Precision Irrigation of Mushrooms Using a Novel Dielectric Tensiometer

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Abstract

A dielectric moisture sensor with a specified porous material which contacts the substrate to be measured, has been developed to measure the matric potential (water suction pressure) of casing and compost. This has enabled the availability of water to measured independtly of the water holding characteristics of the casing or compost. The output from moisture sensors positioned in the casing and compost has been used to control an automated drip irrigation system. The mushroom yield and quality of crops grown with the system were compared with those obtained from an overhead sprinkler irrigation system controlled with a timer but also moniotored with the sensors. Applications of water and mushroom yields with the two irrigation systems were similar. The cropping benefit of the sensor controlled drip irrigation system was a heavier mushroom piece weight and greater tissue density. The moisture sensors can identify wet and dry areas in a growing room and have the potential to improve uniformity in substrate moisture and mushroom cropping.

Introduction

Most aspects of mushroom cultivation are precisely controlled, including mechanized filling of substrates into shelves or trays, and computer-based environmental control of growing room substrate and air temperatures, humidity and carbon dioxide level. Application of correct amounts of water to the crop at suitable intervals is essential in obtaining high mushroom yields and quality, and avoiding water wasteage. Although automated irrigation systems can apply known volumes of water to the casing, the decision to apply water is subjective, depending on visual observation of the crop and 'feel' of the casing, while the moisture status of the underlying compost remains unknown. Manual or timer controlled, semi-automated sprinkler irrigation systems can apply known volumes of water to the surface of the casing, although the correct amount will vary between each crop depending the properties of the casing material, the rate of growth of the mushroom mycelium and population density of developing fruitbodies, and the prevailing ambient air conditions.

The volumetric moisture content of mushroom casing and compost can be measured with dielectric sensors (Balascio & Lomax, 1989) such as the Delta-T SM150. However, a problem in measuring moisture in mushroom casing and compost on a volumetric or gravimetric basis is that different substrates can hold different amounts of water (Table 1).

Table 1. Volumetric water holding capacity of peat and sugar beet lime casings at application and after the third flush of mushrooms. Values are averages of eight samples (± standard deviation)

Stage	Source of peat		
	Britain	Ireland	Germany
At application	69.6 ± 3.1	75.2 ± 4.0	74.6 ± 5.3
After 3rd flush	61.0 ± 4.4	65.8 ± 4.8	65.2 ± 4.5

Even between batches of casing prepared from the same source of peat, there is considerable variability in the water holding capacity. A further challenge is that casing becomes more water repellenat (hydrophobic) as mushroom mycelium grows into it, so that by the end of the crop, the volumteric water holding capacity is significantly lower than at the start. That means the optimum setpoint for volumetric moisture content of casing will differ between casing materials and batches, and will change as the crop progresses. For example, if an irrigation setpoint for a casing volumetric water content of 70% is selected, casing prepared from the Irish and German peats in Table 1 would have to dry out substantially before any water is applied to the crop. However, by the end of the crops, the same setpoint would be above the water holding capacity of all the casings, resulting in continuous watering and run-off.

An advantage of measuring the matric potential (water suction pressure) of a substrate rather than the volumetric water content is that the sensor detects the availablity of water and does not need to be calibrated for each type or cropping stage of casing or compost. All the casings in Table 1 being at their water holding capacity would have zero matric potential (0 kPa) and would not require watering until a matric potential develops by loss of water from the casing. Previous work has shown that mushroom yield and quality are more closely related to casing matric potential (water availability) than to volumteric water content (Noble et al 1999;2000). The matric potential of mushroom casing and compost can be monitored using electronic water filled tensiometers (Noble et al 1999;2000) such as the Delta-T SWT3 and SWT5. These measure water pressure through a ceramic porous cap on the end of a water-filled glass tube connected to a pressure transducer (Figure 1). Although they provide accurate measurements, they are delicate instruments which require regular filling with degassed water and are therefore unsuitable for everyday use on a mushroom farm.

