Setting of a precision farming robotic laboratory for cropping system sustainability and food safety and security: preliminary results

R Orsini1, D Basili2, M Belletti1, D Bentivoglio1, C A Bozzi3, S Chiappini3, C Conti2, A Galli1, E Giorgini3, M Fiorentini1, E S Malinverni3, A Mancini4, L Mazzanti5, E Monaci4, G Passerini4, C Pro2, R Santilocchi1, A Vignini5, S Zenobi1, P Zingaretti4

1: Università Politecnica delle Marche - Dept. of Agricultural, Food and Environmental Sciences
2: Università Politecnica delle Marche - Dept. of Life and Environmental Sciences
3: Università Politecnica delle Marche - Dept. of Construction, Civil Engineering and Architecture
4: Università Politecnica delle Marche - Dept. of Information Engineering
5: Università Politecnica delle Marche - Dept. of Clinical Sciences, Section of Biochemistry, Biology and Physics
6: Università Politecnica delle Marche - Dept. of Industrial Engineering and Mathematical Sciences

Corresponding Author E-mail: r.orsini@univpm.it

Abstract. The acceleration of Digital Agriculture is evident through the increased adoption of digital technologies on farms including smart machines, sensors and cloud computing. In this paper we present the preliminary results of the research project funded by Università Politecnica delle Marche in 2018 "PFRLab: Setting of a precision farming robotic laboratory for cropping system sustainability and food safety and security", which is still underway. In this context, as first result, an interdepartmental Research and Services Center called "Smart Farming" has been set up with the aim to strengthen multidisciplinary collaborations in the fields of Agriculture and Forestry, Geomatics, ICT and Robotics. Regarding field activities the SPAD 502 as well as Normalized Difference Vegetation Index (NDVI) provide a good estimate of the Chlorophylla+b content in durum wheat leaves so can be used to predict in a quickly and non-destructively way, the crop greenness status and to identify any nutritional deficiencies in real time. Future research activities are certainly needed to fully explore the potentialities of conservation agriculture and precision farming, and to drive the transition process from conventional agriculture to modern conservation agriculture and precision farming techniques. In-depth studies are planned on the combined effect of nitrogen fertilization and soil management on the main production variables of durum wheat in order to evaluate whether specific tools for precision agriculture applications can find significant diffusion even in Mediterranean cereal based cropping systems.

1. Introduction
Technological innovations have had a disruptive impact on society and the economy; computers, internet, social media, smartphones, robotics, sensors and cloud-based processes have revolutionized how society organizes itself and how individuals and groups make decisions and behave [1].

The practice of farming and food production is not immune to this digital revolution and is forecast to undergo significant change in the coming years [2].

The acceleration of Digital Agriculture is evident through the increased adoption of digital technologies on farms including smart machines, sensors and cloud computing [3].

The use of these techniques presents advantages when compared with traditional methods based on manual work, however, there are still a number of challenges to be overcome [4]. Smart farming (SF), based on the incorporation of information and communication technologies into machinery, equipment, and sensors in agricultural production systems, allows a large volume of data and information to be generated with progressive insertion of automation into the process. SF relies on data transmission and the concentration of data in remote storage systems to enable the combination and analysis of various farm data for decision making [5].

Demographic trends, including aging populations and continued migration of people from rural to urban areas, have attracted the attention of researchers, because labor issues may become a scarcity factor in agriculture. In addition to these trends, the intensification of climate change will continue to alter growing conditions, such as the temperature, precipitation and soil moisture, in less predictable ways. SF tools can help reduce these impacts, keep them constant or reduce production costs in agricultural activities, and they can assist in minimizing environmental constraints [6].

It is therefore important that even in rural areas strongly linked to tradition, this approach is proposed. In this paper we present the preliminary results of the research project funded by Università Politecnica delle Marche in 2018 "PFRLab: Setting of a precision farming robotic laboratory for cropping system sustainability and food safety and security", which is still underway.

2. Preliminary results:

2.1. Research and Services Center “SMART FARMING”

The Research and Service Center called "SMART FARMING" is based in the Department of Agricultural, Food and Environmental Sciences (D3A) of the (UNIVPM).

The Center was created to respond to the growing importance that the acquisition and automated processing of data obtained through Geomatics, ICT and Robotics tools are assuming in agriculture and forestry, both in research and in the applications development. The wide technical-scientific implications that characterize the emerging sector of Precision Farming induce to operate through an ever greater integration between the numerous and different disciplines involved. The Italian Ministry of agricultural food, forestry and tourism policies (Mipaaft) highlights the breadth and multidisciplinary inherent in the concept of Precision Farming: "business management (agricultural, forestry and zootechnics) based on the observation, measurement and response of the set of quantitative-qualitative variables inter and intra-field that intervene in the productive order. This in order to define, after analysis of site-specific data, a decision support system for the entire company management, with the aim of optimizing returns with a view to an advanced sustainability of the climatic and environmental, economic, productive type and social ".

