A Method for Precision Closed-Loop Irrigation Control

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Abstract

The control of water supply in growth experiments is an area where experimental difficulties persist[1]. This study evaluates a precision soil moisture sensor controlled irrigation system that maintains the plant water status so that either: a) plant water status is consistent throughout the experiment or b) the system can be used to investigate the effects of varying soil water deficit irrigation on plant growth. The instrumentation described enables precision closed-loop irrigation control and consists of soil moisture sensors and irrigation control equipment with data logging capability. PC based software enables easy adjustment of irrigation parameters based on soil conditions and sensor responses to irrigation events. The data presented is from a tomato crop grown in a poly-tunnel and shows a method that can provide a stable soil matric-potential environment using irrigation-frequency-modulation techniques. The irrigation protocol takes into account the soil moisture sensor response to irrigation events where the aim has been to deliver a known quantity of water that avoids significant soil moisture overshoot from the desired soil moisture set-point without significantly stressing the crop. Using this plant water availability control/logging system, the plant water availability status can be maintained at pre-set values with minimal deviation so that the plant is subjected to the same conditions throughout the experiment. The plant water availability can be adjusted simply and easily at any time without the need to stop data logging. In this poster we demonstrate an approach that is much simpler than the use of weighing lysimeters or the use of tension tables. We present diagrams of our new approach as well as some example data sets.

Irrigation control strategy

In theory, to obtain precise closed-loop control of a system it is necessary to characterise every component in the control loop to derive the appropriate controller parameters, i.e. proportional, integral & derivative (PID) parameters in a PID controller. In practice this is often difficult to achieve. As a result empirical methods are employed to estimate the PID parameters by observing how the system performs under open-loop conditions[2]. Furthermore, the dynamics of the root zone can change with time and may require revised PID parameters.

In this poster we present an easy-to-use empirical method. This enables a researcher to create a simple control algorithm that accommodates the following soil moisture sensor parameters:

- time to fully respond to an irrigation event,
- maximum change in soil moisture for a known quantity of water.

These parameters can be easily estimated by inspection with Delta-T's: DeltaLINK software, a GP1 data logger and an SM300 soil moisture sensor.

By including a matric potential sensor it is possible to create an in-situ water retention curve to help select a suitable soil moisture irrigation set-point.

Measuring soil moisture

Soil moisture sensors supplied by Delta-T Devices Ltd. include the ML2x ThetaProbe, PR2/6 Profile Probe and the SM300 (soil moisture and soil temperature sensor).

Measuring matric potential

A prototype dielectric tensiometer sensor from Delta-T Devices Ltd., the DT160, measures the dielectric properties of ceramic blocks that are in equilibrium with the matric potential of the surrounding soil.

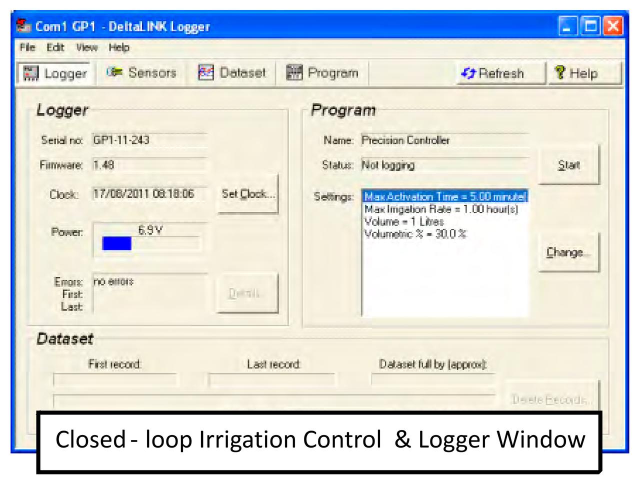
Irrigation control with data logging capability

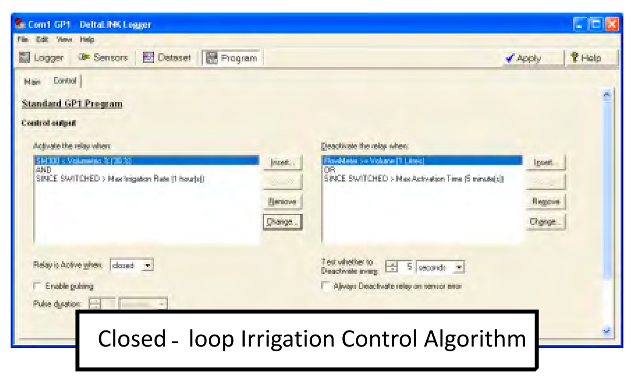
The GP1 data logger supplied by Delta-T Devices Ltd. operates with DeltaLink software. This provides real-time irrigation set-point adjustment and data logging capabilities.

