Optimization of fertilization recommendation in Greek rice fields using precision agriculture

Miltiadis Iatrou[1], Christos Karydas[1], George Iatrou[1], Zois Zartaloudis[2], Kostas Kravvas[3] and Spiros Mourelatos[1]

Abstract

The objective of this research was to evaluate the correlation between rice yield and soil properties for improving fertilizer recommendations. This was achieved through the application of a new precision agriculture methodology on a large experimental setup of about 115 ha in Chalastra, Greece. The methodology uses multispectral satellite images acquired during the previous cropping season for the delineation of preliminary zones, inside of which representative soil samples are extracted and analyzed and fertilizer recommendations are formulated per zone. The spatial distribution of yield performances was recorded with a yield mapper mounted on the harvester. As a result of the zone-based applications in the 2017 cropping season, the grower realized 15% increase in yield compared to the mean of the previous decade's yields, while the fertilizer inputs were reduced by 20%. Moreover, it was showed that the nitrogen added with the basal fertilization and soil magnesium were the major contributors of yield differences, whereas phosphorus and potassium needs were covered with the applied fertilization.

Keywords: *Precision agriculture, Rice, Fertilization, Soil analysis, Satellite images, Yield maps*

Introduction

Nitrogen is the most important element for rice growing, because supra- or sub-optimum nitrogen fertilization leads to reduced yields. The current commercial practice in Greece is that rice growers tend to over supply with nitrogen for pursuing maximum yields and avoid yield losses. If the yield is reduced, because of reduced fertilization, then the economic saving due to the reduced cost of inputs cannot compensate for the economic loss caused by the reduction of yield. For this reason, the growers tend to overfertilize with nitrogen. This causes a series of problems, such as the increased cost for inputs and environmental issues (Yousaf et al., 2017). Also, over-application of nitrogen can lead to reduced yields, because it causes spikelet sterility under cool weather conditions (Williams, 2010).

Another issue is that the growers tend to use an NPK 32-5-5 fertilizer (containing mostly nitrogen and providing low concentrations of phosphorus and potassium) due to

---

[1] Ecodevelopment S.A. Filiro P.O. 2420, 57010, Thessaloniki, Greece;
[2] Agroecosystem L.P., N. Moudania, Chalkidiki, Greece;
[3] NLGworldwide, Egnatia 8, Thessaloniki, Greece;

high potassium supplying capacity of many soils and the increased phosphorus availability under flooded conditions. Moreover, due to increased phosphorus availability under flooded conditions, phosphorus tends to increase in toxicity levels if it is constantly supplied with fertilization in certain areas of the field and it tends to be deficient in other areas (Khalid et al., 1976). Potassium availability is also dependent on soil texture.

Application of nitrogen using standard composites, such the NPK 32-5-5 fertilizer, results to inappropriate fertilization of the crop with potassium and phosphorus. Considering that the total amount of nitrogen supplied by broadcasting and surface application of nitrogen is high, the imbalanced nutrition of rice leads to low nitrogen use efficiency causing environmental problems.

However, the growers would be content to provide a balanced nutrition to their crops including increased levels of potassium and phosphorus (and thus accept an increase in their fertilization cost), if they were assured for obtaining increased yields. In this case, site-specific management needs to be employed for ensuring balanced nutrition with potassium. This is a novel approach as it is used to provide optimized fertilizer recommendations for rice growers based on remote sensing and yield map data.

The objective of this research was to evaluate the correlation between yield and soil physical and chemical properties in rice cultivations with a view to improve fertilizer recommendations for increased yields and lower fertilizer input costs.