Fig. 1 Delta-T SWT3 water filled electronic tensiometers

A solution to this problem used in this project was to cover the electrodes of a dielectric moisture sensor with a specified porous material (PM) which contacts the substrate to be measured. The matric potential or water suction pressure of the substrate is converted into the same matric potential in the PM. The volumetric water content of the PM can be measured with a dielectric sensor, and since the water holding properties of the PM are characterized, the volumetric water content can be converted into a matric potential, the same as in the casing or compost. Specifically produced PMs with a controlled small pore size matrix enable substrate matric potentials of -1 to -3 kPa (i.e. high moisture) to be measured. The new Delta-T FT1 dielectric tensiometer (Goodchild et al. 2016) is based on the patented SM150 and SM300 dielectric moisture probes with a PM enclosed in a protective metal cage (Figure 2). The PM is disposable and is replaced by removing the screw-on bayonet fitting cage.

Fig. 2 Delta-T SM300 dielectric moisture sensor (left) and prototype FT1 tensiometers

This article describes the results of a three-year collaborative project involving a designer and manufacturer of electronic sensors (Delta-T Devices Ltd.), a leading UK mushroom producer (G's Fresh) and mushroom researchers (NIAB EMR) together with Innovate UK. The work had the following objectives:

1. To determine if the FT1 sensors were sufficiently sensitive to be able to detect changes in moisture content in the high moisture casing and medium moisture compost layers
2. To asses whether the FT1 sensors were sufficiently robust to withstand use and cleaning on a mushroom farm
3. To use the FT1 sensor output to control an automated drip irrigation system
4. To compare mushroom yields and quality obtained from a sensor controlled drip irrigation system with that obtained from a timer controlled sprinkler irrigation system.

Materials and Methods

Prototype FT1 sensors were used for measuring casing and compost moisture at G's Fresh Littleport Mushroom Farm, Cambridgeshire. Two identical growing rooms were used for the tests, each with a cropping surface area of 640 m^2 divided between 16 shelves stacked four high. Three FT1 tensiometers were inserted in the casing and compost of different shelves to account for positional variability in the growing room. The data from the probes was sent to a GP2 Data Logger Controller (Delta-T Devices Ltd, 2016), and monitored in the same way as for air and compost temperatures on a remotely positioned PC. The GP2 was programmed as an irrigation controller where user adjustable setpoints were used to control a drip irrigation system (Figure 3). Maximum and minimum setpoints in the casing, and a maximum setpoint in the compost were used to manage the irrigation system. Irrigation events were determined by the GP2 using a trigger from averaged sensor measurements and were stopped after a fixed time duration (1 minute), or with sensor measurements.

Fig. 3 Mushroom crop with drip irrigation controlled with FT1 tensiometers in casing and compost

Fig. 4 Overhead sprinkler irrigation system

Mushrooms were also grown at G's Fresh May farm using an overhead sprinkler irrrigation system controlled with a timer, but monitored with FT1 sensors in the casing and compost, and the applications of water adjusted accordingly (Figure 4).

A series of 12 pairs of mushroom crops were grown, with sensor controlled drip irrigation and timer controlled sprinkler irrigation used for a crop in each pair. The same source (Sterckx, Belgium) of compost (Phase III spawn run with Sylvan A15) and casing was used throughout the trials. The yield and quality (% class I) of mushrooms were recorded in three flushes. More detailed measurements for mushroom quality were made on two consecutive pairs of crops using a Minolta colormeter, and by measuring the individual piece weight of mushrooms, the density of cubes of mushroom tissue, an accurate measure of mushroom texture (McGarry & Burton 1994) and dry matter content.

At the end of each pair of crops, the sensors were removed from the compost and casing and cleaned with a proprietary disinfectant. The PM on the sensors was replaced before the start of the next pair of crops. At the end of some of the crops, a steam cook-out (60ºC for 6 hours) was used to test the resilience of the sensors.

