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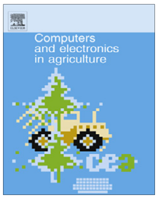

Application note

RFID temperature sensors for monitoring soil solarization with biodegradable films

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ABSTRACT

Soil-borne pathogen and weed control can be achieved by soil solarization even if estimation of time treatment is difficult to assess. Thus, due to dependence to environmental conditions and the need to minimize the time of treatments, the implementation of monitoring tools may help in solarization managements, especially when biodegradable films were applied or weather condition are subjected to significant variation. Digitalization of data relative to plants thanks to RFID applications has been used for health or treatment monitoring, sample collecting and retrieving sanitary information: this paper presents the testing of RFID sensor application for soil solarization purposes. Different matrices were selected to assess RFID temperature sensors performances. Sandy, loam and clay soils with different moisture-holding capacity were selected for sensor burial. Sensors were covered by 5 or 10 cm of fresh matrix and read immediately. Reliability was found to be more than 90% in all tested conditions, while higher failure in tag reading was recorded in clay soil at 90% of moisture-holding capacity (−7% of tag reliability). Soil solarization treatment was carried out as case of study during a period characterized by changeable weather using a biodegradable film. Data, expressed as thermal addition and temperature classes, collected continuously by sensors permitted to design real-time graphs that help the farmer to understand the thermal effect caused by treatment. Throughout the second and third week of treatments, T_{max} at 5 cm depth is increased by 9–13 °C or 11–14 °C compared to environment, respectively. Otherwise, T_{max} at 10 cm depth is increased by 7–9 °C compared to environment throughout the second and third week, showing as sensors are able to collect temperature during solarization. The soil microbial community of soils treated with solarization exhibited a slight reduction of cumulative carbon metabolic activity compared to control (8.8% of reduction), while among 31 preselected carbon sources, the soil microbial communities were capable of utilizing up to 23 carbon source without difference between treatments. Unified Modeling Language activity diagrams for solarization management via digital sensors were designed and effects of biodegradable film on microbial population were observed. The integration of information technology solutions with new-generation biodegradable films may offer an interesting revaluation of soil solarization in actual farm organization.

1. Introduction

Soil-borne pathogen and weed control can be achieved by soil solarization, a traditional approach to plant protection which effectiveness rely on potentially wide spectrum of action and lack of residues (Katan, 2000; Gill and McSorley, 2011). Solarization consists of trapping solar radiation with plastic films laid on the soil, which allows soil temperature increases of up to 50 °C near the surface. Recently, technological improvements were developed, thanks to novel plastic films able to reduce treatment time and enhance biological effects (Gill et al., 2009). Moreover, novel approach of solarization (e.g. biosolarization, biodegradable films) represent promising sustainable options for plant protection (Bonanomi et al., 2008; Mauromicale et al., 2010; Klein et al., 2012; Domínguez et al., 2014; Kanaan et al., 2015) with beneficial effects on soil microbes (Camprubí et al., 2007). As reported by Collange et al. (2014), the heating intensity, thus the control efficacy, depends on a rapid increase of temperature that must be achieved during the first days of the treatment and maintained during several weeks (Chellemi et al., 1997), and the soil-borne pest localization, because heating effect decreases in deeper soil

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layers (Stapleton, 1997). As a consequence, in order to control fungi (Patricio et al., 2006; Bonanomi et al., 2008) or viruses (Luvisi et al., 2015), it is recommended to start solarization in the warmer season and make it last for at least 3–4 weeks, even if estimation of time treatment is difficult to assess. Thus, due to dependence to environmental conditions and the need to minimize the time of treatments, the implementation of monitoring tools may help in solarization managements, especially when biodegradable films were applied or weather condition are subjected to significant variation. Generally, biodegradable films are fragile compared to polyethylene one and, after some weeks from soil application, are subjected to micro lesions that lead to break the film, leaving film scraps over the treated soils that are ineffective to control pests and weeds. Thus a pre-established time of treatment may easily lead to useless and expensive prolongation of solarization. Similarly, in countries such as Italy were weather conditions may vary over the short term even in the warmer seasons, a real-time evaluation of temperature achieved in the soil could be useful. Thanks to frequent acquisition of thermal parameter of solarized soils (such as thermal addition or temperature classes), farmers can be supported in decision making process, such as stop the treatment if the thermal values achieved are considered sufficient or extend the treatment over the predicted time. Thus, objectives of research in solarization management may relay in integration of IT solution for real-time monitoring of temperature, evaluation of commercial sensors for application in soils or development of novel one due to signal attenuation, as well as definition of theoretical model for data management via software.