The Center is conceived, therefore, as a scientific structure that promotes synergies and collaborations between different competences, in order to promote the integration of knowledge and the enhancement of equipment (UAVs, Multispectral cameras, GIS tools, meteorological stations, soil moisture sensors, etc.) and laboratories (for soil, vegetable, water, pests, etc. analysis) with a view to enhancing research, experimentation and teaching in the field of Precision Farming with a strong push also to the involvement of national and international companies operating in the sector. The specific purposes of the Center are synthesized below:
1. Strengthen multidisciplinary collaborations, both in research and in teaching, between professors and researchers working in the fields of Agriculture and Forestry, Geomatics, ICT and Robotics and promote training and connection initiatives between academic world and citizenship, public bodies, associations and companies, in relation to the issues covered by the Center's activities;

2. promote the Center's participation in national and international research projects on the Precision Farming issues;

3. Implementing at the UNIVPM scale, using the expertise of the Center, a specific equipped laboratory dedicated to "Precision Farming" where to carry out research and experimentation activities.

2.2. SPAD reading and leaf chlorophyll content

Field activities were conducted on a long-term experiment (LTE) described by Seddaiu et al., 2016 [7] consisting on a rainfed 2-years rotation with durum wheat (Triticum durum L.) in rotation with maize (Zea mays L.).

The crop rotation is duplicated in two adjacent fields to allow for all crops to be present each year.

Here we present only the results observed on durum wheat in the year 2018. Within each field, starting from 1994, three tillage (main plot: conventional tillage vs minimum tillage vs no tillage) and three nitrogen fertilizer treatments (sub-plot: 0, 90 and 180 kg N ha$^{-1}$ distributed in two rates) were repeated in the same plots every year and arranged according to a split plot experimental design with two replications.

Before and after each nitrogen fertilization, images were acquired through a drone (mod. 3DR SOLO) equipped with multispectral camera (mod. Red-Edge M - MicaSense).

In order to interpret the imagery and calculate vegetation indices on the leaves of durum wheat were made readings using the chlorophyll meter SPAD 502 (Minolta Camera Co., Osaka, Japan) [8] which assesses the relative greenness of the plants in a rapid, in vivo and non-destructive manner. SPAD -502 is based on the indirect measurement of leaf chlorophyll content. It measures the leaf transmittance in red light at 650 nm (at which chlorophyll absorbs) and in near-infrared light at 940 nm (for the correction of leaf thickness). The readings were taken on the central and distal portion of the 30 randomly selected fully expanded leaves of 30 plants of each sub-plot. After each reading the leaves were removed, hermetically sealed in a plastic bag and immediately refrigerated and then transported to the laboratory where they have been analyzed to determine the chlorophyll content using the Arnon et al., 1949 method [9].

Figure 1 shows the positive relationship between SPAD readings and chlorophyll concentration (mg/g) in durum wheat leaves collected in three different soil managements. SPAD 502 Minolta, according whit Debaeke et al., 2006 [10] is a valid tool for tracing, in a non-destructive way, the chlorophyll content present in the foliar tissues and indirectly for test the nutritional status of the crop.

The adoption of conservative soil management techniques (NT or MT) does not lead depressing effects when compared with conventional techniques opening up interesting prospects for the diffusion of such techniques in the considered environment.
Figure 1: SPAD units and Chlorophyll $a+b$ (mg/g) relationship on durum wheat leaves subjected to three different soil managements. Data Points show the average of two replications measured (NT = no tillage; MT = minimum tillage; CT = Conventional tillage)

2.3 Normalized Difference Vegetation Index (NDVI)

The contemporary long-time satellite remote sensing data provides an advanced way to monitor the surface vegetation dynamics at different spatiotemporal scales [11]. With merits of long continuous time series, good data availability of products based on different remote sensors, the Normalized Difference Vegetation Index (NDVI) is utilized most frequently to analyze the vegetation variations and its correlation with environmental factors in the Northern Hemisphere [12]. NDVI is based on the differential absorption of red and near-infrared spectral bands [13] and quantifies vegetation greenness as related to vegetation vigor and extent [14].

It is strongly correlated to the photosynthetically active radiation absorbed by vegetation, and it is recognized as an indicator of vegetation productivity.

Figure 2 shows the positive relationship between NDVI and chlorophyll concentration (mg/g) in durum wheat leaves subjected to different soil management.

Since NDVI is linked to chlorophyll content, according with Wang et al., 2003 [15], it varies based on vegetation type, the extent of the vegetation cover, the soil, geomorphology and climatic constraints. In the research activities that will be carried out during the 2019, other vegetation indices (i.e. Canopy Chlorophyll Content Index (CCCI), Enhanced Vegetation Index (EVI) [16]) will be calculated and compared to evaluate which is best correlated to the crop nutritional status and to the yield to draw up prescription maps for the contribution with a variable rate of production inputs reducing the potential environmental impact of crop systems.
3. Conclusions and future perspectives

According to the general objective of Horizon 2020 “to build an economy based on the knowledge and innovation of the European Union, contributing to sustainable development”, and following “A strategy for Smart, Sustainable and Inclusive Growth”, the project “PFRLab: Setting-up of a Precision Farming Robotic Laboratory for cropping system sustainability and food safety and security” was founded by Università Politecnica delle Marche at the beginning of 2018. As a first result an interdepartmental Research and Services Center called "Smart Farming" has been set up with the aim to strengthen multidisciplinary collaborations in the fields of Agriculture and Forestry, Geomatics, ICT and Robotics and promote training and connection initiatives between academic world and citizenship, public bodies, associations and companies, in relation to the issues covered by the Center's activities.

