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SITE SPECIFIC AGRICULTURAL SOIL MANAGEMENT WITH THE USE OF NEW TECHNOLOGIES

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ABSTRACT

The Soil Science Institute of Thessaloniki produces new digitized Soil Maps that provide a useful electronic database for the spatial representation of the soil variation within a region, based on *in situ* soil sampling, laboratory analyses, GIS techniques and plant nutrition mathematical models, coupled with the local land cadastre.

The novelty of these studies is that local agronomists have immediate access to a wide range of soil information by clicking on a field parcel shown in this digital interface and, therefore, can suggest an appropriate treatment (e.g. liming, manure incorporation, desalination, application of proper type and quantity of fertilizer) depending on the field conditions and cultivated crops.

A specific case study is presented in the current work with regards to the construction of the digitized Soil Map of the regional unit of Kastoria. The potential of this map can easily be realized by the fact that the mapping of the physicochemical properties of the soils in this region provided delineation zones for differential fertilization management. An experiment was also conducted using remote sensing techniques for the enhancement of the fertilization advisory software database, which is a component of the digitized map, and the optimization of nitrogen management in agricultural areas.

KEYWORDS: soil map, new technologies, fertilization, GIS.

1. INTRODUCTION

Excessive fertilizer application results in many negative environmental issues. On the other hand, deficient fertilizer application causes crop yield limitations. Thus, aspects of commercial practice have to go through serious review in order the problems currently concerning sound fertilizer application to be addressed. Precision agriculture is gaining interest worldwide because it allows site specific management practices to be applied minimizing the effect of crop growing in the environment and people. One important component of precision agriculture is soil mapping so that we are given accurate location information for the field and also its physical and chemical properties (Cambardella and Karlen, 1999). Without soil maps, there is not sound exploitation of the natural resources because modern technical knowledge (precision agriculture) cannot be used (Vavoulidou *et al.,* 2009). Moreover, the systematic inventory of soil resources constitutes a national, economic and social necessity for a country. The rational exploitation of soil resources should be supported by technical knowledge (e.g. soil studies), and should not be based entirely on the "experience" or empirical methods. The new Common Agricultural Policy of E.U. (C.A.P. reform) imposes to member states the implementation of correct agricultural and environmentally friendly practices (rational irrigation and fertilization, prevention of groundwater nitrate pollution and eutrophication of water bodies from agricultural activities among others) from the farmers, as essential conditions for their subsidy.

The objective of the current work was to develop a new digitized Soil Map that provides a useful electronic database for the spatial representation of the soil variation of a region, based on in situ soil sampling, laboratory analysis, GIS techniques and plant nutrition mathematical modeling, coupled with the local land cadastre (Thompson *et al.,* 2012). For this reason, a Soil Map study was conducted in the regional unit of Kastoria. The innovation of this digitized Soil Map system is that any user, by just clicking on a field parcel shown in this digital database (sampled for the purposes of the conducted Soil Map study), can have access on: a) identity information (the name of the grower, general information about the crop grown in the field etc), b) the physical and chemical properties of the soil and c) recommendations for sound fertilization for a number of crops (that potentially can be grown in the area) In Figure 1, an example of the output provided to the user is displayed.As it is, the system can be a useful tool in a precision agriculture program, taking into account that precision agriculture requires three main elements: a) global positioning system to know where the field is located b) latest data for the nutrient levels in the soil and c) databases for combining the above mentioned information into useful fertilizer application recommendations (Cambardella and Karlen, 1999). Thus, the operational potential of the system is huge given that it is actually an immediate mechanism for providing all the pre-mentioned useful data to farmers and agronomists (i.e. physical soil characteristic, current status of macro and micronutrients in soil etc.).