Commonly, in order to monitor soil temperature during solarization, temperature sensors connected to data loggers had to be deployed in field. Conventional loggers are very effective in order to collect with high precision the soil temperature during solarization period (Luvisi et al., 2006; Peruzzi et al., 2012;) but they are expensive and, due to their professional purpose, they may be not user-friendly by farmers. Moreover, while sensors are buried, loggers are usually leaved on the ground during treatments and they is exposed to risks (i.e. animals or thefts), thus they should be monitored. Thus, up-to-date Information Technology (IT) solutions may be desirable. Digitalization of data relative to plants has been used for health monitoring, sample collecting and retrieving sanitary information (Thrane, 2008; Cunha et al., 2010). To establish a safe link between data and plant-associated samples, radiofrequency identification (RFID) tags have been proposed (Bowman, 2005; Bollen et al., 2007); their use in plant pathology has also been proposed (Kumagai and Miller, 2006; Luvisi et al., 2012a). The importance of hypermedia knowledge and information transfer in agriculture has been investigated since the last decade of the 20th century (Carrascal et al., 1995) and more recently information sharing and collaboration between users via the web have been introduced through the Agricultural Information Management System of FAO (http://aims.fao.org/), forestry information systems (Farcy et al., 2005) or the plant-associated microbe database (Almeida et al., 2010), with useful features for stakeholders. In addition, platforms to share and manage information in agriculture can be implemented by RFID-based technologies (Sørensen et al., 2010), providing a safe and durable link between items and information. Finally, health or treatments data can be integrated with Web 2.0 collaborative workspace, provided for useful data interchange and communications between users: generally, retrieving information from activities, samples or documents is easier when using RFID-labelling with workspace support (Luvisi et al., 2012b). In order to evaluate IT solutions for the management of soil-borne pathogens, this paper presents the testing of an RFID application for soil solarization purposes. Soil depth cause significant effects on signal attenuation, as well as soil water content (Li et al., 2007; Bogena et al., 2009). Thus evaluation of RFID sensor characteristics and tag distribution in soil are investigated in order to overcome obstacle to tag readability. Moreover diagrams were designed to define the workflow of operations necessary to perform a comparison between real-time data collected from sensors and farm historical data, in order to design specific management software. A treatment using a novel biodegradable film was reported as case of study.

2. Materials and methods

2.1. RFID temperature sensor tests

Semi-passive Ultra-High Frequency (UHF) logger tags (Easy2Log RT0005, Caen RFID, Italy) were used as temperature sensors. Tags are compatible with the EPCGlobal C1G2 and ISO18000-6C standards. Frequency range is 860–928 MHz. A handheld reader (qID-mini, Caen RFID, Italy), compliant with UHF tag standards was used. The reader, with an integrated linear antenna, was connected via Bluetooth with a laptop, working at 865.600–867.600 MHz. RF power was programmable from 5 dBm e.r.p. (3 mW e.r.p.) to 22 dBm e.r.p. (150 mW e.r.p.). Tags were configured to store temperature samples in intervals of 1 h in the internal memory. Temperature operating range was −20 to 70 °C with temperature accuracy of ±0.5 °C Different matrices were selected to assess RFID temperature sensors performances. Sandy, loam and clay soils with different moisture-holding capacity (10%, 50% and 90%) were selected for sensor burial. Tags were buried to cover the temperature sensors by 5 or 10 cm of soil and read immediately. Thanks to RFID antenna disposition within tag compare to temperature sensors, the antenna is nearer to the soil surface compared to temperature sensor (Fig. 1). Thus, the antenna is at ground level (±0.5 cm) at 5 cm depth temperature sensor, while about 2.4 cm of soil cover the antenna when temperature sensor is 10 cm depth.

To estimate the system reliability in selected environmental conditions, the number of detected tags was divided by the total, with 15 tags for three replications. Replications were necessary because the reliability is essentially a random variable and therefore mean values have to be estimated (Ampatzidis and Vougioukas, 2009).

2.2. Case of study

In order to evaluate the effectiveness of RFID sensors for monitoring soil temperatures, soil solarization was carried out during periods characterized by changeable weather (late May–June). Soil solarization was carried out in San Piero a Grado (PI), central Italy, using a starch based biodegradable film MaterBi (biodegradable film). Biodegradable film is a transparent film (thickness 30 mm) produced from a starch base (Novamont S.p.a., Italy). Films covered the soil for 60 days. Full details regarding field preparation are presented elsewhere (Stapleton, 2000). Tags were buried placing the temperature sensor at 5 and 10 cm depth. Manual reading with a handheld every week in order to assess real-time retrieving of temperature. Measured temperatures were divided into three classes ($T \leqslant 35$ °C, 35 °C $> T \leqslant 40$ °C, 40 °C $> T \leqslant 45$ °C). The length of time each class persisted in the soil was taken into account, along with the temperature measured each hour. The thermal addition parameter ($\sum T$) was calculated as sum of the individual temperatures (measured every hour) for the 8 weeks following treatment. A microbial test was carried out in order to evaluate soil solarization effectiveness. Soil samples were collected to evaluate total fungi, *Trichoderma* spp. and actinomycetes as CFU per gr of soil, using potato dextrose agar, P190 and water–agar medium, respectively (Papavizas and Davey, 1959; Ho and Ko, 1979). Community-level physiological profiles of soil microbial communities, using EcoPlates (Biolog Inc., CA, USA) incubation, were carried out by calculating the average well colour development, richness and