USING A WETTING FRONT DETECTOR TO MANAGE DRIP IRRIGATION IN STRAWBERRY

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Summary

During irrigation, water infiltrates into the soil forming a wetting front, defined as the boundary between wet soil above and drier soil below. The depth the wetting front reaches can be used to manage irrigation. The Wetting Front Detector (WFD) is a buried funnel that allows to detect when a wetting front has reached a given depth, and to collect the corresponding solution. The objectives of the present experiment were: 1) to verify the feasibility of managing the irrigation of a strawberry crop using only the information provided by a set of Wetting Front Detectors, 2) to verify whether this irrigation practice matched the demand of the crop by comparing it with 25% lower or 25% higher irrigations amounts.

Three irrigation treatments with 3 replicates were applied in a field experiment. The "control" treatment, in which the irrigation was managed so that the wetting front depth was stable around 45 cm, was compared with two other treatments, in which irrigation levels 25% lower ("deficit") and 25% higher ("excess") respectively were applied. Vegetative growth was evaluated by destructive sampling of 3 plants per treatment every 3 to 4 weeks. The fruits were harvested during the whole production cycle to evaluate yield and fruit quality. The plants that received the "control" and "excess" irrigation had a similar yield and fruit quality while the plants receiving "deficit" irrigation had a smaller yield and their fruits were drier (with higher °Brix). We conclude that the WFD allowed to manage the irrigation within an error margin lower than 25%.

Introduction

The applications of irrigation water and nitrogen fertilizer for strawberry crops in the state of Michoacán (México) are, in general, excessive. The Comisión Nacional del Agua estimates the water requirements of the crop at 12 500 m^3 ha^{-1} (1250 mm) during the cultivation cycle (CNA, 2005), but calculations of evaporative demand based on local reference evapo-transpiration (ETo) data and crop coefficients published for strawberries grown in California and Florida leads to an estimated demand of less than 7000 m^3 ha^{-1} (700 mm) (Clark, 1993; McNiesh, 1985; Snyder and Schulbach, 1992; Hansen and Bendixen, 2004; AgriMet, 1975). Excessive irrigation probably leads to significant nitrate loss by leaching, which may explain why farmers apply nitrogen doses up to 600 kg N ha^{-1} (Cárdenas Navarro, personal communication), against 50 to 250 kg ha^{-1} in the United States and Spain (Voth, 1991; Hochmuth et al., 1996; Miner et al., 1997; Cadahia, 1998).

Many techniques exist to monitor the water status of horticultural crops but most producers do not use them. The "Wetting Front Detector” is a new device that may help growers better manage water and fertilizer (Stirzaker, 2003, Stirzaker and Hutchinson 2005). During each irrigation event, water infiltrates into the soil forming a wetting front, which is the boundary between the wetted bulb (i.e., a volume of soil below the water source with a water content higher than field capacity) and the rest of the soil. The Wetting Front Detector is composed of a funnel buried in the ground. When the wetting front reaches the funnel, the water flow concentrates until the retention capacity of the soil is saturated and free water gathers at the base, moves through a filter and is collected in a reservoir. The depth the wetting front reaches before becoming undetectable depends mainly on the amount of water applied and the initial water content of the soil.

In previous studies, the inventors of the Wetting Front Detector have proposed several protocols to manage irrigation (Stirzaker et al., 2004). The objective of the present work was: 1) to validate a protocol to manage irrigation in a strawberry crop, and 2) to verify whether this irrigation practice matched the demand of the crop by comparing its performance with 25% lower or 25% higher irrigations amounts.