The low-cost irrigation control system consists of:

- GP1 data logger operating with DeltaLINK software,
- SM300 soil moisture and soil temperature sensor,
- water flow meter (1 litre count resolution),
- solenoid water valve,and requires the following inputs:
- soil moisture,
- maximum irrigation frequency,
- irrigation water volume.

The GP1's relay is used to switch power to the solenoid water valve.





Experimental method

A small-scale experiment was set-up consisting of 9 tomato plants individually grown in pots containing John Innes No. 3 compost. The tomato plants were surface irrigated using two irrigation control strategies for comparison:

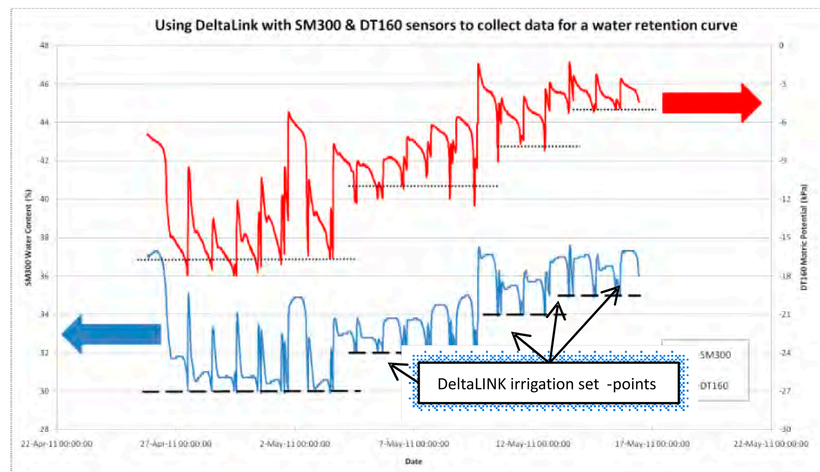
- Timed Irrigation with fixed water volume (3 plants),
- Closed-loop Irrigation using a soil moisture sensor (2 controllers for 6 plants).

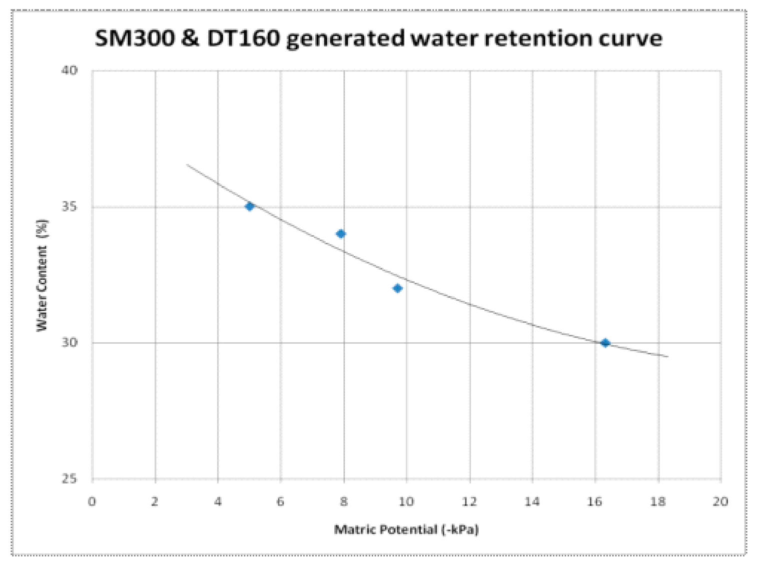
Soil moisture and matric potential data was obtained for a range of irrigation water volumes during early growth to:

- select an appropriate soil-moisture irrigation set-point, see in-situ water retention curve,
- identify the time required for the sensor to respond to an irrigation event, to set maximum irrigation frequency,
- select an appropriate irrigation water volume to achieve a 4 to 5% change in soil moisture.