Results

Typical FT1 sensor outputs from the casing and compost in a sprinkler irrigated mushroom crop are shown in Figure 5. At the start of a crop, there is a high output from the casing sensors after filling of fresh casing followed by watering (upper graph). The casing sensor output then declines as the casing dries out; followed by an increase in output in response to a pre-flush watering. During the first flush, the sensor output again declines as mushrooms take water out of the casing, followed by an increase in response to watering after the flush has been picked. The sensors in the compost also detect the drying out during the first flush and subsequent re-wetting from post-flush watering (lower graph). The quantities of water applied in a typical overhead sprinkler irrigated crop are shown in Figure 6. Applications of water to sprinkler irrigated crops (52 to 69 litres/m^2) were similar to those irrigated with the automated drip system.

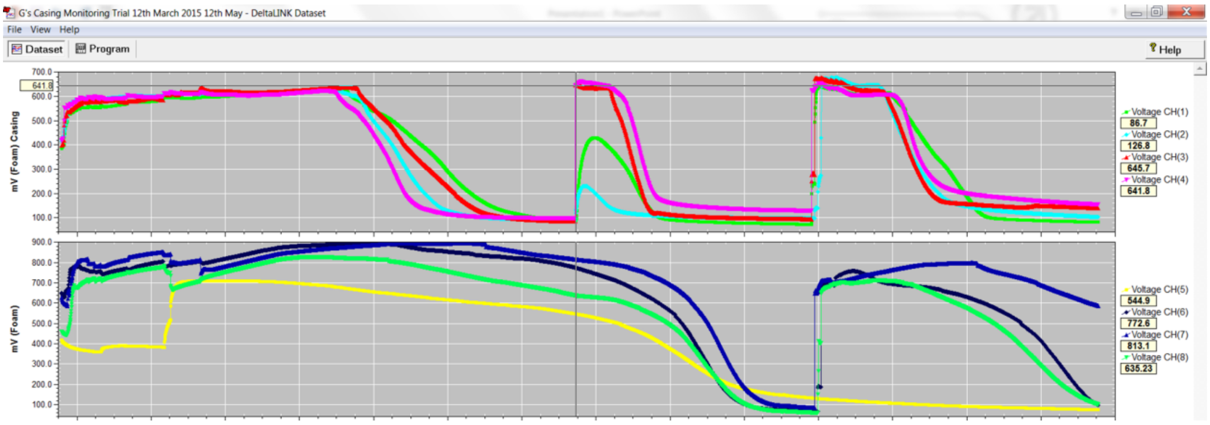

Fig. 5 Output from four FT1 tensiometers in casing (top graph) - high after filling, declining as the casing dries out and increasing after watering then during cropping the sensor output declines as mushrooms grow, followed by an increase due to watering). The sensors in the compost (lower graph) detect the drying out during the first flush and subsequent re-wetting from watering