Nitrogen (N) management is the major component in a fertilizer recommendation program, because over-application of this element can result in: i) environmental pollution by nitrate contamination of the aquifers and ii) increased cost of inputs in agriculture. Furthermore, excessive N application usually renders the crop sensitive to various diseases, affects the storability and degrades the quality of the final product. On the other hand, deficient application of N results in yield reductions. The digitized Soil Map integrated with the fertilization advisory software uses quantitative equations to determine the N balance in the soil. The total N budget for the season is determined as a function of N mineralization and the soil nitrate levels measured at the beginning of the season. Nitrogen mineralization rates are determined as a function of soil texture and organic matter content (Koukoulakis and Papadopoulos, 2001; Bolger *et al.,* 2003). Nitrogen losses are estimated taking into account soil pH, soil texture and $CaCO_3$ content. Finally, the N application rate is calculated by abstracting the N that will become available with mineralization in the soil from the total crop demand. Guidelines for N placement and timing are also given by the software. Thus, a fraction of the total amount of N is supplied to the plants as basic fertilization and the remaining amount is supplied during crop growth, depending on the current expected production, plant analysis data or canopy spectral reflectance data taken by a remote sensor (Justes *et al.,* 1997). Since extensive soil analysis of the field parcels is not cost effective, the digitized Soil Map system uses the data already taken for soil properties, such as organic matter and soil texture, and real time data are inserted in the software (i.e. soil nitrate levels, plant analysis, remote sensing data and water inputs) to determine the total N balance and finally the N fertilizer doses. The databases and mathematical models regarding soil, plant analysis and canopy spectral reflectance data are constantly revised and updated by research conducted at the Soil Science Institute of Thessaloniki.

In addition to N, the fertilization advisory software, which as stated above is a component of the digitized Soil Map system, calculates the fertilizer recommendation doses of all the other macronutrients (phosphorus, potassium, calcium and magnesium) and micronutrients (zinc, iron, copper, manganese and boron) for the main regional crops. The fertilization advisory software, taking into account the physical and chemical properties in the field parcels (soil texture, pH, organic matter) found in the digitized Soil Map and determined concentration at the beginning of the season, calculates the recommendation fertilizer rates, the critical time and the manner of application (soil or foliar application). It is important to notice that despite the complicated mathematical background of the software, the integrated digital Soil Map system is a lightweight and user friendly interface.

Finally, thematic maps can be developed for the examined area (Figure 2 and 3), so that soil fertility can be assessed by choosing one parameter at a time in the digitized Map (such as pH, $CaCO_3$, EC, organic matter, soil texture, N, P, K, Mg, Zn, Fe, Cu, Mn and B) (Tziachris, 2007). This can aid in the characterization of the area for its soil fertility status or delineation of zones having saline, alkaline, acid and calcareous soils, thus allowing a land use program to be implemented (Charoulis *et al.,* 2013; Kavvadias *et al.,* 2013).

The implementation in practice of this system greatly provides opportunities for advancement of the agricultural policy currently being implemented by the Greek government, because several benefits can be realized as follows:

a) Over-application of fertilizers is eliminated based on recommendations made on the specific soil conditions of each field parcel.

b) Safety of public health can be ensured because products are produced meeting the requirements for nitrate levels in plant tissue.

c) The environment can be protected because growers are advised to follow the least polluting fertilization practice, resulting in reduced nitrate pollution of underground waters, reduced eutrophication of surface waters and increased competiveness of the agricultural products.

The aim of this work was: a) the development of a digitized Soil Map, using as a model area the regional unit of Kastoria, integrated with fertilization advisory software and b) the enhancement of the fertilization advisory software database by experiments conducted at the Soil Science Institute of Thessaloniki.

2. MATERIALS AND METHODS

A soil survey was conducted in the regional unit of Kastoria, where 630 field parcels were sampled from November 2011 to November 2012. A composite soil sample was taken to the 30 cm depth from each field parcel comprised of several sub-samples. Soil sampling took place during the period autumn-winter for two consecutive years. Soil samples were dried in the Soil Science Institute lab and analyzed for soil texture, pH, $CaCO_3$, organic matter, EC, soil nitrates, P, K, Mg, B, Mn, Fe, Cu and Zn. Global positioning system receivers were used to identify the field at the time of sampling. Orthophotomaps were provided by O.P.E.K.E.P.E. (Greek Payment Agency) and were incorporated in the software for making the land parcel GIS imaging. The fertilization advisory module was constructed using the Map Object (ESRI, California, USA), and Visual Basic 6 by Microsoft.

