SELFSUSTAINED CROSS-BORDER CUSTOMIZED CYBERPHYSICAL SYSTEM EXPERIMENTS FOR CAPACITY BUILDING AMONG EUROPEAN STAKEHOLDERS

Precision farming and IoT case studies across the world (part 2)

University "UKSHIN HOTI" Prizren

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Content

- Precision agriculture in Greece - Introduction
- History of the agricultural sector of Greece - Current situation
- Difficulties of adopting precision agriculture in Greece
- Adoption of precision agriculture in Greece
- Future potential for further adoption of precision agriculture in Greece
- Italy - nitrogen fertilization based on prescription maps and on-the-go variable rate crop sensors in northern Italy maize cultivation
- ‘On-the-go’ fertilization approach
- ‘On-the-go’ equipment and working principles
- Georgia, USA e smart irrigation in Georgia, USA. A case study on cotton
- VRI in the United States and Georgia state
- Testing the irrigation systems
- Cotton harvest and yield data analysis

Precision agriculture in Greece - Introduction

- The importance of agricultural sector in Greek economy is acknowledged since ancient times
- It is worth mentioning that the Byzantine emperor Constantine VII Porphyrogenitus published `Geoponika`, which was a collection of agricultural lore that included cultivation practices across the empire
- After the World War 2, Greece saw dramatic changes in the agricultural sector with people moving from rural areas to the cities
- Moreover, agricultural sector started to decrease its share in the Greek economy when Greece joined the European Union, while the imports-exports balance was negative afterwards

History of the agricultural sector of Greece - Current situation

- Nowadays, almost 5 million ha are utilized in Greece for agricultural purposes while there are almost 700,000 farm holdings that employ more than 460,000 people

- The primary sector employs more than 10% of the Greece's workforce and the importance of this sector is increasing when compared to the other European Union countries

- Most of the Greek farm holdings have an economic budget less than 15,000 €, 80% of the holders are over 45 years old and almost 55% of the farm holdings have access to broadband Internet connection

- In 2016, 53% of the cultivated area was used for arable crops, 34.2% for perennial crops and 2% for vegetables with almost 30% of the cultivated agricultural area being under irrigation

Difficulties of adopting precision agriculture in Greece

- Many studies have indicated the factors that influence the adoption of precision agriculture technologies and methods

- The factors such as long payback period, low level of technical support and service and mismatched costs and benefits were also highlighted for affecting the adoption of these technologies

- Based on what aforementioned, other factors are the low educational level of farmers, the high percentage of very old farm holders, the low use of broadband connections in rural areas and the limited support from the technology providers

Adoption of precision agriculture in Greece

- Greece is currently facing important problems in its agricultural sector due to a combination of factors such as the economic crisis, the ageing of its rural population and the immigration of rural population to cities

- There are many studies related with the adoption of precision agriculture in a variety of annual and perennial crops, using different types of precision agriculture technologies, such as
  - variable rate application (VRA),
  - yield monitors, satellites,
  - proximal canopy sensors,
  - multispectral cameras,
  - laser scanners,
  - soil electrical conductivity sensors, etc.

Future potential for further adoption of precision agriculture in Greece

- The application of precision agriculture methods and technologies in Greece is in its infancy
- The initial studies present high potential for application of precision agriculture technologies and methods in a vast number of crops due to the high spatial and temporal variability of soil in Greek regions
- More and more Greek farmers are learning about the benefits that precision agriculture can offer to them in terms of cost savings, crop yield, quality and environmental benefits and precision agriculture technologies
- Further actions are needed for the adoption of precision agriculture by farmers in Greece, to reduce crop production costs and support environmental

Italy - nitrogen fertilization based on prescription maps and on-the-go variable rate crop sensors in northern Italy maize cultivation

- The archived yield maps and the corresponding prescription maps of variable rate nitrogen were analyzed to investigate the benefits on long-term VRA management