Materials and Methods

The experiment was carried out in a field of the Instituto de Investigaciones Agropecuarias y Forestales, in the Posta Veterinaria of the Universidad Michoacana de San Nicolás de Hidalgo (Morelia, Michoacán, México). The soil was a swelling clay (62% clay, 20% silt, 18% sand). The strawberry plants (cv. Aromas) were planted on 15

October 2005, in double lines at a density of 10 plants per meter on 85 cm wide furrows. Nine experimental units with an area of 15 m^2 each (4 furrows of 85 cm, with the two lateral furrows used as borders) were delimited and distributed in a completely randomized design. In these 9 units, 3 irrigation treatments with 3 replicates were applied. Irrigation was applied daily with a drip line (1.6 l/h drippers 30 cm apart). Each experimental unit was equipped with three Wetting Front Detectors buried at 30, 45 and 60 cm depths (27 detectors in total). The detectors were checked twice per week (once per day during the first two month). During the first month, excess irrigation was applied to allow plant establishment, then irrigation was managed using the Wetting Front Detector. The amount of water required was estimated by the response of the detectors at 45 and 60 cm depths. The "control" treatment was generated by adjusting irrigation up or down depending on the Wetting Front Detector response to the previous irrigation. The control treatment aimed for a > 2/3 response rate at 45 cm, but less than 1/3 at 60 cm. The other two treatment were then given 25% more water ("excess") and 25% less water ("deficit") than the control.

In each experimental unit, the maximum depth reached by the wetting front was estimated as that of the deepest detector that responded. The average depth of the wetting front was calculated as the average of the maximum depth in the three experimental units of the same treatment.

In an adjacent parcel, a weather station (Davis, Vantage Pro) was installed that provided an estimate of the potential evapo-transpiration (ETo). The applied crop coefficient (Kc) was calculated as the ratio of irrigation by ETo. Mature fruits were harvested twice a week, and the total fresh weight of the crop was measured. At each harvest, the soluble solids content (°Brix) of 5 representative fruits of each experimental unit was measured with a hand-held refractometer (Leica 7531L). The yield (sum of the fruit weight harvested in both harvests of the same week), average fruit size (yield divided by the number of fruits harvested in both harvests of the week) and average °Brix (average of 10 fruit sampled in both harvests of the week) were calculated every week. The statistical analysis was performed by ANOVA with repeated measures design (with irrigation fully randomized within the each harvest date and the experimental unit as a repeated factor). Since the variance of plant dry mass, leaf area and fruit yield were approximately proportional to the value of these variables, the ANOVA was performed on the logarithm of these variables to comply with the condition of homogeneity of variances. The software used to perform statistical analyses was R (R Development core team, 2004).

Results

Irrigation management

The objective of the “control” treatment, which was to obtain a 2/3 response rate in the detectors at 45 cm depth, was achieved during almost the whole experiment (Figure 1.B), and the average depth of the wetting front remained around 45 +/- 10 cm (Figure 1.D). In addition, over the 38 times the detectors were checked, in a single occasion (3% of the cases) the average depth of the wetting front exceeded 60 cm, and in other four occasions (8% of the cases) it did not reach 30 cm (Figure 1.D). The response rate at 30 cm, also around 2/3 was more stable than at 45 cm depth (Figure 1.A). However this reflected the heterogeneity of the irrigation system rather than a response to the irrigation dose: the detectors that were immediately below a dripper responded most of the time, while those that were between two drippers almost never responded. At 60 cm depth (Figure 1.C), the detectors never responded, except during two short periods of over-irrigation (with response rates above 75% at 45 cm) at the end of January and during mid-March. The only time we failed to achieve the objective of 2/3 response rate at 45 cm in the “control” treatment was during the last month of the experiment, because of a problem with the quality of the fertirrigation solution that clogged the filters of the dripper lines in the “control” and “excess” treatments. In the “control” treatment the clogging started progressively in mid-March and went unnoticed for a month. In the “excess” treatment, the clogging was sudden and almost blocked irrigation for a week during mid-March, until the problem was corrected.

In contrast to the “control”, in the “deficit” treatment the response rate at 30 cm fell down to less than 25% two month after planting (that is, when the “control” irrigation regime was fully established), and to almost nil at 45 and 60 cm depth. In the “excess” irrigation, the response rate at 30 cm (Figure 1.A) was similar to that of the “control” (again reflecting the heterogeneity of the irrigation system rather than a response to the irrigation dose). At 45 cm, the response rate was always above 75%, and higher than in the “control” (Figure 1.B). The “excess” treatment was the only one to show a significant response at 60 cm, with a response rate consistently higher than 50% (Figure 1.C).