The digitized Soil Map software on CD is a lightweight and simple spatial application in Greek language. It combines spatial data, such as orthophotos, data from the Soil Map study and a fertilization advisory module developed by the Soil Science Institute of Thessaloniki. The software calculated automatically the fertilization requirements of the crops. It opens directly into the aerial imagery of the area and the user can click on a field parcel. Once the field parcel is chosen, the aerial photo of the field parcel is displayed along with the nutritional status of the soil to the 30 cm depth (in pdf format). The user then is prompted to the next section where the fertilizer recommendation rates of all the macro and micronutrients, according to the physical and chemical properties of the soil, are presented in one printable pdf page (Figure 1).

A second study was conducted at the Soil Science Institute of Thessaloniki experimental area in cooperation with Geonalysis SA in 2011. Triticale (x *Triticosecale* Wittmack,Vronti) and corn (*Zea mays* L., Pioneer G44) were grown under different rates of N for determining N fertilization rates with the use of a helicopter (UAV). Imaging data were collected by Geoanalysis SA with remote sensing techniques derived from a standard multispectral camera fitted on an Unmanned Aerial Vehicle (UAV helicopter). Canopy spectral reflectance measurements took place at the mid-jointing and V8 stages for the triticale and corn, respectively.The triticale experiment was set out as a completely randomized experimental design with four replicates. 30 kg N ha^{-1} were broadcasted on the 1st December 2010. Three N fertilizer levels of 0, 50 and 100 kg N ha^{-1} were applied as ammonium nitrate at planting. Thus, the experiment included three N fertilizer treatments of 30, 80 and 130 kg N ha^{-1}. Plots were sown and fertilized on the 9th February 2011.The corn experiment comprised of 16 experimental plots covering each an area of 16 by 9 m and the row spacing was 80 cm. Four N fertilizer treatments were supplied as ammonium nitrate: 0, 150, 250 and 350 kg N ha^{-1}. Plots were sown on 2nd May 2011.The Normalized Difference Vegetative Index (NDVI) was used to assess crop's N status. The NDVI values taken from the various N rates were divided by the maximum NDVI value for each replicate within each experiment to obtain the Sufficiency Index (SI).

Data collected from both studies were analyzed using the Genstat statistical package (version 11, VSN International Ltd, Oxford, UK). The unbalanced Anova procedure was used for the first study at a probability level of 0.05. Regression models were fitted for the second study based on the best-fit R^2 values for each relationship.