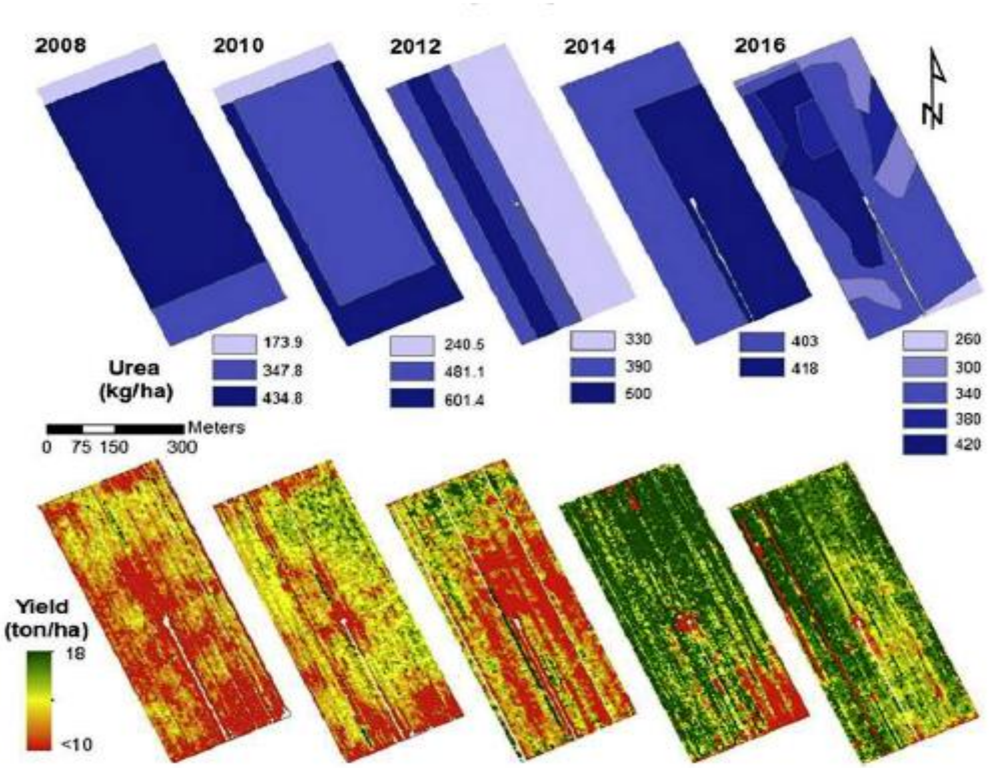
- The first prescription maps are quite simple: indeed, they were defined only on the basis of previous years yield maps and limited soil information

- After field testing in 2012, prescription maps were modified on the basis of a combination of soil and yield information, still with prescription recommendation from an expert agronomist

- Production results were analyzed both in terms of yield and partial factor productivity for nitrogen

Italy - nitrogen fertilization based on prescription maps and on-the-go variable rate crop sensors in northern Italy maize cultivation (2)

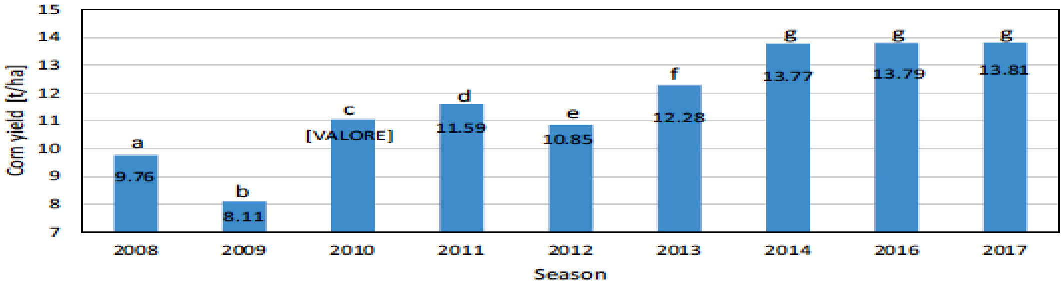
Year	Technology	Effect on PA
1999	First yield paper maps	Recognition of variability
2001	First digital yield maps	Creation of a digital archive
2002	Soil sampling	Recognition of variation between fields
2005	Satellite guidance systems	Reduction of overlaps and monitoring
2007	DSS software	Field based recommendations
2007	Controlled rate fertilizer	VR fertilization
2011	ARP soil mapping	Recognition of within-field variability and precise definition of homogeneous MZs
2011	PA ready implements	VR seeding and spraying
2012	Higher resolution yield maps	Precise information on yield variability
2014	DSS software	Definition of MZ within fields and prescriptions
2015	Sentinel-2 and drone maps	Recognition of higher resolution variability