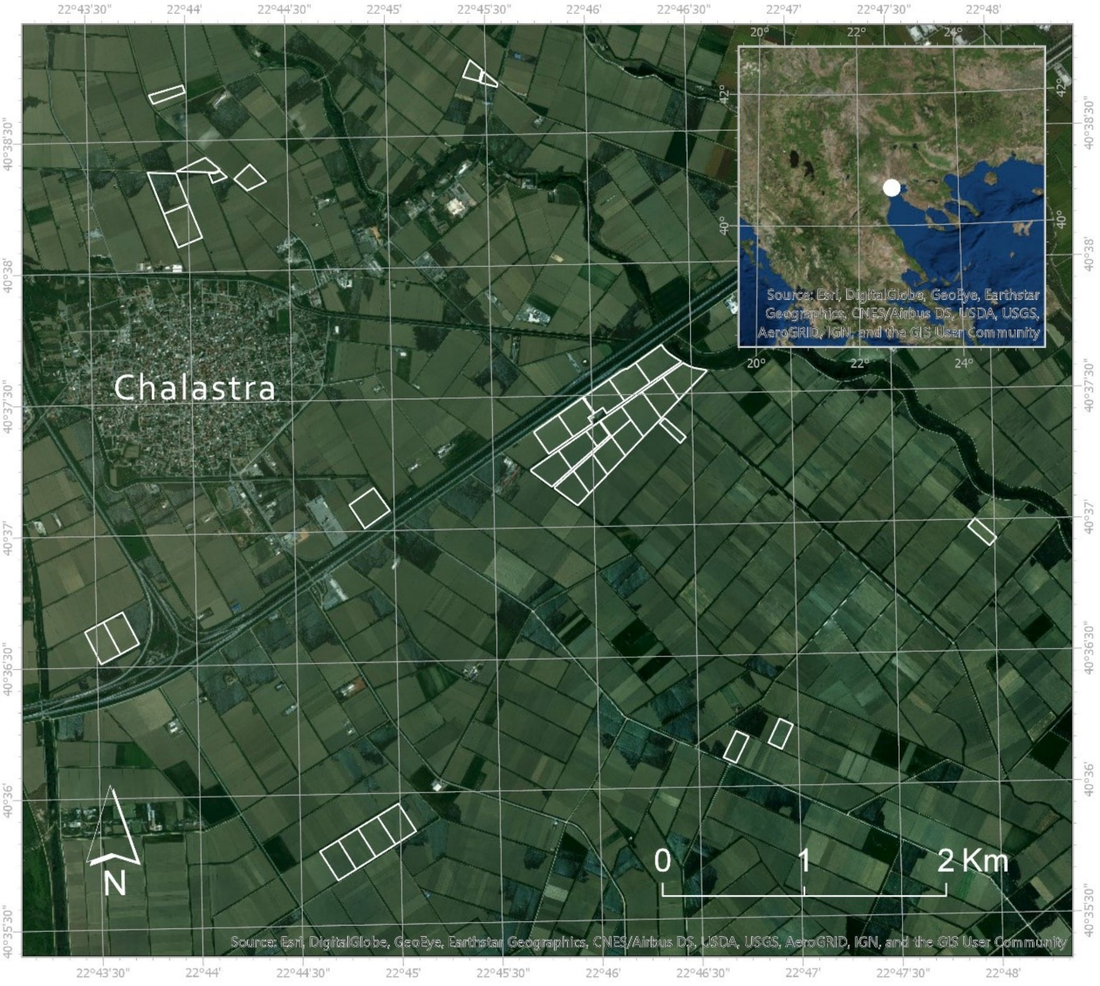
Study area and methods

Belonging to a single rice grower, the study farm is in Chalastra, a monocrop cultivation area in the Plain of Thessaloniki, Greece. The studied rice farm covered an extent of 114.8 ha in 2017, shared between 38 rice lagoons, with about the half of the extent (56 ha) concentrated in 17 adjacent fields located at the center of the area (Fig.1).

A long and a medium grain variety (*cv. Thai Bonnet* and *Ronaldo*, respectively) were water seeded from 9 to 21 May 2017. During the growing season the grower tried to maintain a 10 cm flood depth except for two weeks due to the chemical weed control, when the lagoons were drained. This flood depth usually fails to be established continuously in the Plain of Thessaloniki, as it is strongly dependent on the physical properties of the soil and water availability by the collective irrigation system of the Plain, a fact contributing substantially to nitrogen losses.

The methodology is placed in the field of precision agriculture as it realizes site-specific soil sampling to provide zone-based fertilizer recommendations.

Satellite image analysis was conducted to detect spatial variability of the physical and chemical properties of the soil within and between the rice fields. Specifically, a time series of three RapidEye images was acquired on 30 May 2015, 04 July 2015, and 26 August 2015. RapidEye was the first commercial imagery to supply an individual band in the red edge wavelengths, which is linked to critical crop parameters, such as chlorophyll content, biomass, and water content (Filella and Penuelas 1994). The RapidEye image dataset in hands was a radiometrically corrected and orthorectified product (3A-level), in the WGS84 projection, UTM zone 34. The pixel size of the images was 5 m.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1. The study farm, located in the rice cultivation area of Chalastra, Thessaloniki Plain, Greece.

A methodology appropriate for detecting local variation in image data is image segmentation, which is defined as the procedure of image division into spatially continuous, disjoint and homogeneous regions, called image objects (Blaschke 2004). The most critical parameter in image segmentation is scale factor, which influences the desired object size and shape (Kim et al., 2008). The analysis targeted at a mean object size which would correspond to management zones of about 1.5 ha, thus overwhelming the conventional grid density of 1 sample per 2 ha, suggested for cereals according to Wetterlind et al. (2008).

Image segmentation of the Rapideye image time series (a composite of the three dates) resulted in the delineation of several preliminary zones, out of which the very small or long-shaped ones were masked out. Finally, 83 zones were kept, at the centroids of which equal number of samples at a 30-cm depth were extracted. The soil extracts underwent full analysis of their physical and chemical properties in the Laboratory of the State Soil Institute in Thessaloniki (ELGO-DEMETER).

The scope of defining zones is the determination of the availability of phosphorus, potassium, calcium, magnesium and trace elements availability in the soil before the application of base dressing (Song et al., 2009). By delineating zones from the satellite images, zone areas with deficiencies of phosphorus and potassium were revealed. All the experimental plots received phosphorus and potassium, as triple superphospate and potassium sulfate respectively, at a rate which was adjusted according to the results of soil analysis.