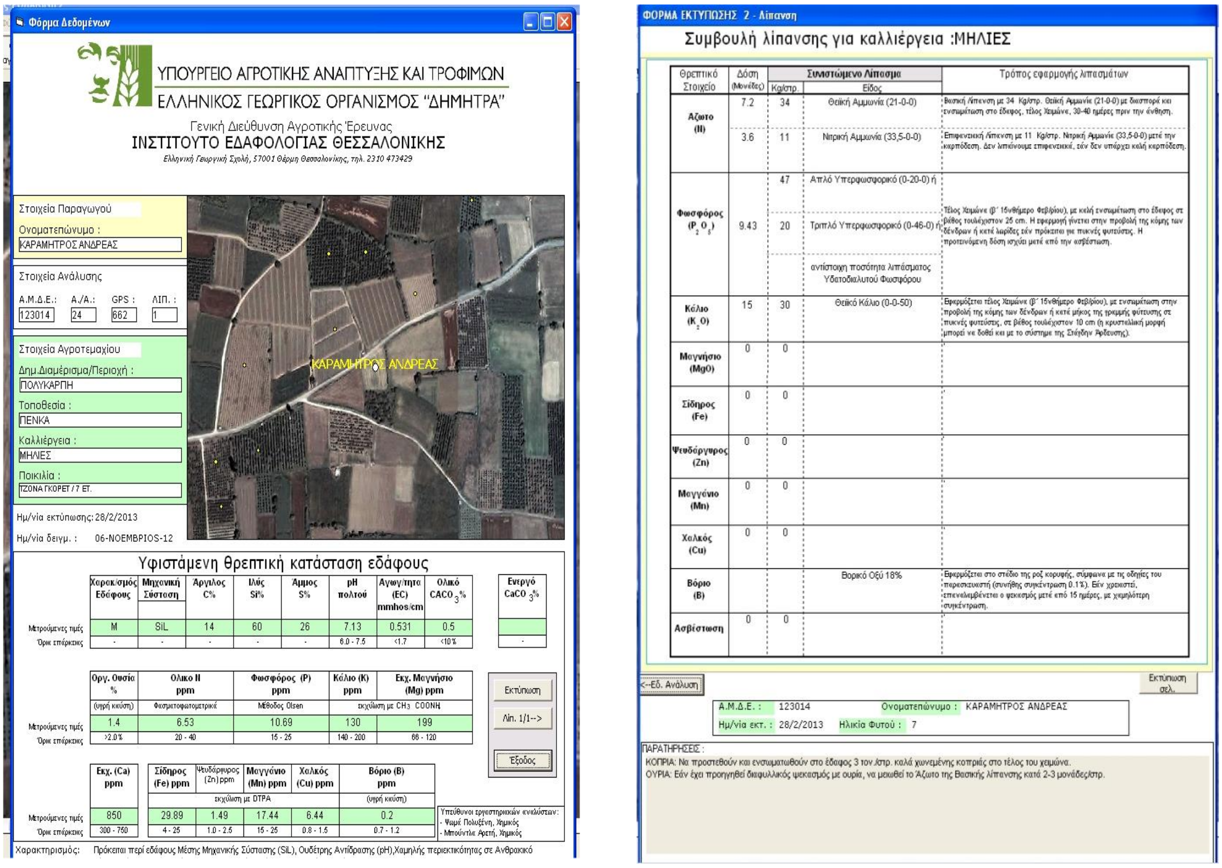

Figure 1. First and second page of the software. First page (on the left): map of the farm and information regarding farm's nutritional status according to soil analysis. Second page (on the right): fertilization advice based on the soil nutritional status which is presented in the first page.

3. RESULTS

3.1 Soil mapping in the regional unit of Kastoria

Percentages of the soils in the regional unit of Kastoria having very low, low, medium, high and very high levels of clay, pH, $CaCO_3$, EC, organic matter, NO_3, P, K, Mg, B, Mn, Fe, Cu and Zn are presented in Table 1. Generally, most of the soils in this area are medium textured, have medium acidity, are not saline or calcareous, have low organic matter levels, have adequate levels of P, Mg, Fe, B, Cu, Zn and are deficient in K and Mn. An important conclusion that was made about the distribution of exchangeable K is that soils around Lithia area had significantly more K ($p< 0.001$), with a mean value of 196.8 mg K kg^{-1} soil, compared to the other soils in the area, which had a mean value of 81.4 mg K kg^{-1} soil. This major conclusion was made by inspection of the digitized Soil Map when the K parameter was chosen to be displayed by the system, as shown in Figure 2, which proves its great potential.

3.2 Precision N fertilization with the use of an unmanned aerial vehicle as a component of the digitized Soil Map system

The second study conducted at the Soil Science Institute of Thessaloniki demonstrated that equations can be used to determine corn and triticale N requirements based on canopy spectral reflectance data (see Figure 4). Hence, algorithms were developed for translating Normalized Difference Vegetative Index (NDVI) values into appropriate N fertilizer rates using the procedure suggest by Varvel *et al.* (2007). Sufficiency Index (SI) data (standardized NDVI) were obtained by the NDVI values. If a well fertilized area in the field could be established (not yield limiting), SI values in a real time mechanism would be obtained. NDVI values taken from the rest of the field can be standardized compared to the well fertilized area and SI can be determined. SI is the ratio of NDVI values measured at field to the NDVI that were obtained from the well fertilized area. Thus, for the corn experiment, N fertilization was related to SI according to the following equation:

$SI = 0.655 + 0.002(N\ rate) - 0.000003(N\ rate)^2$, $R^2 = 0.60$ (1) (N rate in kg ha^{-1})

Also, for the triticale experiment, N fertilization was related to SI according to the following equation:

$SI = 0.939 + 0.001\ (N\ rate) - 0.000006\ (N\ rate)^2$, $R^2 = 0.69$ (2)

Equation (1) shows that yield was maximized (when the equation reached the maximum SI) at 333 kg N ha^{-1}. This is a normal estimation given that growers in Greece need to apply 320-350 kg N ha^{-1} if N is supplied to plants at two doses and this could be reduced to 170-210 kg N ha^{-1} if N was applied at 10-13 doses through drip irrigation (Karyotis *et al.* 2006). For triticale experiment according to equation (2) yield was maximized at a N application rate of 85 kg N ha^{-1}.

