Bulgarian Journal of Agricultural Science, 21 (No 3) 2015, 554-559
Agricultural Academy

THE BENEFIT GIS TECHNOLOGIES AND PRECISION AGRICULTURE PRINCIPLES IN SOIL NUTRIENT MANAGEMENT FOR AGRICULTURAL CROP PRODUCTION

M. MARKOSKI[1], S. ARSOV[2], T. MITKOVA[1] and I. JANESKA-STAMENKOVSKA[1]
[1] *Institute of Environment and Institute of Agricultural Economics, Faculty of Agricultural Sciences and Food, 1000 Skopje, R. Macedonia*
[2] *ZK Pelagonija AD-Bitola, 7000 Bitola, R. Macedonia*

Abstract

MARKOSKI, M., S. ARSOV, T. MITKOVA and I. JANESKA-STAMENKOVSKA, 2015. The benefit GIS technologies and precision agriculture principles in soil nutrient management for agricultural crop production. *Bulg. J. Agric. Sci.*, 21: 554–559

The paper discusses the benefit of applying precision agriculture practices and GIS in soil nutrient management for agricultural crop production. As a case study the soil variability of Macedonia's largest agricultural producer ZK Pelagonija AD is taken as an example. The company is mapping out the soil variability of its land by way GIS technologies. Soil nutrient information from the fields' shows the existence of significant nutrient variability within the production units (parcel of land). Conclusions from the analysis point that the use of advanced GIS soil sampling and soil nutrient management, will lead the company to increased yields, reduced fertilizer costs and better management of the environmental impact of intensive agriculture practices.

Key words: GIS technologies, soil sampling, soil nutrient

Introduction

Most fertilizer recommendation programs contain the crucial steps of collecting representative soil samples, accurate and precise laboratory analysis, and using a well-calibrated fertilizer recommendation model to estimate fertilizer recommendations. It is often assumed that collecting a soil samples is trivial. This is not so. Obtaining accurate and representative soil samples is the basic for soils-based fertilizer recommendations (David et al., 2009). A representative soil samples is one that adequately portrays the nutrient content of the area sampled. There are several excellent papers that review various aspects of soil sampling protocols (Kitchen et al., 1990), (Brown et al., 1983). As a rule, the difficulty of obtaining a representative sample increases with variability. Fertilizing highly variable fields based on a signal composite sample can result in substantial areas that are under-fertilized and other areas that are over-fertilized. (Clay et al., 2002), proposed four specific guidelines for soil sampling fields impacted by prior management. First, crop producers need to keep track of were fertilizers containing immobile nutrients are band applied. Band application can cause small - scale variability for many years. To avoid over sampling fertilizer bands, sampling protocols for fields with residual bands should by followed. Third, whenever possible avoid soil sampling geese rows. Fourth recommendations are improved by including at least 15 to 20 individual cores in a composite sample.

Agriculture production has always been a challenging area of work and with time the challenges rise. Agricultural producers are faced with a variety of difficulties to deal with as the global situation move and change. Globalization and world trade has allowed for agriculture to become a greatly competitive market. While governments try to protect their own producers and insure food safety for its countries many debates have arisen on the matter. Ranging from regulations on quality to funding and financial incentive that impact trade and hence the producer of our food be they small or large (WTO, 2014). While matters of trade and market prices are in constant fluctuation another pressing challenge and constraint has arisen adding pressure on the producer. The pressing question of sustainability and the environmental impact of agriculture gains momentum. Many countries par-

E-mail: mile_markoski@yahoo.com; mmarkoski@zf.ukim.edu.mk

ticularly members of the European Union are implementing regulations and measures that address this issues - Council Regulation (EC) No 1698/2005. And as an important trading partner regulations and moves of EU in agriculture directly impact the trading power of Macedonia's producers. While these issues persist and yet remain to be resolved the local producers have little to do to affect these matters directly. What remains is to be consistent in adapting and increasing their own competitiveness.