The detected zones were simplified, in order to facilitate fertilizer applications according to the recommendations, as at the time of applications an automated guidance of the VRT system had not been established yet. The applications followed multiple runs, one per macro-nutrient (N,P,K), while the micronutrients were applied uniformly throughout the farm (Fig. 2).

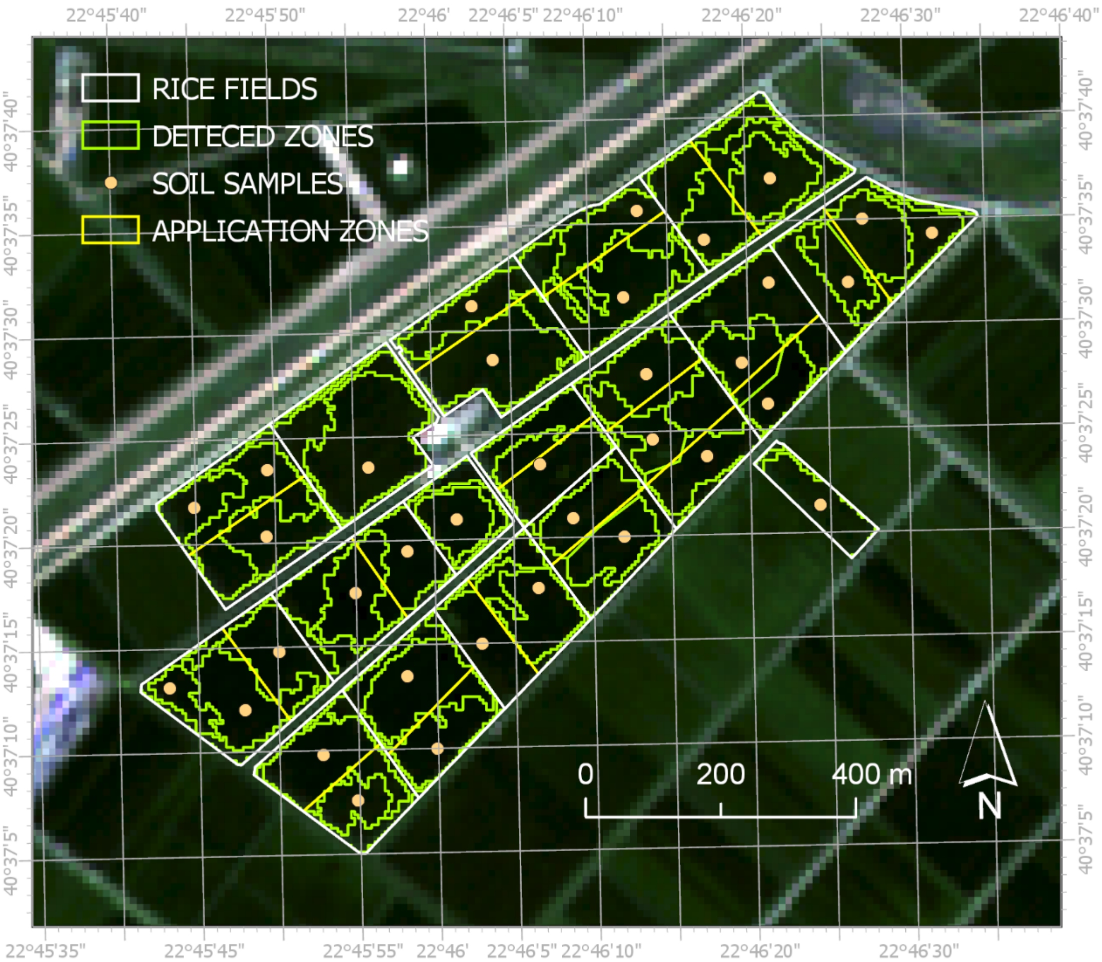
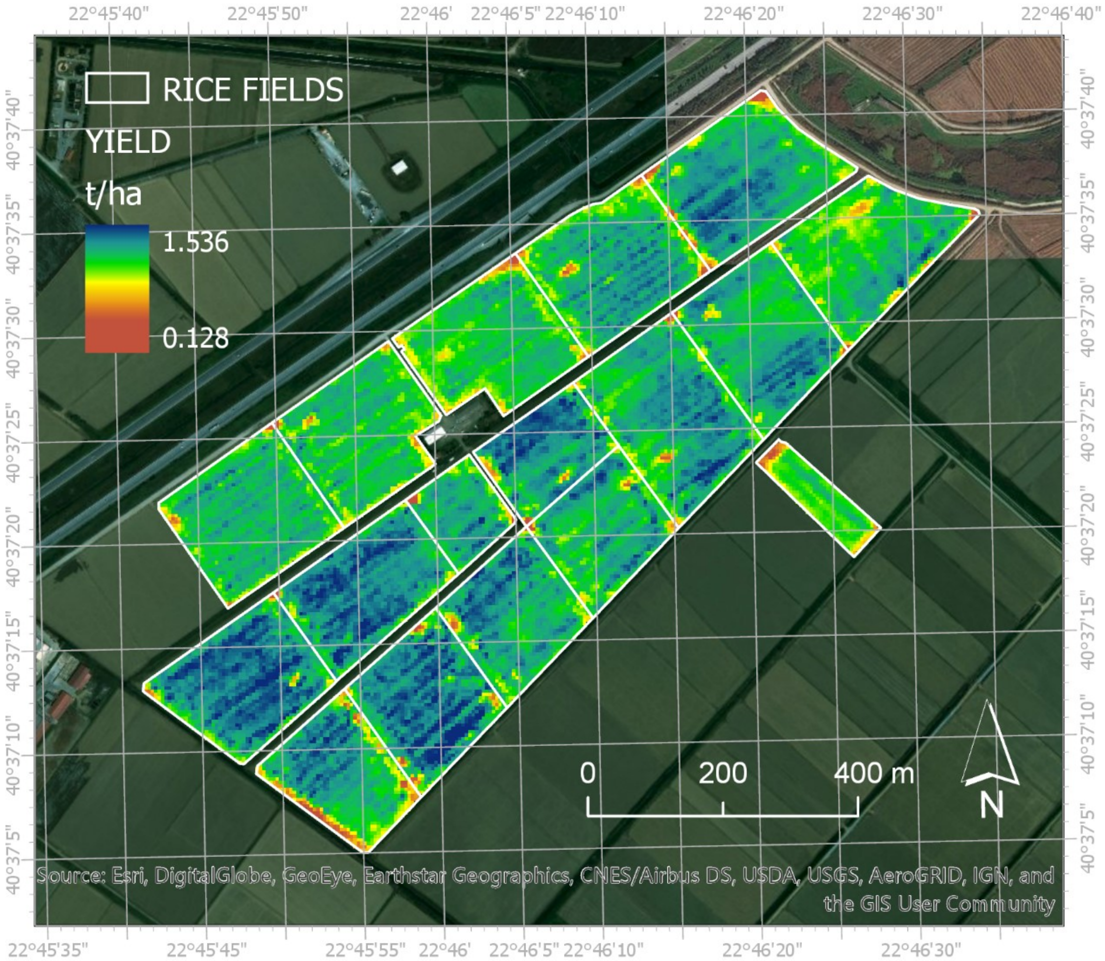