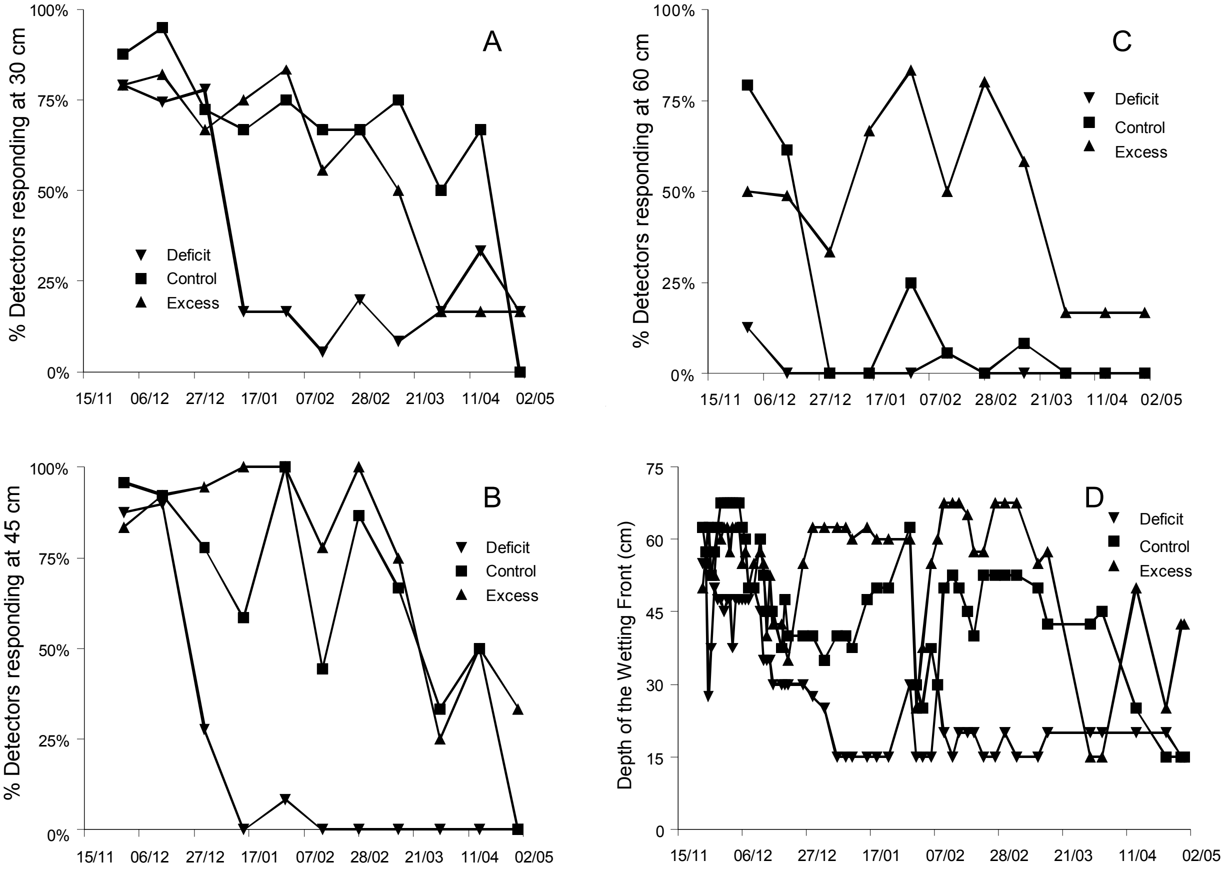


Figure 1. A., B., C. Percentage of the detectors that respond at 30 cm, 45 cm and 60 cm respectively, calculated as biweekly average (3 detectors over 4 observations), D. Evolution of the average depth of the wetting fronts (calculated as the average depth at which the deepest detector responds in three replicates explain in more detail) at each observation date. Irrigation in the ”control" treatment was managed using the WFD. The “deficit", and" excess" treatments corresponded to irrigation levels of 25% lower and 25% higher respectively than the “control”.

The irrigation amount applied in the “control” treatment increased regularly during the crop cycle, from approximately 2 mm/day in December to 4 mm/day in May (Figure 2.A). This corresponded to a variation of the applied crop coefficient (Kc) from 0.66 in January to 0.8 in May (Figure 2.B).