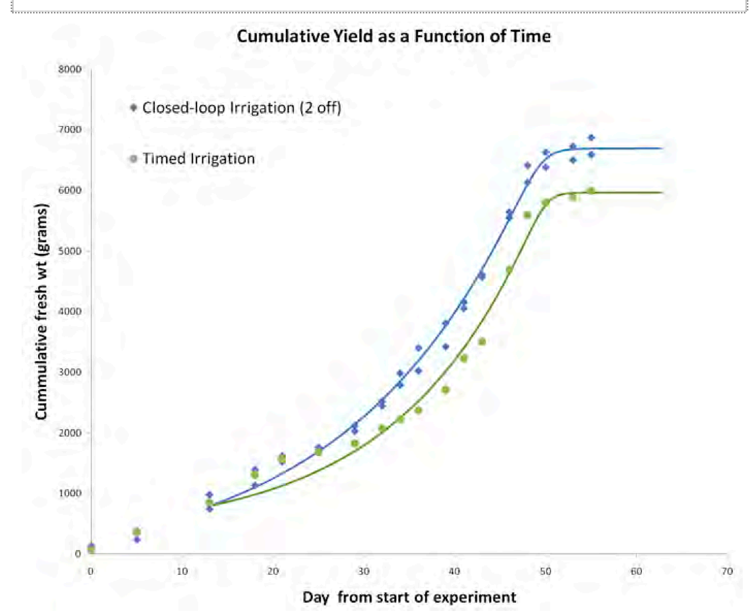
In-situ water retention curve with DeltaLINK

By adjusting the irrigation set-point over a range of soil moisture levels (via DeltaLINK) and logging sensor data for a number of irrigation events it is possible to collect data to generate an in-situ water retention curve.





From the logger data above a water retention (drying) curve can be created by plotting the average of the matric potential sensor (DT160 dotted lines) against the soil moisture irrigation set point (SM300 broken lines) at the point of irrigation. This data can help identify a soil moisture range that avoids plant stress[3] and over-watering conditions. In the tomato plant study the irrigation set-point was set at 30% soil moisture.

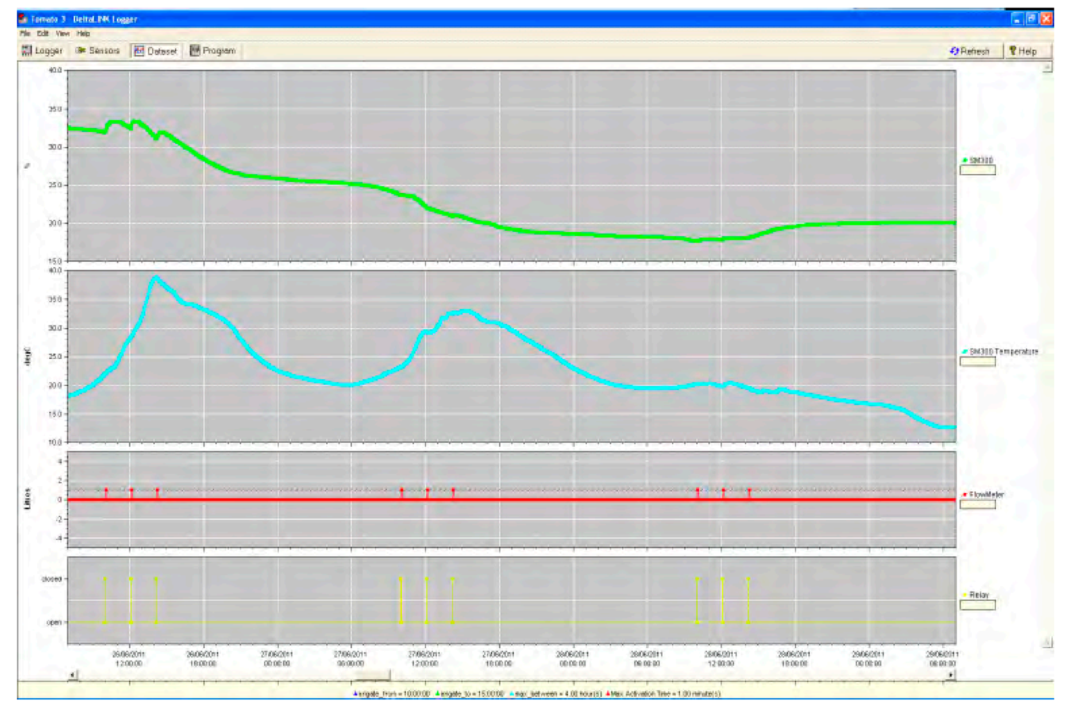


Crop yield comparison

Cumulative yield from the 3 plants in each of the 3 irrigation systems has been graphed against time. The crop production from the 2 sets of 3 plants under Closed-loop Irrigation are so similar they are graphed as one (•) whilst crop production from the 3 plants under Timed Irrigation (•) may show the effects of earlier soil moisture stress events.

