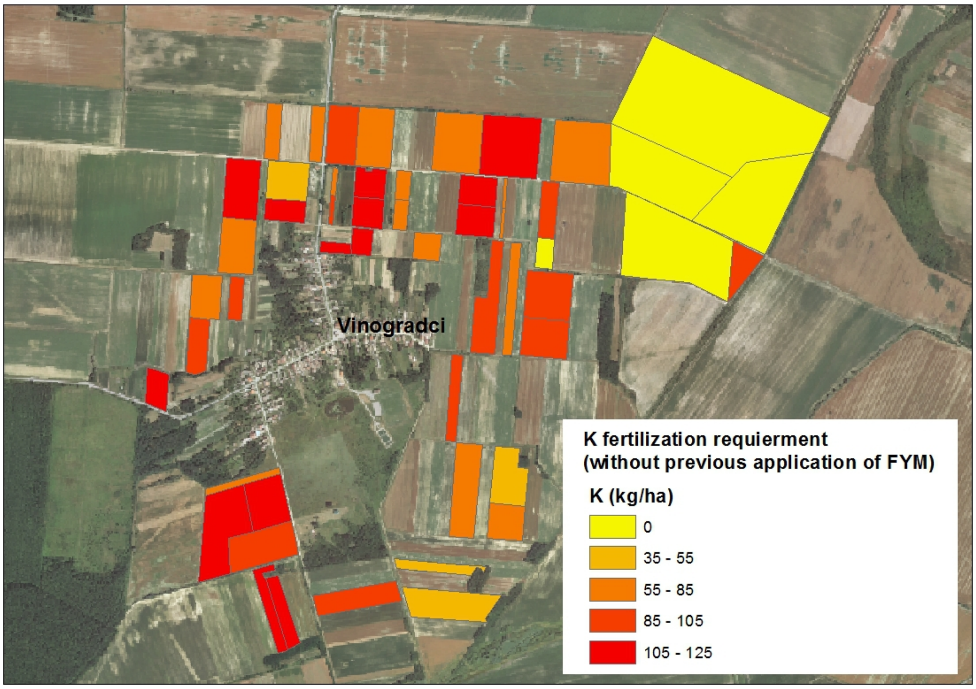
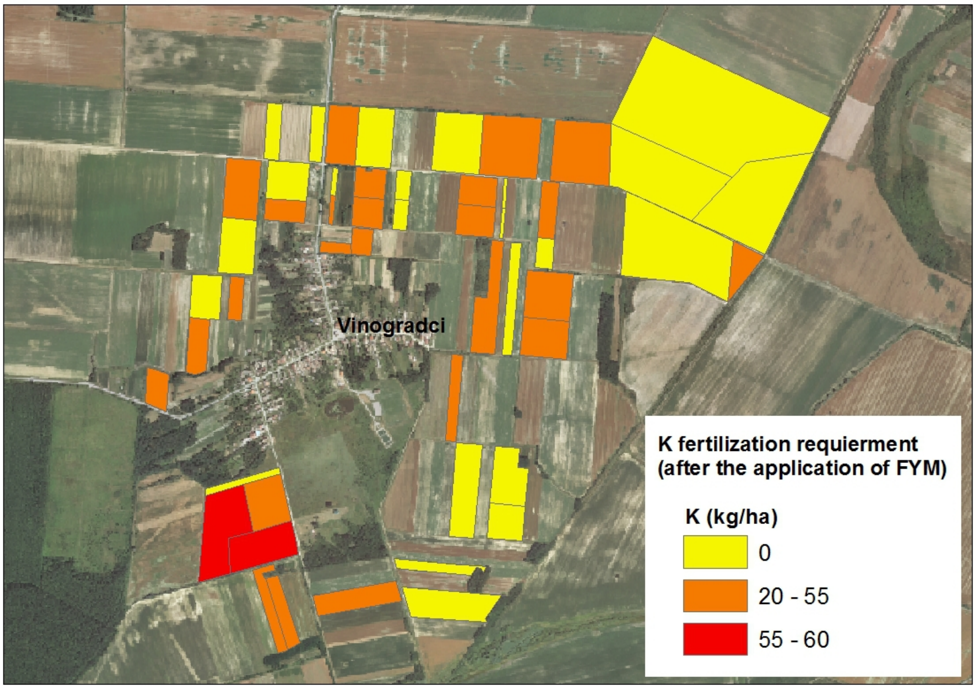


Figure 6. Need for mineral potassium fertilization after applying FMY



Comparing the values of the recommended mineral fertilization with and without FYM on both farms, it is clear that the amounts of needed mineral fertilizer are reduced if applied together with FYM (Table 2, Figures 5 and 6), whereas the quality and health of the soil would be improved and the costs of mineral fertilization would be reduced. Better choice of crops and site specific application of adequate amounts of fertilizer, FYM and mineral, in the long run would contribute to better quality of the soil and therefore crops. Farm yard manure application is important because it improves the properties of the soil, especially soil structure which then results in better water retention, greater availability of nutrients and reduces soil erosion on slopes (Škvorc et al., 2014). Also, modelling provides a logical procedure for predicting process outcomes in circumstances other than those that have been observed and by that are very versatile in their application and their users (Day et al., 2007). Numerous outcomes can be predicted as well as the positive and negative. Therefore, the more information there is about a certain plot, the better the modelling quality. There are numerous modelling systems available to farmers today that need implementation in their farming system and they represent one of the key factors of sustainable farming (Tayari et al., 2015).

Conclusion

Significant differences in soil properties of two sites were observed and there is a clear higher need of liming and fertilization at family farm Vinogradci. The importance of maps and visualization of soil properties is in visual display of the spatial distribution of the available data of the soil and finding the causes for such a patterns. Such modeling approach improves and contributes to the efficient elimination of the negative effects on the spatial distribution of the investigated properties. On the family farm Vinogradci is obvious that 13 plots have to acid pH reaction and have a high need for liming. The plots on family farm Vinogradci are less fertile compared to family farm Berak, as it was shown on maps. Possible explanation for this could be consistent FYM application on the family farm Berak making soil richer in nutrients. Based on this modeling approach and having in mind the initial pH reaction of the agricultural plots and fertilizer requirements, we should consider choosing mineral fertilizers more appropriate to acid soils at family farm Vinogradci, more combine mineral fertilization with FYM to improve the soil quality and decrease use of mineral fertilization. On the other hand, at family farm Berak should be used mineral fertilizer with acid residual reaction which are more appropriate to alkaline soils.

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