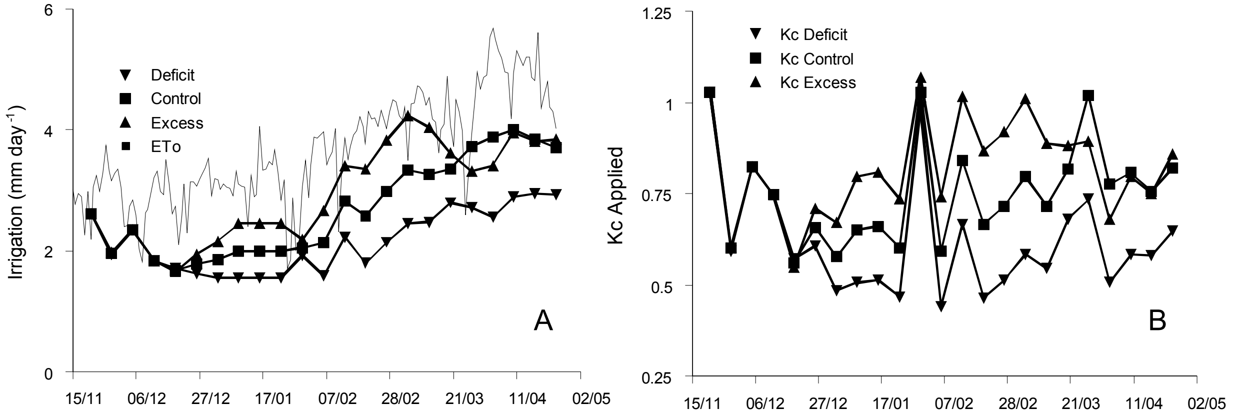
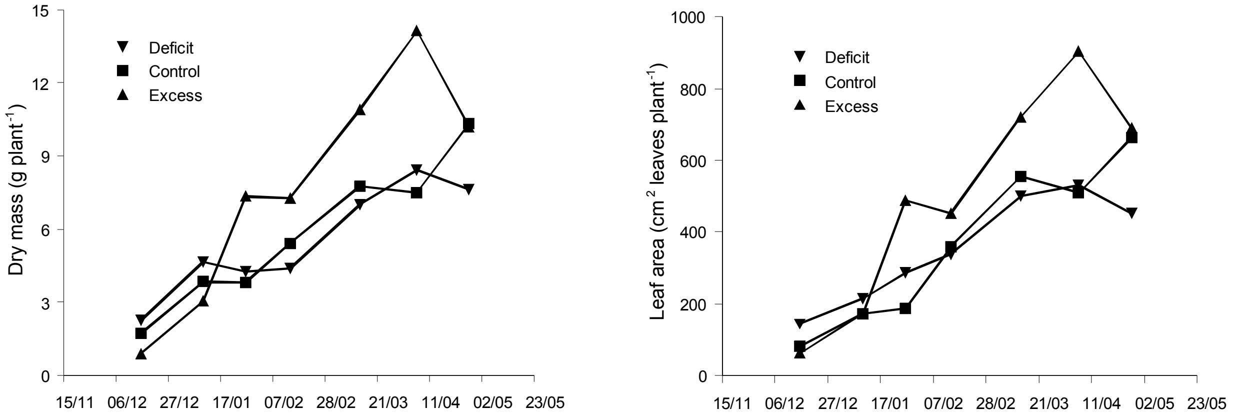


Figure 2. A) Evolution of reference evapo-transpiration (ETo, thin line) and irrigation dose in the three treatments during the crop cycle, B) Evolution of the applied crop coefficient (Kc). Irrigation in the "control" treatment was managed using the WFD. The "deficit", and" excess" treatments corresponded to irrigation levels of 25% lower and 25% higher respectively than the "control". The peak in the crop coefficient observed in February corresponds to a rain of 10.5 mm.