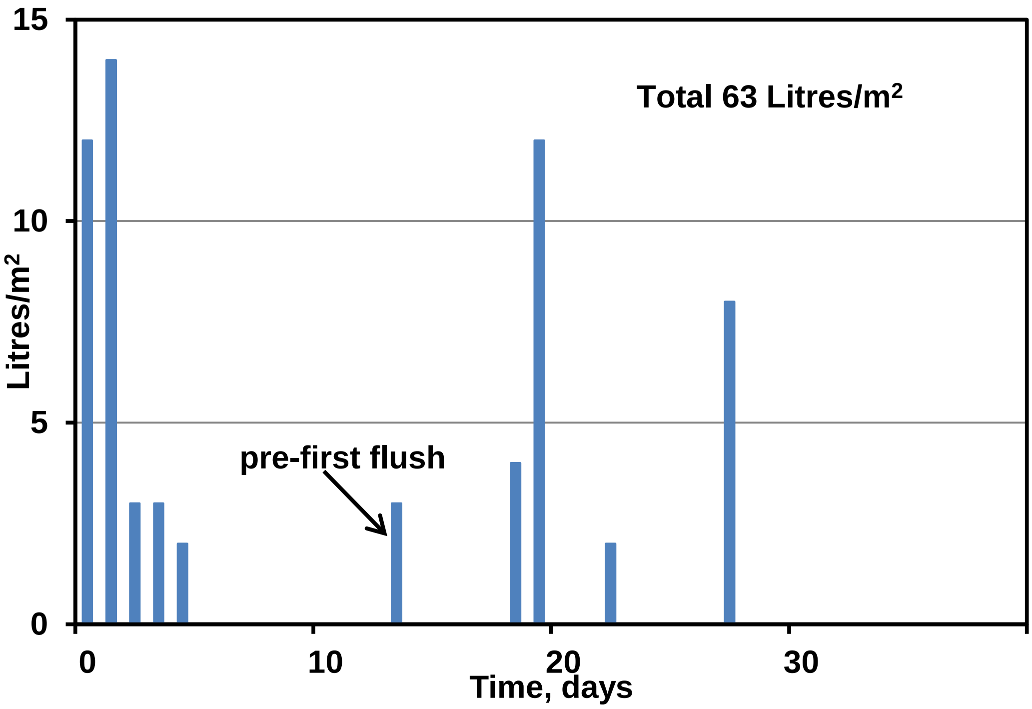

Fig. 6 Typical application of water to an overhead sprinkler irrigated crop

The application of individual waterings in response to the average output of three tensiometers in both the casing and compost is shown in Figure 7 where drip irrigation events were triggered using the average casing reading with a fixed duration irrigation. In Figure 7 the GP2 Data Logger is also recording individual irrigation volumes in litres/m^2 as well as calculating a running total of applied water in litres/m^2.