If remote sensing application is integrated with digitized Soil Map system, an important implication for site specific management can be realized. For example, the fertilization advisory module predicts the total N requirements for corn according to the physicochemical parameters of the field parcel, and then provides a N fertilizer recommendation split in two doses. The grower is advised to broadcast the first dose at planting. Data taken by a remote sensor from V8 to V12 corn growth stages are inserted in the digitized Soil Map system. Despite the fact that equation (1) was constructed for corn during the current study using data taken at V8 corn growth stage, equation (1) can be used from V8 to V12 corn growth stages. This is because according to Varvel *et al.*, (2007) the amount of N fertilizer recommended using one universal equation from V8 to V12 corn growth stages is within the level of range of N recommended using one equation for each growth stage. Obviously, this gives a long enough time span under commercial conditions for canopy spectral reflectance data to be collected without compromising the prediction of N application and making easier to implement remote sensing in practice. Once the SI values are calculated, the equation is solved for N, and this represents the corn N fertilizer requirement that needs to be applied as a second dose. For instance, if a SI of 0.89 was obtained, equation (1) would provide an estimate of 153 kg N ha^{-1}, which theoretically has already been supplied to plants by N application and N supplied to plants by mineralization. The equation then predicts that 180 (333-153) kg N ha^{-1} more are needed to obtain the maximum SI (and thus the maximum yield).

The same procedure can be followed to predict triticale N fertilizer requirements using equation (2).

4. FUTURE PERSPECTIVES

Taking into account the experience gained by the work so far, the system is further upgraded to become a dynamic online service (CD setup will be not needed) that can be freely accessed by the local growers, agronomists, agricultural services etc) (Figure 5). Specifically, there is currently a pilot in house application developed, where the user by inserting a password can identify on a digital map the field parcels and see online the soil data. In parallel, the system is offering the potential for updating the data from recently conducted soil analysis, keeping though in record historical data. The user can print or store a pdf file including photo of the field, the physical and chemical properties and recommendations for fertilizer applications. Further research needs to be conducted so that another advisory module can be inserted in the system regarding plant protection. A holistic approach to the crop management of the field parcels can be provided by including the plant protection component in the digitized Soil Map system. Thus, by one click on a digitized map someone could receive all the information needed for managing a crop production system. The digitized Soil Map system can also play another important key role in the precision management of agricultural areas. By using the data taken for the soil properties of the field parcels, the spatial distribution of the soil properties can be identified for all the fields in the area, allowing site specific management to be applied and precision agriculture technology to be implemented of the whole of e.g. a regional unit (Geypens *et al.,* 1999; Heisel *et al.,* 1999) The development of spatial data representation of soils using kriging interpolation techniques has been a great advancement for precision agriculture, because it has allowed efficient mapping to be developed that accurately defines the spatial variability of the physicochemical parameters of the soil (Webster and Oliver, 1992; Lopez-Granados *et al.,* 2002). Thus, even a field not sampled within the Soil Map study area can be defined by extrapolation of data from segments adjacent to the field for some physical and chemical characteristics, such as soil texture, pH, percentage of organic matter and calcium carbonate (Stevenson *et al.,* 2001). However, as mentioned above the, fertilization advisory component of the digitized Soil Map system uses these soil properties, and real time data for the nutrient levels, to determine the total N balance and also to calculate deficiencies for other nutrients.

Thus, the potential from kriging interpolation is large, considering that extensive soil analysis is not always effective. This is a renewed challenge because it allows the integrated precision management of the total area. Obviously, this can have significant impact in the local economy (reduced crop production inputs for growers) and the environmental protection (prevention of large scale pollution for the surface and underground waters by advising all the growers involved in the area to follow the least polluting practice).