MZ maps for urea (N fertilizer) and corresponding Corn yield maps

Prescription maps results

- In 2017, corn yield increased by 40% compared with 2008 season; in the meanwhile, PFP-N increased from around 50 to more than 87 kg of grain per 1 kg of applied nitrogen between the same periods
- In 2008 season, 99% of the field produced less than 13 ton/ha and 44% was less than 10 ton/ha, while in 2016, 81% of the field produced more than 13 ton/ha
- Concurrently, yield variability within each management zone exhibited an average reduction of 0.6% per year
- Statistical analysis on yield data showed a significant difference between different seasons with the exception of the last 3 years, exhibiting homogeneous productions



Prescription maps discussion

- Concurrently with the evolution of prescription maps, which changed every year, an increase in the average yield was recognized over the whole field

- Indeed, implementation of new technologies and development of progressively deeper field variability understanding allow quantification of crop needs with an increasing level of accuracy, with the result of enhanced yields or profits

- After 2013, ARP data integrated with archived yield maps could improve PFP-N, with reduced fluctuation in corn yield

- Since 2016, after further integration with Sentinel-2 data, corn yield reached a new record for this farm (13.91 t/ha), as well as a new record for PFP-N (87.2 kg/kg)

On-the-go’ fertilization approach

- The rapidly developing sector of precision farming is now facing new problems related to the increase of data frequency, the possibility to design specific crop fertilization programs, pest control and yield monitoring

- Traditionally, making prescription maps from yield maps or from satellite imagery requires tailored workflows carried out by experts, hence the costs could be due to change in crops and varieties

- In the Mantua district, about 55,000 ha have been cultivated with maize in 2017 and 2018, registering a slight decrease compared to the previous years

- The capabilities of the proximal active sensor (CropSpec) Topcon were tested in terms of nitrogen distribution optimization in corn fields compared to the uniform rate applied by most farmers throughout the region

‘On-the-go’ equipment and working principles

- The connectivity of the technology used is modular ISObus for variable-rate fertilizer spreader
- The control of the fields receiving fixed-rate fertilization is practiced by harrowing, with a quantity of urea chosen on the basis of farmer`s fertilization plan and equally at the maximum given by the sensor-driven fertilization
- During the fertilization procedures, the vigour analysis of the maize canopy was done in real time from each sensor using an index derived by the values from the two active bands of CropSpec
- The system is by default set at 10 Hz frequency and consequently generates the target fertilizer rate in real time
- ISO 11783, known as tractors and machinery for agriculture and forestry - serial control and communications data network (referred to as `ISO Bus`), is a communication protocol for the agriculture industry based on the SAE J1939 protocol (which includes CANbus)

Soil sampling before fertilization and after harvest

General conclusions

- During the field tests, variable rate applications were scheduled to manage within-field variability
- The 10-years study showed constant improvements on a 10-years basis, with nitrogen reduction up to 32% and yield increase of 40%. The 'on-the-go' approach highlighted the importance of proximal sensing active sensors, which allowed for a rapid temporal and spatial information on the crop and field variability
- These promising results can be considered as one of the success stories in the VRA of nitrogen fertilization based on either management zone delineation or real-time application
- Field study results highlighted the necessity of understanding the relevance of soil spatial variability and the need to define a tailored management strategy, to optimize farmers' profits and reduce environmental impacts