One such producer of raw agricultural produces working on a large scale is ZK Pelagonija AD. It is the largest company of its kind in the country operating on more than 17 000 ha of land. Managing and producing on such scale brings its own set of challenges to overcome. Land fragmentation, machinery and production costs represent significant constraints which limit productivity. While machinery and operation costs can be altered to a higher degree, they remain bound to the most restrictive factor, which is the soil itself. The limited potential of the arable land is the main factor which dictates the majority of the practices and technologies. The land parcels are spread out at over an area of more than 300 square kilometers making production and management even more challenging. With that in mind it becomes ever more important for the company to start adopting new technologies and finding ways to integrate site specific management practices.

For the purpose of improving soil management and quality as well as cost control the company is beginning to implement advanced production practices which signify an increased presence of geographic information systems (GIS). In terms of machinery and tillage GPS guidance is being implemented in order to increase precision and reduce machinery costs. With the help of guidance systems processes such as crop protection, nutrient application and seed planting are becoming increasingly more effective. However one specific challenge remains yet to be completely addressed and that is the matter of soil variability. Apart from having to deal with localized soil variability, the company is has to deal with the same which is spread out over a large area covering a variety of geographic terrains with its' specific microclimates. This study further examines the use of GIS technologies in production processes and soil management for improved cost-benefits results of agricultural producers by adapting to new technologies. For this purpose we outline the significance of soil nutrient spatial variability and identify the challenges that ZK Pelagonija AD is faced in terms of the same. The spatial variability of soils is naturally occurring and as such can be a consequence of any number of factors. Whether it's a matter soil forming geological and pedological occurrences, or human factors such as tillage and planting or ultimately as a result of these factors' interacting (Iqbal et al., 2005).

No matter if the variability in a field is caused by natural or human factors, it must be recognized that as such it reflects on the characteristics of soil which are of value in agricultural production. These soil characteristics could physical attributes like bulk density, hydraulic conductivity, and available water content or soil chemical properties. It has been found that electric conductivity, Ca, K, Mg, Na and organic matter show notable variability within a small surface area (as small as 3 ha) inside the same field. What is of significant importance however the impact is which such variability in the soils can impact crop production. To that affect there have been studies which document how variability can reflect on the productivity potential of the fields and hence result in variability of yields even in areas of a small size (Chung et al., 2001). In a study (Mzuku et al., 2005) documents the significant relationship between spatial variability of fields and their productivity potential as it applies in site specific management zones. The authors conclude that the use of precision agriculture can be used to reliably determine the different productivity potential inherent to a specific field. And the same allows for the creation of field management zones for the purpose of more cost effective production.

Such research confirms that producers are able to identify areas in which to reduce or increase inputs to reach the optimal productivity of their fields using a variety of precision agriculture methods (Kweon, 2012). When looking into spatial variability geographic information systems have become the most readily used tools in agriculture. In a study by (Walke et al., 2012) soil mapping was used to determine suitably for cotton as a crop over are large area in India. The applicative aspect of such approaches does not change the methods of evaluating soils or the criteria for the same. The value in such applications such as in the aforementioned study is the ability to delineate such areas using required criteria as was done in the aforementioned study. According to (White, 2009) the yield response to soil variation can be mapped by acquiring data with a yield monitor attached to a mechanical harvester and importing it into a GIS.

If the pattern of yield variation is consistent from year to year, blocks of vines can be identified for which soil management and fertilizer inputs are tailored to achieve desired outcomes, according to the style of wine produced and the price point. As more data are recorded from year to year under different weather conditions, the information for decision making can be revised so that uncertainty in the predicted outcomes is decreased. Precision nutrient management is potentially a big improvement on the traditional practice of taking bulk soil or plant samples for analysis, whereby variation within a block is "averaged." Specific nutrient management allows yield and grape quality to be optimized and potentially reduces the loss of nutrients such as $N0_3$" through leaching and/or denitrification. Tony Proffitt and co-authors (2006) give more details of the concept of precision viticulture and its applications in vineyards. In order to address the issue of soil variability and increase the efficiency of inputs such as fertilizer site specific management zones are used in order the define zones within one field that are homogenous in terms of crop yield factors (Fridgen, 2000). While the factors may vary depending on crops, climates and a variety of specifics in regions, the concept of zones remains the same. For this very purpose this study takes a look at the possibility of applying GIS technologies and the potential need for a site specific management approach in the fields of Pelagonija in the Republic of Macedonia.