*Table 1***.** Percentage of fields in the regional unit of Kastoria having very low, low, medium, high and very high levels of the parameters characterizing the soils. Critical levels are based on IFA (1992) as modified by Koukoulakis (1995) for Greek conditions

Soil property	**Critical levels (mg kg^{-1} soil)**				
	Very low	**Low**	**Medium**	**High**	**Very high**
Soil texture	LS, S*	SL*	L, SiL, Si*	CL, SCL*	SC, SiC*
%	1.0	45.2	52.4	1.4	0
pH	<5.5	5.6-6.5	6.6-7.5	7.6-8.5	>8.6
%	3.8	19.2	53.8	23.1	0
$CaCO_3$	0	0.01-2	2.1-5	5.1-10	>10
%	38.0	55.8	3.4	1.4	1.4
EC	<1.0	1.1-1.7	1.7-2.0	2.1-4.0	>4.1
%	87.5	6.3	1.4	4.8	0
Organic matter	<0.5	0.6-1.0	1.1-2.0	2.1-4.0	>4.1
%	0.5	7.2	77.4	14.9	0
P	0-5	5.1-13	13.1-15	15.1-25	>25.1
%	0	0.5	1.9	9.6	88.0
K	0-50	51-75	76-100	101-200	>200
%	31.7	26.0	7.7	20.7	13.9
Mg	<20	21-40	41-50	51-100	>101
%	2.9	16.8	4.3	19.7	56.3
Fe	<1	1.1-2.5	2.6-4	4.1-25	>26
%	0	0	0	26.9	73.1
B	<0.10	0.11-0.30	0.31-0.50	0.51-1.25	>1.25
%	0.5	9.6	23.6	61.5	4.8
Mn	<4.0	4.1-13	13.1-15	15.1-25	>26
%	5.3	63.0	11.5	15.4	4.3
Zn	<0.1	0.2-0.8	0.9-1.0	1.1-2.5	>2.6
%	0	6.3	5.8	52.4	35.6
Cu	<0.3	0.4-0.5	0.6-0.9	0.9-1.5	>1.6
%	0	0	0.5	3.4	96.2

*LS: Loamy Sand, S: Sandy, SL: Sandy Loam, L: Loamy, SiL: Silty Loam, Si: Silty, CL: Clay Loam, SCL: Sandy Clay Loam, SC: Sandy Clay and SiC: Silty Clay

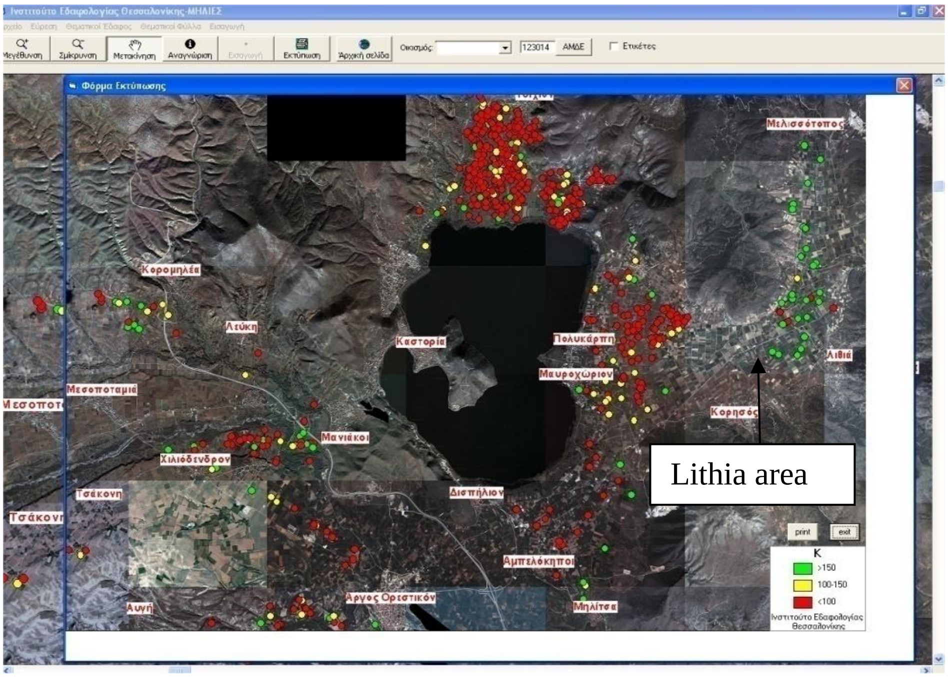

Figure 2. Map showing potassium distribution in the regional unit of Kastoria. On the right of the image, the Lithia area is displayed. The map shows that soils in Lithia area haveadequate levels of potassium (green color: high K level, >150, yellow color: medium K level, 100-150 and red color: low K level, <100)