Figure 2. The central section of the study farm with the detected zones, the soil sample locations, and the application zones.

To map rice yield, a yield monitor mounted on a harvester was employed (Fig. 3).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3. Yield map derived from the yield monitor mounted on the harvester (central sector of the rice farm, 56 ha); note the extreme variance within specific fields.

To correlate the rice yield with the physical and chemical properties of the soil, multiple linear correlation analysis was used (5% probability). Regression was fitted using the Genstat statistical package (VSN International, Oxford, UK) at a probability level of 0.05. Principal component analysis (PCA) was also applied in this study to identify the factors influencing yield. PCA analysis was conducted using the R statistical software and the dimdesc function of FactorMineR package in R (Stacklies et al., 2007; Sebastien Le et al, 2008).

Results and discussion

Correlation analysis did not show significant relationship between most of the soil properties and rice yield (Table 1). These low correlations confirm data presented by other researchers, who show that linear regression between soil properties and yield cannot explain yield variability (Yanai et al., 2001; Cerri and Maglhaes, 2012). Thus, for most of the soil properties, the correlation coefficients between yield and soil properties are below 0.1. Unlike to multiple linear regression, Principal Component Analysis (PCA) defines which soil parameters are critical on rice yield. This is because the PCA simplifies the structure of a set of variables by replacing them with few uncorrelated linear combinations of this initial set of variables (Juhos et al., 2015). The soil properties and crop management practices, such as the rice cultivars, the amount of nitrogen applied at broadcasting and the amount of nitrogen applied at topdressing, were included in the PCA. The PCA shows that the four principal components (PC1 to PC4) explained 70.4% of the total variance, and the remaining components were considered less significant.

Table 1. Linear correlation matrix between yield and soil physical and chemical properties

	B	$CaCO_3$	Cu	EC	Fe	K	Mg	P	SOM	Yield	Zn	clay	pH
$CaCO_3$	-0.362												
Cu	-0.424	0.037											
EC	0.282	-0.3	-0.081										
Fe	0.118	0.013	-0.541	-0.09									
K	0.379	-0.281	-0.144	0.301	0.1								
Mg	-0.309	0.125	0.161	-0.182	0.006	-0.259							
P	-0.294	0.35	0.237	-0.473	-0.345	-0.611	0.535						
SOM	-0.248	-0.173	0.082	0.08	0.121	-0.056	0.001	-0.234					
Yield	0.056	-0.041	0.131	-0.084	-0.206	-0.068	-0.175	0.04	-0.036				
Zn	0.112	0.034	0.037	0.303	-0.156	0.231	-0.263	-0.402	0.109	-0.096			
clay	0.367	-0.161	-0.255	0.145	-0.122	-0.209	-0.636	-0.083	-0.371	0.099	0.085		
pH	0.2	-0.06	-0.141	0.63	-0.067	0.208	-0.493	-0.276	0.094	-0.23	0.331	0.295	
silt	0.098	-0.113	-0.134	-0.232	0.079	-0.199	-0.293	-0.038	-0.153	-0.026	0.194	0.438	-0.082