Georgia, USA e smart irrigation in Georgia, USA. A case study on cotton

- The traditional practices support uniform applications of agricultural inputs such as fertilizers, irrigation and pesticides within fields
- Smart irrigation (SI) was developed to replace traditional irrigation practices
- Such systems run models which combine weather, soil and plant data to calculate the appropriate amount of irrigation needed every day
- The models which ran by the apps calculate daily soil water balance, for example, how much water is released into the air through the evapotranspiration
- Continuously SI apps notify users when is the appropriate time for irrigation or the ideal amount of irrigation
- The app uses a soil water balance model to notify users about the daily water deficit and when it is the correct time for irrigation

VRI in the United States and Georgia state

- The irrigation systems such as central pivot and laterals can be easily customized to receive a VRI system
- Many scientists tried to develop irrigation methods using VRI at different crops such as potatoes, corn, peanuts and cotton
- It has been proved that VRI technology can lead to water savings because farmers can cut off the water at specific areas within a field
- Considering the irrigation problems in Georgia, the precision agriculture team of the University of Georgia developed a VRI system for central pivots
- This system enabled farmers to apply irrigation water at different rates

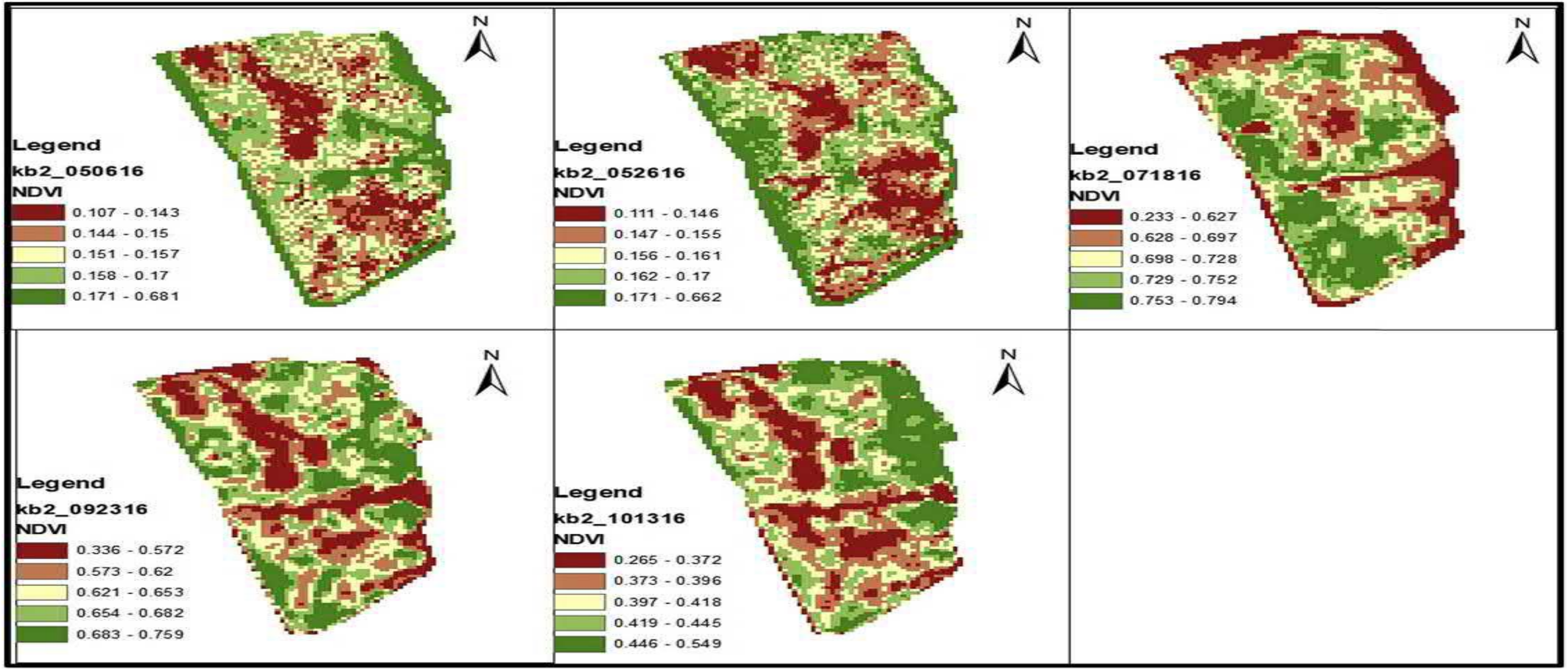
Testing the irrigation systems

- To assess the functionality of the pivot and detect problems which could affect the experiment (e.g., clogged sprinklers), the pivot was tested for its uniformity before planting
- After that the pivot ran over the cups using 12.7 mm of water (this is the irrigation rate the farmer usually uses), the volume of the collected cups was measured
- To assess the performance of the VRI system and detect potential problems, such as clogged valves or broken pipes, the pivot was run with different rates after the uniformity test
- At the second VRI test, the rates were inverted (100% and 0%)
- Moreover, various rates from 0% to 100% at 10% intervals were used during the last VRI test

UGA soil moisture monitoring system (1)

- The University of Georgia Smart Sensor Array consists of smart sensor nodes, a base station and a web-based decision support system
- The term sensor node refers to the combination of electronics and sensors installed within a field including a circuit board, a radio frequency transmitter, soil moisture sensors and temperature sensors