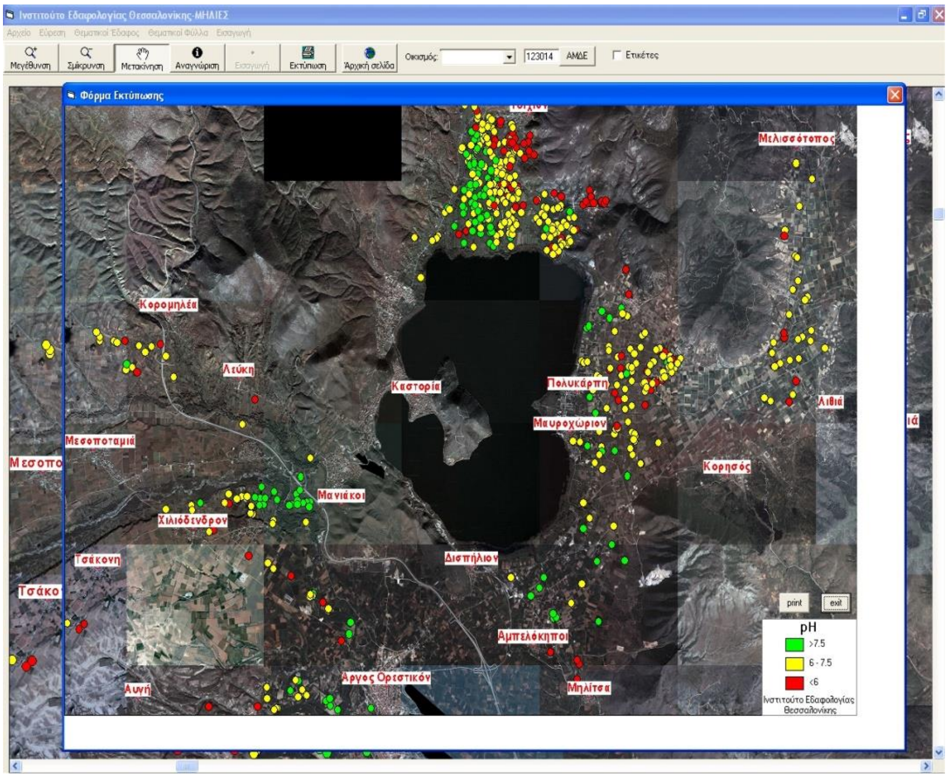

Figure 3. Thematic map of pH

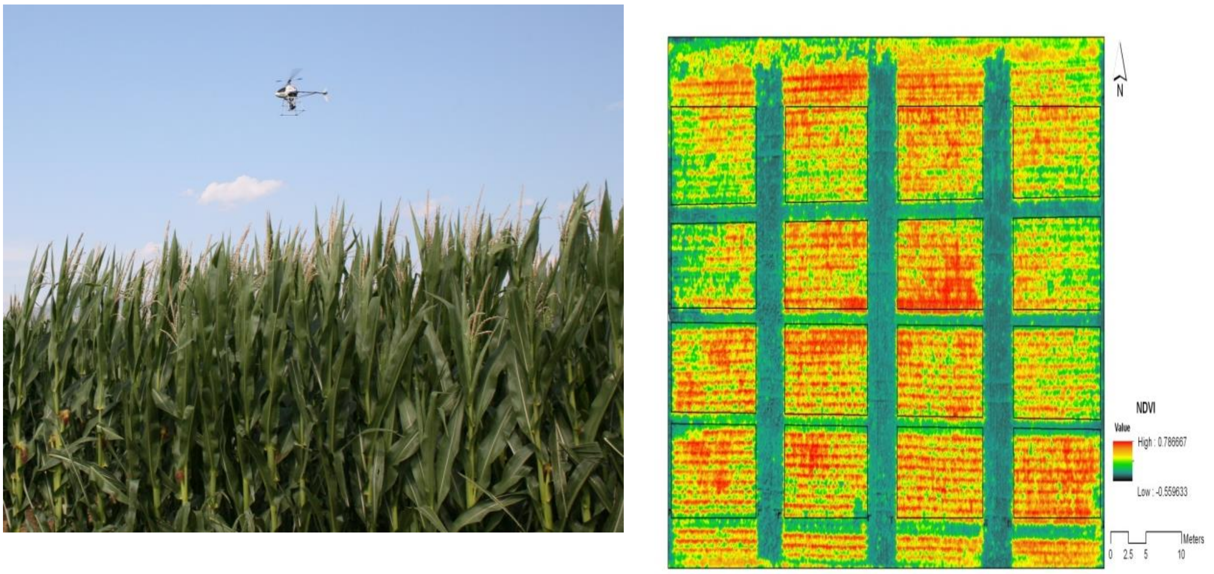

Figure 4. The unmanned aerial vehicle used for the present study on the left photo and the map of the corn chlorophyll status as determined by canopy spectral reflectance on the right photo

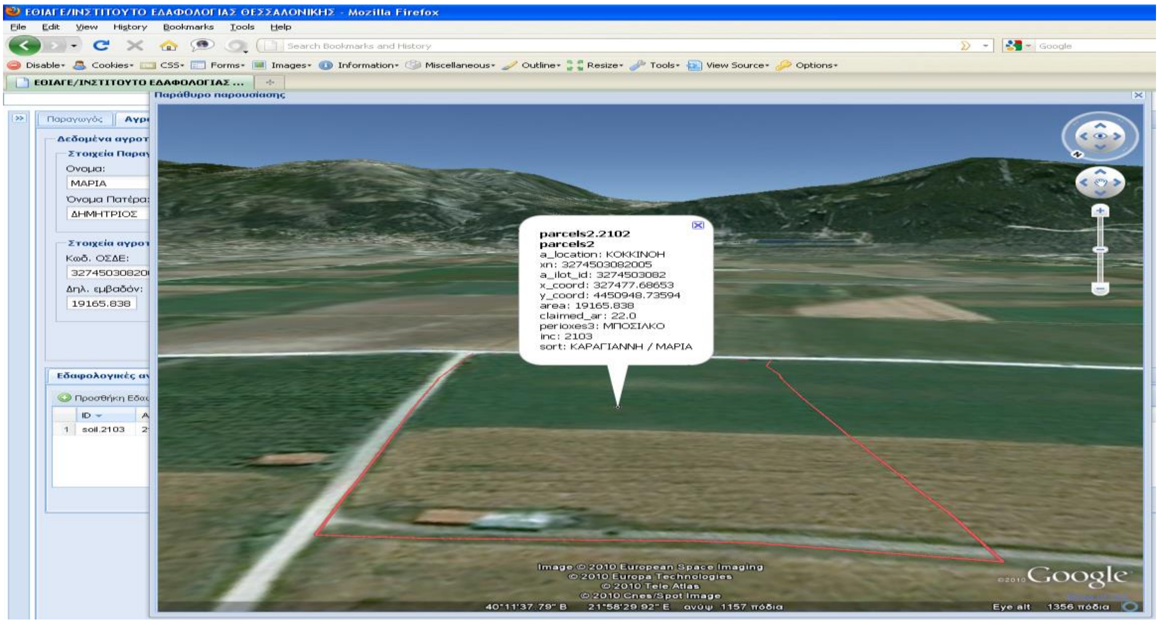

Figure 5. A 3D view of the field parcel. This application will be offered to the online user, when the system becomes an online service

5. CONCLUSIONS

Soil mapping of an area obviously has important implications for the local growers. A great example is the potassium variation in the soils of the regional unit of Kastoria, as it was shown by the Soil Map study. This obviously means that different potassium fertilization strategies can be developed in the area, providing financial earnings for Lithia growers and giving the opportunity for the other growers in the regional unit of Kastoria to increase yields and improve quality of their products. Resultsof canopy spectral reflectance data taken by the unmanned aerial vehicle are also very promising as a remote sensingcrop monitoring technique in conjunction with the digitized Soil Map system for precision management of agricultural areas. This can result in reduced N fertilization when there are observations of N sufficiency by canopy spectral reflectance without though compromising yield.

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