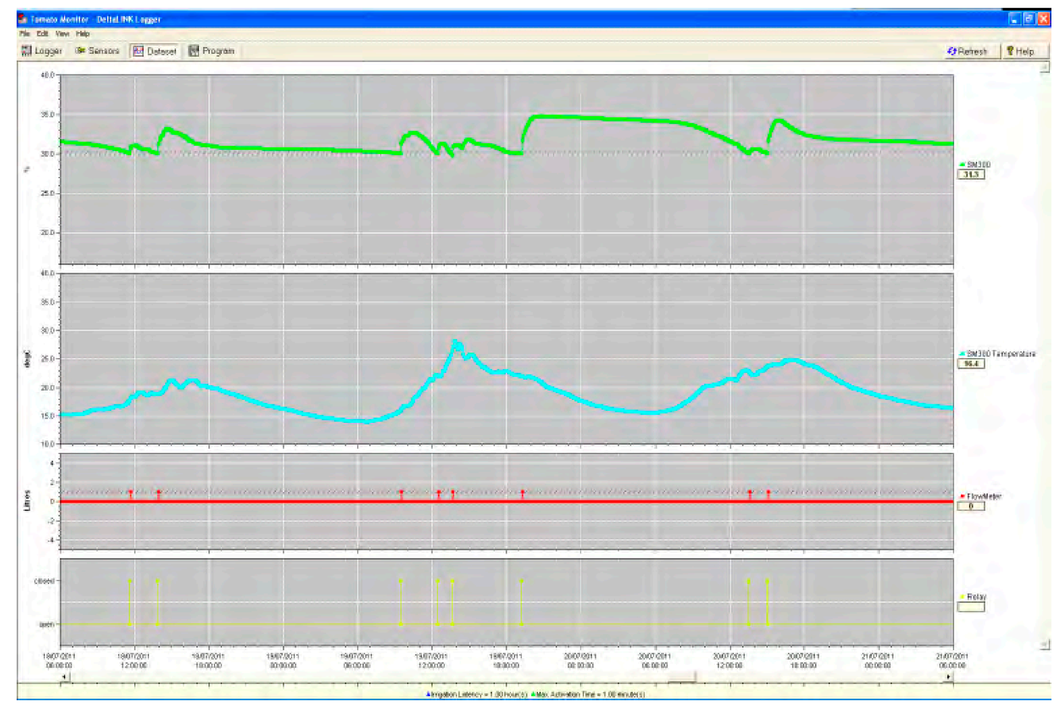
Irrigation strategy: Timed vs. Closed-loop Irrigation

The data shown below uses the same irrigation water volume of 1ltr/3 plants. In the case of Closed-loop Irrigation the maximum irrigation frequency is 1 irrigation per hour. The change in soil moisture in response to irrigation water volume is a linear relationship. In this experimental arrangement the precision level of 4-5% is limited by the resolution of the flow meter (1litre). With a higher resolution flow meter the precision level could be improved to 2-3%.



The data on the left shows that Timed Irrigation can result in significant variation in soil moisture that risks stressing the plant as the soil moisture drops from 33.5% to 17%.

The data on the right shows that soil moisture can be easily maintained above the set-point (30%) with Closed-loop Irrigation. This avoids plant stress conditions as well as providing effective water use management where the soil moisture remains between 30% and 35%.



Conclusions

In this work we have demonstrated a method of precision closed-loop irrigation control that can maintain plant water status so that either: a) plant water status is consistent throughout the experiment or b) the system can be used to investigate the effects of varying soil water deficit irrigation on plant growth.

By combining soil moisture and matric potential data for a range of soil moisture irrigation set-points it has been possible to generate an in-situ water retention (drying) curve. This aids the selection of an appropriate irrigation set-point to minimize water usage whilst avoiding the risk of crop stress. Delta-T's DeltaLINK software, with the GP1 data logger, can provide an easy means of empirically determining and adjusting irrigation control parameters whilst logging sensor data.

The small-scale crop study shows that investigations into irrigation methods and growth studies can be easily undertaken using Delta-T's low-cost sensor and irrigation control products. Also, crop weight results are in-line with the literature[4] which shows soil moisture controlled irrigation can deliver improved crop yields over a timed irrigation strategy.

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References

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