Materials and Methods

For the purpose of evaluating soil variability and gagging the potential of applying site specific management we examine data taken from a soil survey of 165 samples analyzed for acidity (pH levels) phosphorous (P_2O_5) and potassium (K_2O). In the laboratories at the Faculty of Agricultural Sciences and Food in Skopje, the following analyses been carried out on the soil samples: hygroscopic moisture; pH of the soil solution; humus content ant total nitrogen; carbonates content and activity lime; available nutrients (P_2O_5), (K_2O). Determinates of chemical properties in soils has been wait standard methods described by (Bogdanović et al., 1966), (Mitrikeski and Mitkova, 2013); (Džamić et al., 1996). All the samples were taken at the same depth of 30 cm using a tractor mounted mechanical probe and the same were geographically referenced using a handheld GPS tools MAMBO2-B6 by Falcom and the company's own GPS fleet management that was adapted for agriculture applications. The soil sampling was done using a soil grid approach and on average one sample was taken per 2 hectares.

Considering the size of the area which the soil survey encompassed it was largely impractical and cost ineffective to analyze all the samples which amounted to more than 600 samples. Furthermore to avoid the issue of extreme outliers within single samples all f the 165 samples analyzed are a representative composite of samples taken from a 10 ha area within each field. Lacking previous or historical data for the purpose of examining the variability of the available parameters within the fields we take two basic and descriptive approaches. Acknowledging the lack of a larger number of analyzed samples within one single field we are unable to look at the variance of the parameters using statistical tests. However for each individual field the absolute value of difference of each sample from the mean is calculated.

Difference from mean = $[\Sigma_n\text{-Par}]$ - Where Par is the parameter examined (P_2O_5 or K_2O).

Additionally a closer look is taken at one randomly chosen field for which digital maps were made using Golden Software Surfer 11. The digital map and girding was made based on the geographical references point for every sample taken and the values of the analyzed samples were placed for the appropriate references. The map was made using interpolation at an inverse distance of a power.

Results and Discussion

In order to better understand the potential benefit of further applying the site specific management approach we take a closer look at the results obtained from the soil survey conducted. Since it is impractical for the study to take a look at each field individually we first view the average difference from the mean for all fields.

When looking at the obtained average results from Table 1 we can see for instance that average differences that occur from the result of the individual samples and the mean do not show a drastic difference in value. A difference of 1.6 mg/100 g of that parameter may not necessarily be that significant on yield dependant the crops in question. On the other hand when the same values are expressed in percent and put into a perspective of large scale production the significance changes. Especially as in cases like ZK Pelagonija AD where for nutrient application the same rate across one field (parcel of land) is applied regardless of the field's size. In the autumn of 2013 the company planted seed for winter wheat on 6247.8 ha.

Knowing that an even amount of fertilizer is applied prior seeding for the entire wheat crop, a 19% variation higher or lower amounts implies a large inefficiency in application of macronutrients. However even if each average for every field is considered individually it serves little purpose in adjusting application rates in the production since the actual area of the fields needs to be delineated.

For the purpose of testing the potential value of applying GIS technologies and concepts such as site specific management we take a closer look at the data for one particular field (land parcel 803) (Table 2, Figure 1). This particular field has a surface area of 65.59 ha and was planted with winter wheat in the autumn of 2013. On the table below we see the values of the parameters for each sample of soil analyzed that represent approximately 9.4 ha of land.

If the values for each sample are examined there is a large variation macronutrient content in the soil of the field. In this case 15936 kilograms per hectare of combined synthetic fertilizer were applied. On Table 3 we see what the difference would be if application would be done according to each sample's difference from the mean in percent appropriately to the area it represents.

If the application of the fertilizer for the field would be changed to correct for the variance as shown in Table 3 there would be only a slight difference in the total amount however there would be a significant redistribution across the field. Separating the field into 6 segments with significantly different rates for application would hence be impossible.