B: boron, SOM: Soil Organic Matter

The order of significance for the soil variables is determined by the eigenvalues presented in Table 2. The PC1 shows that the high weighted variables (factor loading ≥ 0.3) for PC1 consist of sand, clay, bulk density and magnesium. The dimdesc function was applied for identifying the most significantly associated variables with the principal components. Table 3 shows that yield was positively and highly correlated with magnesium, which was a not expected finding because magnesium exceeded 100 ppm in all the soil samples analyzed. Since, nitrogen, phosphorus and potassium were supplied to cover crop requirements according to soil test results, these soil properties were not considered so high weighted as magnesium from the PCA and the dimdesc function. The fields chosen for implementing the current work present a peculiarity compared to other fields in the plain of Thessaloniki, because they contain low magnesium and $CaCO_3$ levels, despite that they have high pH levels, and thus yield is responsive to magnesium content in soil. This is an important finding, because magnesium must be considered as fertilizer input at specific zones of this field.

Table 2. Component loadings and percentage of total variance explained for the first four principal components.

Variable	PC1	PC2	PC3	PC4
Yield	0.23	-0.18	0.17	**-0.35**
Broadcasting	0.23	-0.11	0.15	0.26
Topdressing	-0.11	0.00	-0.16	**-0.55**
sand	**-0.31**	-0.21	0.15	0.07
clay	**0.30**	0.17	0.17	0.19
silt	0.15	0.12	**-0.32**	-0.27
Cultivar	-0.27	0.17	-0.16	**0.33**
pH	0.23	**-0.32**	-0.03	-0.05
EC	-0.19	**0.30**	-0.02	-0.18
SOM	0.21	**0.33**	-0.06	0.07
CaCO3	0.22	0.14	-0.23	-0.02
Bulk Density	**-0.32**	-0.29	0.05	-0.07
N-NO3	-0.09	-0.09	-0.05	0.14
P	-0.16	**0.37**	0.24	-0.12
K	0.22	**0.34**	0.19	0.09
Mg	**0.34**	-0.17	-0.05	0.09
Fe	-0.01	0.21	**0.44**	-0.26
Zn	-0.16	-0.07	**0.41**	-0.08
Mn	0.19	-0.22	**0.34**	0.04
Cu	0.14	0.13	0.15	-0.14
B	0.06	-0.03	-0.29	-0.13
N	0.20	-0.15	0.04	-0.27
Cumulative percentage variance explained (%)	32.47	49.23	60.41	70.4

Broadcasting: Total nitrogen applied at broadcasting; Topdressing: Total nitrogen applied at topdressing; N: total fertilizer nitrogen

Table 3. Correlation coefficients and p-values of the variables which are significantly correlated to the principal dimensions according to the dimdesc function.

Dim.1		
	correlation	**p-value**
Mg	0.90	2.31E-18
clay	0.77	1.43E-10
Broadcasting	0.62	2.96E-06
pH	0.61	4.63E-06
Yield	0.60	7.24E-06
CaCO3	0.55	5.67E-05
N	0.54	7.65E-05
SOM	0.52	1.69E-04
K	0.50	2.53E-04
Mn	0.48	5.09E-04
silt	0.33	2.29E-02
Cu	0.30	4.06E-02
NO_3_N	-0.28	4.99E-02
Zn	-0.44	1.88E-03
P	-0.50	3.21E-04
EC	-0.51	2.36E-04
Cultivar	-0.70	3.47E-08
sand	-0.75	6.87E-10
Bulk Density	-0.78	5.99E-11

Dim.2		
	correlation	**p-value**
EC	0.66	3.67E-07
P	0.63	1.91E-06
SOM	0.60	6.80E-06
K	0.59	1.23E-05
$CaCO_3$	0.34	1.66E-02
silt	0.32	2.51E-02
Cultivar	0.32	2.88E-02
Yield	-0.32	2.77E-02
sand	-0.39	5.98E-03
Mn	-0.50	2.58E-04
Bulk Density	-0.51	1.99E-04
pH	-0.62	2.28E-06

Principal component analysis is presented in Fig. 4. The positively correlated variables are grouped together, and the negatively correlated variables are grouped on opposed quadrants. The size of the arrays measures the importance of the variable in each dimension. The clay content, nitrogen applied at broadcasting, pH, $CaCO_3$, total nitrogen applied for the season, organic matter, potassium, manganese, silt and copper were positively correlated with yield, as it is also shown in the variable correlation plot. The clay content had a significant effect on yield because clay soils had reduced water infiltration rates, and thus saved more nitrogen compared to sandy soils (Sharma et al. 2002; Linquist et al. 2015). Furthermore, the more nitrogen applied at transplanting the higher yield was obtained at harvest. This trend was not confirmed with topdressing nitrogen. Figure 4 also shows that there is a positive correlation between pH, $CaCO_3$ and yield, despite that it is known that phosphorus and micro nutrient availability is reduced at highly calcareous soils (Hopkings and Ellsworth, 2005). However, this correlation can be explained by the higher availability of magnesium at soils having high calcium carbonate content. The organic matter was positively correlated with yield, which was an expected finding.