- Each node allows the connection of up to three watermark soil moisture sensors and up to two thermocouples for measuring soil and/or canopy temperature
- The radio frequency transmitter is responsible for the acquisition, analysis and transmission of the sensor data

UGA soil moisture monitoring system (2)



Examples of the NDVI variability of the crop canopy from May to October of 2016. The spatial resolution of the images is 10 m

Web-based user interface as a DST

- The data are stored on a commercial server space which can manage geographic data with different formats including GeoJSON (Geographic JavaScript Object Notation) format which are used for visual representation of the data
- The responsibility of the FTP server was to store the raw soil moisture data while the commercial server manipulated and processed the raw data
- The purpose of the web based interface was to visualize the soil moisture data
- PHP (Personal Home Page) and Javascript programming languages were utilized to create different representations of the soil moisture data
- For the shallow-rooted plants irrigation recommendations, the Van Genuchten model uses the average soil moisture readings from the shallow and middle sensor, while for the deep root plants the average readings of the three soil moisture sensors

Cotton harvest and yield data analysis

- The harvester was equipped with a yield monitor to record the cotton yield on the go
- The yield monitor was calibrated to record the yield accurately
- Unreliable yield data were removed from the recorded yield data to increase the precision of the yield map
- The criteria for removing data include the yield data recorded when the speed of the harvester was less than 1 mile per hour and when the acceleration and the deceleration was more than 15%
- Finally, the tools cluster and outlier analysis from ArcGIS were utilized to find all the areas where the yield had significantly high or low values

Summary

- Application of VRI based on a soil moisture sensor array with a web-based decision support tool showed promise as an alternative to existing decision support tools
- The use of soil properties, terrain data and satellite images from previous years proved to be very helpful to delineate correct IMZs
- The combination of IMZs with the real-time soil moisture data and their direct transmission to a server enabled the authors to supervise the soil moisture condition of the field in real time
- The results showed that the integration of IMZs with the VRI method was very good because it used less irrigation water than the grower's standard method

Session Q&A