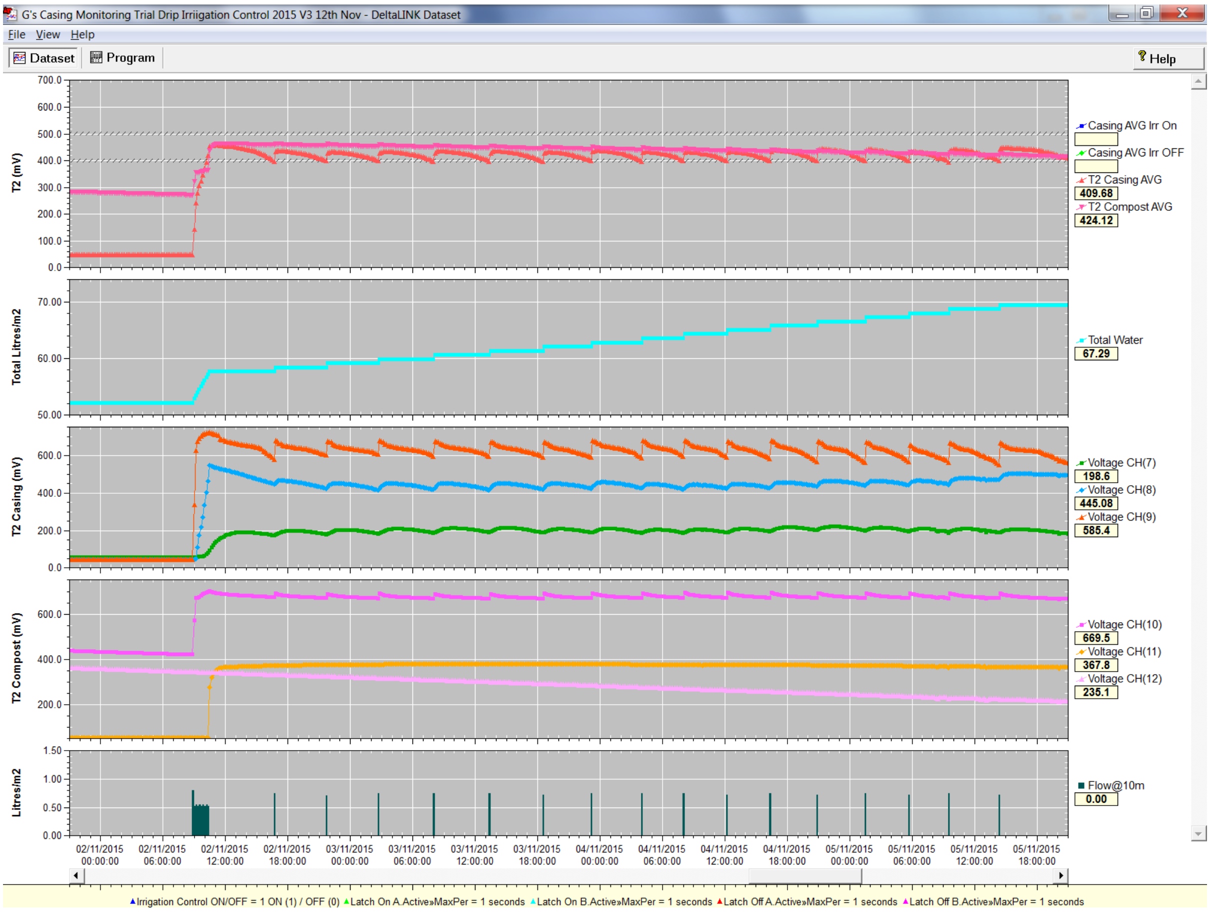

Fig. 7 Output of three FT1 tensiometers in casing (middle graph) and compost (lower middle graph), averages of tensiometers (top graph), water applied in total (upper middle graph) and individual waterings (bottom graph) in a crop with controlled drip irrigation

Measurements taken over the series of 12 crops have shown high mushroom yields (average 29 kg/m^2 in three flushes) and quality (93% class I) from both irrigation systems. Differences in cap color (whiteness and yellowness) or dry matter content between mushrooms grown in the two irrigation systems were not significant. However, the automated drip irrigation system resulted in heavier mushrooms for the same diameter (38.5 mm), with denser tissue than in mushrooms from a manually controlled sprinkler irrigation system (Table 2).

Table 2.Piece weight and tissue density of mushrooms grown on sensor controlled drip irrigation and timer controlled sprinkler irrigation. Each value is the average of five measurements taken on each of four replicate plots.

Flush	Test	Piece weight, g			Tissue density, mg/cm^3		
		Drip Irrigation	Sprinkler Irrigation	Average Flush	Drip Irrigation	Sprinkler Irrigation	Average Flush
1	1	15.2	14.4	**14.0**	658	628	**634**
	2	13.2	13.1		646	621	
2	1	14.8	14.4	**14.2**	682	669	**665**
	2	13.3	14.2		647	662	
3	1	15.5	14.0	**13.9**	765	698	**711**
	2	13.6	12.3		714	668	
Average		**14.1**	**13.5**		**685**	**658**	

Discussion

This work has shown that FT1 tensiometers positioned in the casing and compost can be used to control a drip irrigation system in a mushroom growing room, according to the water requirements of the casing and compost. Unlike an overhead sprinkler irrigation system, this has enabled water to be applied to mushrooms during a flush. The cropping benefit has been an improved mushroom piece weight and greater tissue density. The 4.5% heavier piece weight of mushrooms grown with the sensor controlled drip irrigation system may represent a saving in picking costs. Information from the moisture sensors may also have benefited decision making in when to apply water with the overhead sprinkler irrigation system, particularly in avoiding excess water running into the compost.

The work has shown that the sensors were resilient to disinfectant and steam cook-out. The PM on the sensors was replaced after each crop, but further tests have shown that it remains intact for at least three consecutive crops.

By monitoring the variability in casing and compost moisture between different shelves, the sensors could also benefit farms with conventional irrigation systems in opitimizing water applications and diagnosing watering problems and flucuations in mushroom yield and quality. Probes positioned in different layers and ends of growing rooms can identify wet and dry areas, and potentially enable more uniform availability of water to the crop and mushroom cropping. Data from sensors can be used to calibrate existing methods of irrigation scheduling so that when raw materials or environmental conditions change, the watering requirements can be adjusted accordingly. At May Farm, this information has been particularly useful when changing from one source of casing or compost to another source which has different water holding charcacteristics.

Further work is needed to determine whether information from moisture sensors can be used to reduce the application water and casing material to crops. This would be of particular benefit in countries where the availability of water is scarce and good quality peat casing unavailable. A pre-production FT1 dielectric tensiometer is shown in Figure 8.

Fig. 8 A pre-production FT1 dielectric tensiometer

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