Therefore we observe (Figures 2, 3 and 4) that based on the location of GPS referenced samples the field could practically be split into either 2 or 3 management zones which would allow for a simpler approach to exact such a practice. This map however only represents one parameter that could be addressed. Nevertheless it shows well enough that GIS software can readily be applied for the purpose of analyzing

Fig. 1. The point references of soils samples taken in the fields including the central and largest field (Parcel 803) for which more detailed map was done in order to examine the results in greater detail

Table 1
Average of all fields

Measured parameters			Diff from mean			Diff from mean, %		
pH H_2O	P_2O_5 mg/100g	K_2O mg/100g	pH H_2O	P_2O_5 mg/100g	K_2O mg/100g	pH H_2O	P_2O_5 mg/100g	K_2O mg/100g
6.87	9.09	31.23	0.27	1.60	3.30	4	19	11

Table 2
Measured values and differences for parcel 803

Field 803								
	Measured Values			Diff from mean			Diff from mean%	
Sample	pH in H_2O	P_2O_5 mg/100g	K_2O mg/100g	pH H_2O	P_2O_5 mg/100g	K_2O mg/100g	P_2O_5 mg/100g	K_2O mg/100g
1	6.6	1019	37.25	0.01	0.39	9.55	4%	20%
2	6.49	14.7	58.07	0.12	4.9	11.27	50%	24%
3	6.62	13.14	59.27	0.01	3.34	12.47	34%	27%
4	6.18	8.04	35.64	0.43	1.76	11.16	18%	24%
5	6.24	6.47	47.26	0.37	3.33	0.46	34%	1%
6	6.37	6.27	46.86	0.76	3.53	0.06	36%	0%
7	6.77	9.8	43.25	0.16	0	3.55	0%	8%
average	6.61	9.8	46.8	0.27	2.46	6.93	25%	15%

Table 3
Fertilizer application in kilograms

Fertilizer application in kilograms (phosphate)				
Sample	Difference from mean in %	Actually applied	Corrected for variation	Difference in kg
1	4%	2276.68	2383.78	107.1
2	50%	2276.68	3430.5	1153.82
3	34%	2276.68	3068.44	791.76
4	-18%	2276.68	1884.79	-391.89
5	-34%	2276.68	1520.41	-756.27
6	-36%	2276.68	1474	-802.68
7	0%	2276.68	2293.27	16.59
Total		15936.76	16055.2	118.44

soil variability and has great potential for improving management of agricultural inputs such as fertilizer.

Furthermore this approach is proving to be more effective in the long term allowing for prediction power and quantification of many soil parameters. One simple benefit is that by referencing sample points all future samples would prove more useful for comparison and changes in crop and soil behavior can be tracked more easily which has be found to be the case in number of other studies (Li et al., 2008). This is further supported by research indicating that the use of GIS with a variety of approaches and multivariate analysis could be used for prediction of a varied number of soil properties. Studies have shown that the relation between land use and moisture variability can be identified and defined (Zucco et al., 2014). In one study (Kheir et al., 2010) use a tree model for decision making and with factor weighted factor: pH, surroundings of waste areas (proximity to roads, nearness to cities, distance to drainage line, litho logy, land cover/use, slope gradient, conductivity, soil type organic matter and soil depth are able to predict zinc content distribution in soil with an estimated accuracy of 78%.