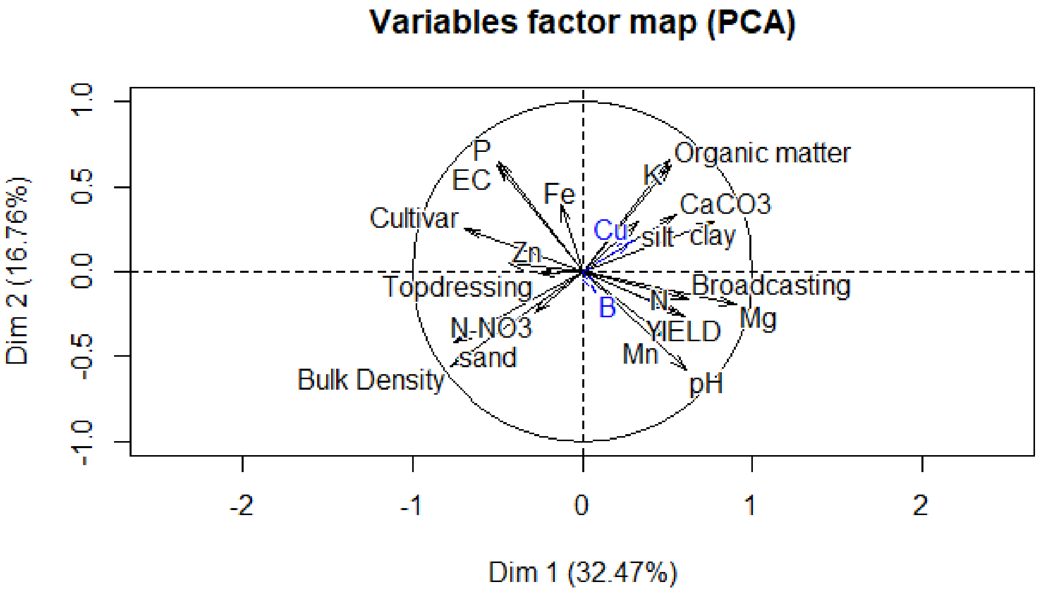


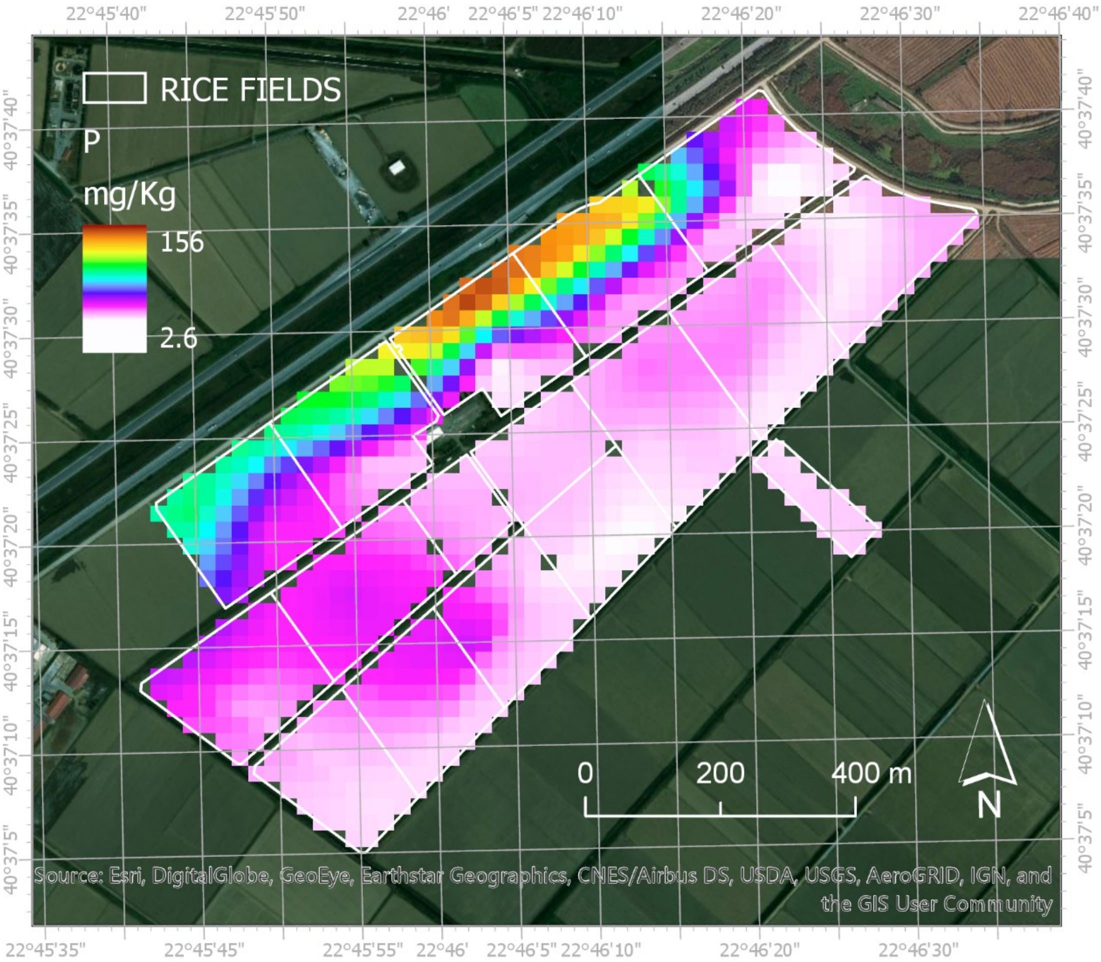
Figure 4. Correlation plot of the yield factor, the soil attributes and the crop management practices.