Regarding field activities emerged encouraging results: the SPAD 502 provides a good estimate of the Chlorophyll $a+b$ content in durum wheat leaves so SPAD 502 can be used to accurately predict in a quickly and non-destructively way, the Chlorophyll $a+b$ for determining the crop nutritional status.

We observed a positive relationship between Normalized Difference Vegetation Index and Chlorophyll $a+b$ content so, NDVI indirectly provides an estimate on the greenness of the crop allowing to identify any nutritional deficiencies in real time using multispectral images acquired by drone.

Given the positive effects that these farming systems can have in the agro-food network (i.e., food security, climate change mitigation, soil fertility, nutrients availability, efficient fertilizer use, low chemicals input), future research is certainly needed to fully explore the potentialities of conservation agriculture and precision farming, and to drive the transition process from conventional agriculture to modern conservation agriculture and precision farming techniques. In-depth studies are planned on the combined effect of nitrogen fertilization and soil management on the main production variables of durum wheat in order to evaluate whether specific tools for precision agriculture applications can find significant diffusion even in Mediterranean cereal based cropping systems.
References

[1] Regan Á 2019 “Smart farming” in Ireland: A risk perception study with key governance actors. NJAS - Wageningen Journal of Life Sciences In Press. DOI: https://doi.org/10.1016/j.njas.2019.02.003

[2] Bronson K and Knezevic I 2016 Big data in food and agriculture Big Data Soc., 3 1

[3] Carolan M 2016 Publicising Food: big data, precision agriculture, and co-experimental techniques of addition Sociol. Ruralis, 57 2

[4] Barbedo JGA 2016 A review on the main challenges in automatic plant disease identification based on visible range images Biosyst. Eng., 144 pp 52-60

[5] Pivoto D Dabda P Waquil Talamini E Finocchio CPS Dalla Corte VF Mores GV 2018 Scientific development of smart farming technologies and their application in Brazil Inf. Processing in Agric. 1 5, pp 21-32

[6] Fountas S Carli G Sørensen CG Tsiropoulos Z Cavalaris C Vatsanidoud A Liakos B Canavari M Wiebensohn J Tisserye B 2015 Farm management information systems: current situation and future perspectives Comput Electron Agri 115 pp 40-50

[7] Seddaiau G Iocola I Farina R Orsini R Iezzi G Roggero PP 2016 Long term effects of tillage practices and N fertilization in rainfed Mediterranean cropping systems: durum wheat, sunflower and maize grain yield Eur. J. Agron., 77 pp 166-78

[8] Minolta 1989 Chlorophyll meter SPAD-502. Instruction manual. Minolta Co., Ltd., Radiometric Instruments Operations, Osaka, Japan

[9] Arnon DI 1949 Copper enzymes in isolated chloroplasts. Polyphenoloxidase in Beta vulgaris. Plant Physiol. 24 pp 1-15

[10] Debaeke P Rouet P Justes E 2006 Relationship between the normalized SPAD index and the nitrogen nutrition index: Application to durum wheat J. Plant Nutr., 29 pp 75–92

[11] Huete A 2016 Ecology vegetation's responses to climate variability Nature, 531 pp 181-2

[12] Lamchin M Lee WK Jeon SW Wang SW Lim CH Song C Sung M 2017 Long-term trend and correlation between vegetation greenness and climate variables in Asia based on satellite data Sci. Total Environ., 618 pp 1089-95

[13] Rouse JHR Schell J Deering D 1973 Monitoring vegetation systems in the great plains with ERTS Third ERTS Symposium 1973 (NASA SP-351) 1 pp 309-17

[14] Rhee J Im J 2017 Meteorological drought forecasting for ungauged areas based on machine learning: using long-range climate forecast and remote sensing data Agric. For. Meteorol., 237 pp 105-22

[15] Wang J Rich PM Price KP 2003 Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA Int. J. Remote Sens., 24 11 pp 2345-64

[16] Cammarano D Fitzgerald GJ Casa R Basso B 2014 Assessing the robustness of vegetation indices to estimate, wheat N in mediterranean environments Remote Sens., 6 pp 2827-2844

Acknowledgments

This study was conducted in the context of the Call for Strategic Projects of the Università Politecnica delle Marche. We are grateful to all those colleagues and students that contributed to the conduction of the field activities. The professionalism and technical contribution of the workers of the “Pasquale Rosati” experimental farm of the Università Politecnica delle Marche are also gratefully acknowledged.