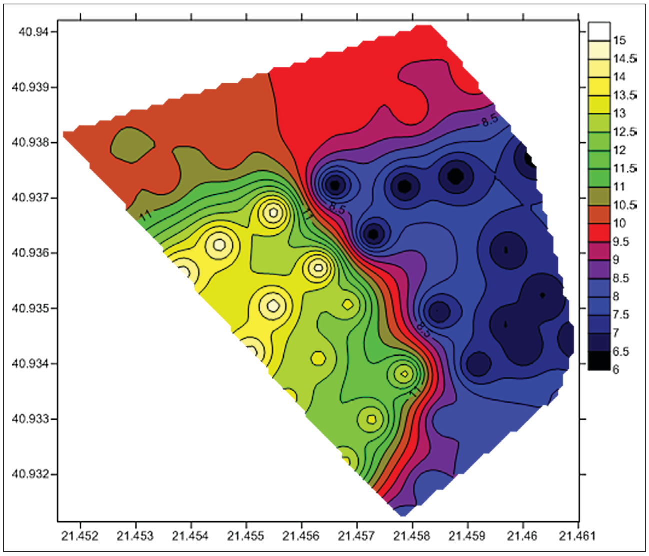

Fig. 2. Phosphate variability map

Conclusion

Results from the study show that use of GIS technologies can simplify and assist in dealing with soil variability. While it may not necessarily have a great impact on absolute amounts of inputs such as fertilizer applied it has the potential to increase the efficiency and effectiveness of the same and potentially increase yields and reduce adverse impacts on soils.

In the case of the examined field when discussing the application of phosphates it may be said that there exist opportunity costs to not adopt such approaches which may reflect negatively on production yields. While for field 803 direct costs might not change substantially, the effectiveness factor and ratio of input to yield could be improved to a fairly high degree by using approaches such as site specific management.

In order to gain the full potential that is offered by precision technology there is a need to advance the methods in

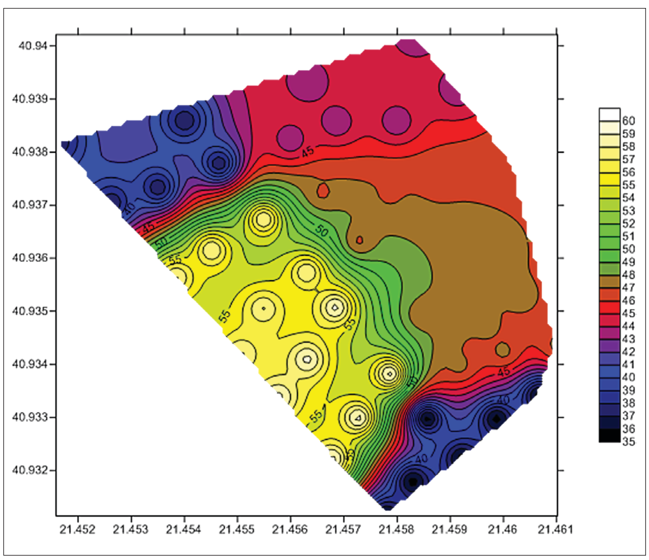

Fig. 3. Potassium variability map

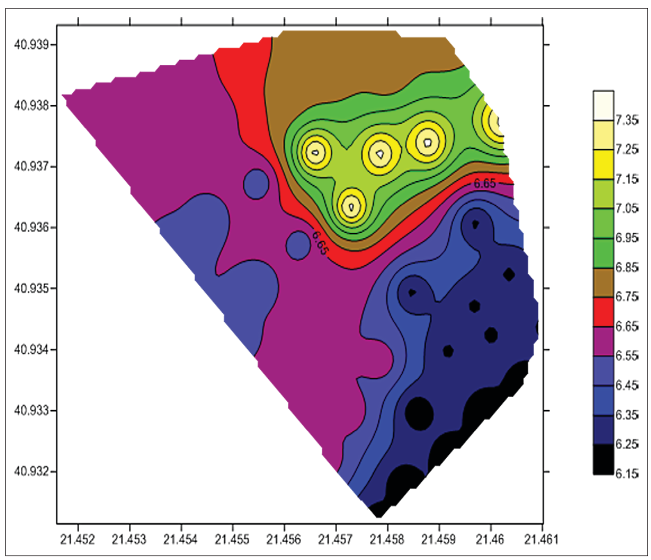

Fig. 4. pH reaction

practice to a higher level. As it stands it is not practical to depend on detailed soil sampling for the purpose improved fertilizer inputs due to costs and technical challenges. It would be necessary for producers to combine a variety of techniques such as soils sampling, remote sensing and real-time measurements of pH and electric conductivity (EC) together with expert knowledge in order to find correlations between them. If significant enough correlation can be found between factors such as EC, topographic and chemical characteristics of field it would be possible to use less costly and time consuming methods for the purpose of improved and site-specific soil management. Nevertheless the producer in this case is laying the groundwork in order to gradually adopt such practices such as the ones mentioned in this paper.

