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Soil-Plant-Atmosphere System in Tomato and Maize Crops: Correlation of Gaseous Emissions to Water Stress

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Abstract

The application of Site Specific Crop Management consists of the knowledge on the soil variability. In particular, for a sustainable water management is fundamental to obtain differentiated response in terms of selective irrigation, analyzing and evaluating the water content of the soil or the water requirement of the plants. The innovative contribution of this research lies in designing, developing and validating a technology platform consisting of a hardware for monitoring of gaseous emissions, such as Volatile Organic Compounds (VOCs) from the soil-plant-atmosphere system of intensive crops, i.e., tomato and maize. In order to determine the water content of these systems, we analyzed experimental data acquired in situ by portable sensing units based on Metal-OXide (MOX) gas sensors, thus comparing the results with meteo-sat data and farming operations (e.g. irrigations, rains or pestice-based treatments). A dependence of gaseous emissions on the hydric/metabolic status of the plants together with a correlation between recorded sensor signals and significant events for the crops were proved.

Key words: water stress, precision farming, chemoresistive gas sensors, metal oxides, crops

Introduction

In the field of sustainable water management, the effective irrigation scheduling has become an important tool that significantly influences growth development and production of crops [1]. In this perspective, once considered the water availability, the starting point for an investigation addressed to conscious water management is the assessment of soil-plant-atmosphere transfer processes that affect the crops water use, defined as EvapoTranspiration (ET) [2]. The crop coefficient-reference ET procedure is a robust method to estimate crop water requirements. Despite this, the ET is difficult and expensive to measure and it is even more difficult to separate transpiration, water released from leaves, and soil evaporation. With the aim of a better understanding of the relationship between crop growth and water content, a wide range of remote sensing systems are being developed and can support such computational methods [3]. Although the technological science provides several tools and analysis techniques for the remote sensing, a well-structured system has not been widely documented for the parallel evaluation of the soil moisture status and the monitoring of emissions variability of the crops over a whole growing season. In fact, on one side the most part of studies on VOCs profiles in the soil atmosphere, i.e. gas fingerprints, are pointed towards the soil microbial metabolic activity [4]. On the other side, the monitoring of VOCs secreted by plants is mainly focused on the control of their health status, which can be affected by insects or disease. However, plants emit a broad range of VOCs, such as terpenes, phenolic, alcohols, and aldehydes. These emissions are affected by internal (genetic and biochemical) and external (abiotic and biotic) factors, in particular are dependent on temperature and radiation. Nonetheless, hydric stress is not yet considered as an input in plant emissions, maybe because it affects them in different ways. Therefore, it is necessary to clarify the relationship between the soil water availability and variability and the potential need of water by plants [5]. For the estimation of VOCs emitted from soil and plants equipment should be cheap and not bulky, whereas analysis techniques should be easy to perform and not invasive. In this perspective, electronic nose is a potential technology, which may comply with these requirements. Starting from this consideration, we designed and prepared two portable units for monitoring gaseous emissions in tomato and maize crops.

Experimental

Despite an e-nose allows real-time acquisition providing a fast response without a direct contact with soil or plants, it needs a complex signals deconvolution system. Then, we studied two proper simple systems to collect data in situ from the sowing to the harvest of tomato and maize crops, respectively. After a lab-calibration, we selected 8 MOX gas sensors to integrate in the two dedicated hardware (see Fig.1), each consisting of: a double protection and compact size outdoor box, 4 aluminum test cells for direct flux exposure, humidity/temperature sensors, a firmware for the real-time signal acquisition, the remote management of the measuring system, storage, data transmission, setting of the operating parameters.

Fig. 1. Portable sensing unit in tomato field during sprinkling irrigation.

The experimental activities were organized as follow:

1. on-field experimental measurements of gaseous emissions in the crops,
2. sampling of agronomic and environmental surveys,
3. laboratory analysis of soil, water and plants for the definition of Ground Control Parameters as markers for the calibration of the innovative technological platform,
4. experimental measurements with an array of chemoresistive sensors and comparison with meteo-sat data and farming operations.

Results and discussion

The in situ measurements covered almost four months. The signals variation highlighted an intense field activity from the point of view of the gaseous emissions of soil-plant-atmosphere systems.

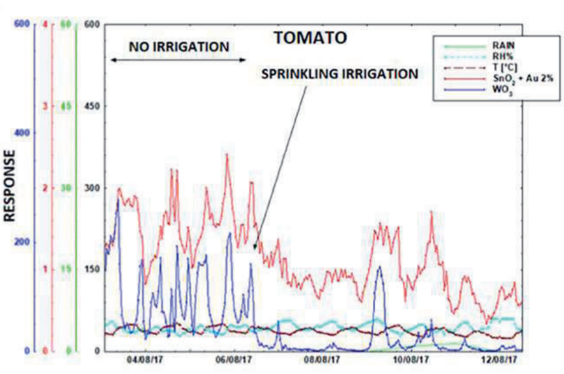

Fig. 2. Effect of sprinkling irrigation on gaseous emissions in tomato field.

In Fig. 2, one can observe the correlation between the usage of irrigation in tomato field and the sensor responses, calculated as $(G_{crop}-G_{base})/G_{base}$ where G_{crop} is the sensor conductance during the crop growth and G_{base} is the conductance at the crop sowing.

For each of the two portable sensing units, two of the MOX sensors selected demonstrated good sensing performance for such application: WO_3 and SnO_2 doped with Au sensors in the case of tomato, a solid solution of Sn, Ti and Nb and SnO_2 doped with Pd/Al in the case of maize.

Signal analysis has highlighted a strong dependence of gaseous emissions on the hydric/metabolic status of the plants and a correlation between recorded sensor signals and significant events for the crops such as irrigation, rain or pestice-based treatments.

Conclusions

A deep understanding about the mechanisms that regulate water stress plays a fundamental role in the water balance determination that is the base of efficient irrigation scheduling. In this sense, the preliminary results obtained with this work will open up to the definition of diverse water management solutions. Indeed, from a technological point of view, the highlighted information may provide irrigation advices about the time of intervention and the volumes to be used in order to obtain a quality product, whereas from a biological point of view it could be possible to investigate the correlation between morphological changes in plants and their water stress, getting at the root cause.

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