Despite that potassium was adequate for many zones, potassium application had a positive impact on yield, and thus it should be added at specific zones at higher rates compared to the current commercial practice for covering crop demand. Sufficient manganese and copper in soil resulted in higher yields, as it is shown in Table 3 and thus, copper and manganese were suggested to be given by foliar application for the recommendations of the following year.

Bulk density and sand content had a negative impact on yield, because water draining was observed from soils having increased sand content, which promoted nitrogen leaching to soil depths that could not be accessed by plant roots. *Ronaldo* cultivar produced significantly more yield compared to *Thai Bonnet*. High electrical conductivity (EC) was associated with lower yield, which is something expected for rice growing in this region, as EC presents high variability. Addition of potassium has been found to decrease sodium content in rice tissue at saline soils and increase yield (Bohra and Doerfling, 1993). According to the results of the soil analysis in the area, it was found that there were many zones with relatively high EC values, which is a common characteristic of the rice growing area of Thessaloniki, and this was probably another reason for the positive correlation between potassium and yield.

From the dimdesc function in Table 3 and dimension 2, it was seen that phosphorus was negatively related to yield, a trend which also exists in the PC4 (Table 2). This is not surprising because there are zones within the experimental area, where phosphorus reached toxicity levels because of previous years fertilization. Fig.5 shows field zones with extreme phosphorus levels covering a large part of the area. Annual application of phosphorus is essential for cereal crops, particularly for calcareous soils, because phosphorus availability tends to decrease during time, due to the reaction products formed in the soil. However, when phosphorus levels are high in the soil, yield compromise may occur, because of reduced availability of micronutrients in plant tissue

(Ali et al., 2014). Figure 4 also shows the negative correlation between phosphorus availability in the soil and yield observed for this experiment.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 5. The map of phosphorus for the central sector; note the extreme variance (from deficiency to toxic surplus) within specific fields.

A negative correlation between zinc and yield was observed, as it is shown in Table 3. This is because zinc availability increases in soils with low $CaCO_3$ levels and relatively lower pH levels. These soils though produced lower yields due to the lower magnesium availability, and thus zinc levels in soil indirectly related to lower yields. Finally, nitrate-nitrogen levels (NO_3-N) presented a negative correlation with yield. This occurred because nitrate levels are increased before seeding in May (when the soil sampling was conducted) for soils having low levels of clay. This is because increased soil aeration promotes nitrogen mineralization (Cai et al., 2016). However, as mentioned above, soils having low levels of clay produced less yield due to increased nitrogen losses.

Conclusion

Implementation of PCA analysis of chemical and physical soil properties and rice yield was necessary to define which of the properties are decisive for yield variability in the area. As it was shown, the soil parameters contributing significantly to yield were mainly the clay content, nitrogen applied at broadcasting, pH, $CaCO_3$, total nitrogen applied for the season, organic matter, potassium, manganese, silt and copper. It was also shown that magnesium was highly correlated with yield when exceeding 100 ppm in the soil, levels which were considered adequate for rice growth in the past (and thus never included in fertilization plans in this area). Consequently, the threshold of adequate magnesium levels for rice growth were reset to 300 ppm in the fertilization advice of 2018.

Acknowledgements

The authors would like to thank the technical personnel of Ecodevelopment S.A. involved for conducting the field surveys; also, Mr. Tasos Panagis, IT technician of NLGworldwide, for his precious scripting solutions for the VRT applications; and the personnel of the Soil and Water Resources Institute, Hellenic Agricultural Organization (H.A.O.) DEMETER, Thessaloniki, Greece, for conducting the soil analyses.