References

Bogdanovic, M. et. al (ed.)**,** 1966. Hemijske Metode Ispitivanja Zemljista. *JDZPZ*, Beograd (Sr).

Brown, J. R. and R. R. Rodriguez, 1983. Soil testing in Missouri: a guide for conducting soil tests in Missouri, Univ. of Missouri, Extension Division, Columbia, Missouri. *Exten. Cir.*, **923**.

Chung, S. O., J. H. Sung, K. A. Sudduth, S. T. Drummond and B. K. Hyun, 2001. Spatial Variability of Yield, Chlorophyll Content and Organic Matter Soil Properties in a Korean Rice Paddy Field.

Clay, D. E., 2002. Collecting representative soil samples for N and P fertilizer recommendations. *Crop Manag. Doi*: 10.1094/CM-2002-12XX-01-MA.

David, E., N. Clay, K. Kithen, C. Greeg, J. Klenjal and G. Chang, 2009. Using historical management to reduce soil sampling errors. In: GIS Application in Agricultural, pp. 53-69.

Džamić et al. (ed)**,** 1996. Prakticum iz Agrohemije, *Poljoprivredni fakultet*, Beograd–Zemun, pp. 1-190 (Sr).

Council Regulation (EC), 2014. EUR-Lex. On support for rural development by the *European Agricultural Fund for Rural Development* (EAFRD), No 1698.

Fridgen, J., 2000. Delineation and analysis of site-specific management zones. Second International Conference on *Geospatial Information in Agriculture and Forestry.*

Iqbal, J., A. John, J. N. Thomasson, P. R. Jenkins, Owens and D. Frank, 2005. Whistler Spatial Variability Analysis of Soil Physical Properties of Alluvial Soils.

Kitchen, N. R., J. L. Havlin and D. G. Westfall, 1990. Soil sampling under no-till banded phosphorus, *Soil Sci. Soc. Am. J.*, **54**: 1661.

Kheir, R. B., M. H. Greve, C. Abdallah and T. Dalgaard, 2010. Determination of potential management zones from soil electrical conductivity, yield and crop data. *Journal of environmental pollution*, **158** (2): 520-528.

Kewon, G., 2012. Delineation of Site-Specific Productivity Zones Using Soil Properties and Topographic Attributes with d Fuzzy Logic System. *IAgrE. Elsevier Ltd.*, pp. 261-277.

Li, Y., Z. Shi, C. Wu, H. Li and F. Li, 2008. Determination of potential management zones from soil electrical conductivity, yield and crop data. *J. Zhejiang Univ Sci B.*, **9** (1): 68-76.

Mitrikeski, J. and T. Mitkova, 2013. A Practice of Pedology. "Sv. Kiril I Metody" University, Faculty of Agricultural Sciences and Food, Skopje, pp. 1-164 (Mk).

Mzuku, M., R. Khosla, D. Reich, R. Inman, F. Smith and L. MacDonald, 2005. Spatial variability of measured soil properties across site-specific management zones. *Soil Science Society of America*, pp. 1572-1579.

Proffitt, T., R. Bramley, D. Lamb and E. Winter, 2006. Precision viticulture: A new era in vineyard management and wine production. *Adelaide***, Wine titles, pp. 31-39.**

Walke, N., A. K. Obi Reddy and S. Thayalan, 2012. GIS-based multicriteria overlay analysis in soil-suitability evaluation for cotton (*Gossypium* spp.): A case study in the black soil region of Central India. *Computers & Geosciences*, **41**: 108-118.

World Trade Organization, 2014. Disputes by Agreement–Agriculture. http://www.wto.org/english/tratop_e/dispu_e/dispu_agreements_index_e.htm?id=A1#selected_agreement

White, R. E., 2009. Understanding Vineyard Soils. *Oxford University Press***, pp. 96.**

Zucco, G., L. Brocca, T. Moramarco and R. Motbidelli, 2014. Influence of land use on soil moisture spatial–temporal variability and monitoring. *Journal of Hydrology.*

Received July, 2, 2014; accepted for printing January, 20, 2015.