References

Ali, F., Sadiq, A., Ali, I., Amin, M. and Amir, M. (2014). Effect of Applied Phosphorus on the Availability of Micronutrients in Alkaline-Calcareous Soils. Journal of Environment and Earth Science, 4(15), pp. 143-148.

Blaschke, T. (2004). Object Based Image Analysis for Remote Sensing. ISPRS Journal of Photogrammetry and Remote Sensing, 65(1), pp. 2-16.

Bohra, J. S. and Doerfling, K. (1993). Potassium Nutrition of Rice (Oryza Sativa L.) Varieties Under NACL Salinity. Plant and Soil, 152, pp. 299–303.

Cai, A., Xu, H., Shao, X., Zhu, P., Zhang, W., Xu, M., and Murphy, D. V. (2016). Carbon and Nitrogen Mineralization in Relation to Soil Particle-Size Fractions after 32 Years of Chemical and Manure Application in a Continuous Maize Cropping System. PloS One, 11(3), e0152521.

Cerri, D. G. P., and Magalhães, P. S. G. (2012). Correlation of Physical and Chemical Attributes of Soil with Sugarcane Yield. Pesquisa Agropecuária Brasileira. 47(4), pp. 613-620.

Filella, I. and Penuelas, J. (1994). The Red Edge Position and Shape as Indicators of Plant Chlorophyll Content, Biomass and Hydric States. International Journal of Remote Sensing, 15, pp. 1459-1470.

Hopkins, B.G., and Ellsworth, J.W. (2005). Phosphorus Availability with Alkaline/ Calcareous Soil. Western Nutrient Management Conference. Salt Lake City, UT, USA, Vol. 6. pp. 88-93.

Juhos, K., Szabó, S., and Ladányi, M. (2015). Influence of Soil Properties On Crop Yield: A Multivariate Statistical Approach. International Agrophysics, 29(4), pp. 433–440.

Khalid, R. A., Patrcik W.H. and Peterson, F. J., (1976). Relationship Between Rice Yield and Soil Phosphorus Evaluated Under Aerobic and Anaerobic Conditions. Soil Science and Plant Nutrition, 25, pp. 155-164.

Kim, M., Madden, M., and Warner, T. (2008). Estimation of Optimal Image Object Size for The Segmentation of Forest Stands with Multispectral IKONOS Imagery. In: Object-Based Image Analysis – Spatial Concepts for Knowledge Driven Remote Sensing Applications. Edited by: Blaschke, T., Lang, S., and Hay, G. J., Springer, Berlin, Germany, pp. 291-307.

Linquist, B., Snyder, R., and Anderson, F. (2015). Water Balances and Evapotranspiration in Water- and Dry-Seeded Rice Systems. Irrigation Science, 33, pp. 375–385.

R Core Team (2018). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Sebastien, L., Julie, J., and Francois, H. (2008). FactoMineR: An R Package for Multivariate Analysis. Journal of Statistical Software, 25(1), pp. 1-18.

Sharma, P.K., Lav, Bhushan, Ladha, J.K., Naresh, R.K., Gupta, R.K., Balasubramanian, B.V., and Bouman, B.A.M. (2002). Crop-Water Relations in Rice-Wheat Cropping Under Different Tillage Systems and Water-Management Practices in A Marginally Sodic, Medium-Textured Soil. In: Water-Wise Rice Production. International Rice Research Institute, edited by Bouman, B.A.M., Hengsdijk, H., Hardy, B., Bindraban, P.S., Tuong, T.P., Ladha, J.K., (Los Banos: Philippines), pp. 223–235.

Song, X., Wang, J., Huang, W., Liu, L., Yan, G. and Pu., R. (2009). The Delineation of Agricultural Management Zones with High Resolution Remotely Sensed Data. Precision Agriculture, 10, pp. 471–487.

Stacklies, W., Redestig, H., Scholz, M., Walther, D. and Selbig, J. (2007). Pcamethods -- A Bioconductor Package Providing PCA Methods for Incomplete Data. Bioinformatics, 23, pp.1164-1167.

Wetterlind, J., Stenberg, B. and Soderstrom, M. (2008). The Use of Near Infrared (NIR) Spectroscopy to Improve Soil Mapping at The Farm Scale. Precision Agriculture, 9, pp. 57-69.

Williams, J.F. (2010). Rice Nutrient Management in California (Richmond, CA: University of California, Agriculture and Natural Resources).

Yanai, J., Lee, C.K., Kaho, T., Iida, M., Matsui, T., Umeda, M., and Kosaki, T. (2001). Geostatistical Analysis of Soil Chemical Properties and Rice Yield in a Paddy Field and Application to the Analysis of Yield-Determining Factors. Soil Science and Plant Nutrition, 47(2), pp. 291-301.

Yousaf, M., Li, J., Lu, J., Ren, T., Cong, R., Fahad, S., and Li, X. (2017). Effects of Fertilization on Crop Production and Nutrient-Supplying Capacity Under Rice-Oilseed Rape Rotation System. Scientific Reports, *7*(1), pp. 1270.