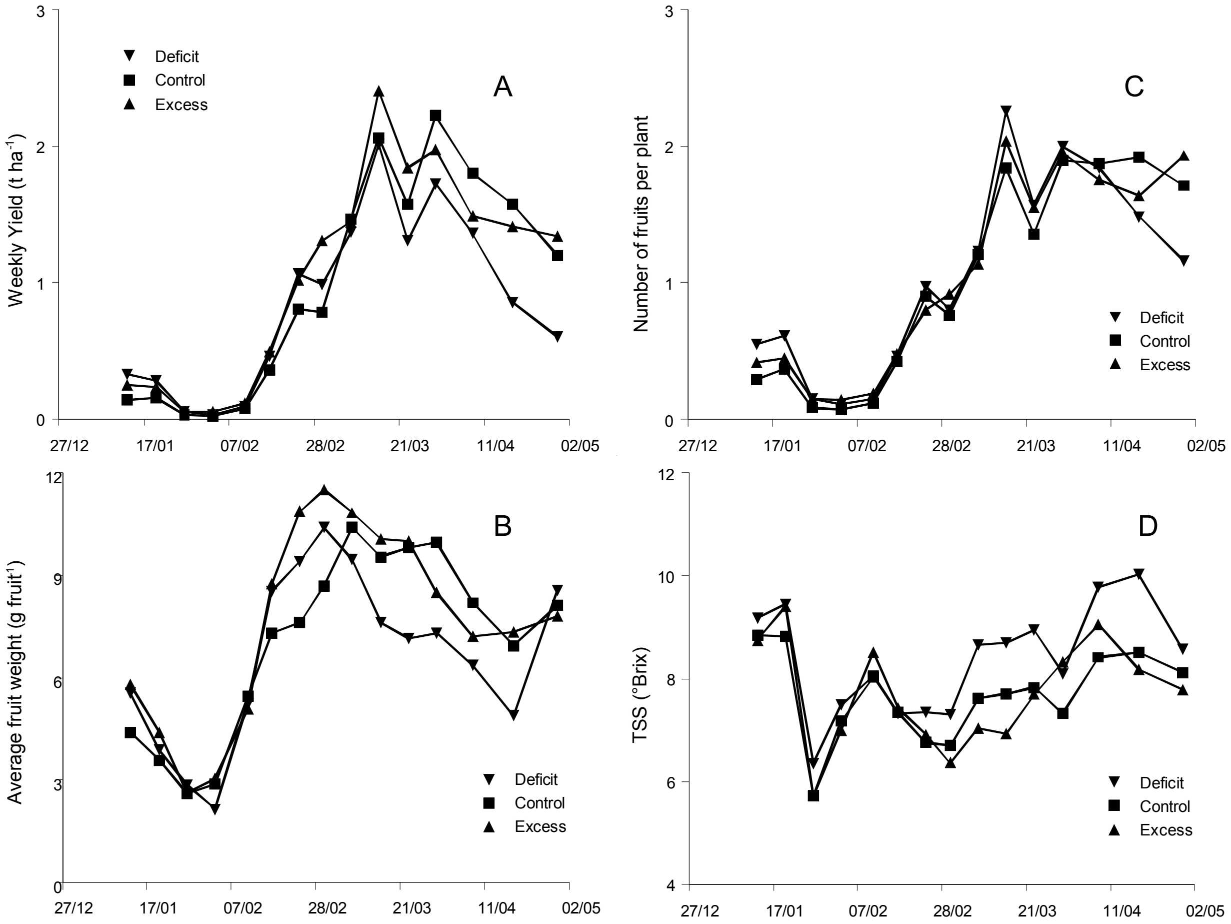
Crop performance

The behavior of the crop allowed to verify whether the irrigation applied in the "control" treatment was really optimum. In this case, no significant differences in crop performance should be observed between the "control" and the "excess" irrigation, while the "deficit" irrigation should affect the crop.



Figures 3. A. Dry matter accumulation and B. Leaf area increase per plant. Irrigation in the ”control" treatment was managed using the WFD. The “deficit", and" excess" treatments corresponded to irrigation levels of 25% lower and 25% higher respectively than the “control”.

Vegetative growth was apparently affected by irrigation, with higher leaf area and plant dry mass in the “excess” treatment. In the field, plants from the “deficit” irrigation also appeared to have a less developed canopy with smaller leaves. However, a careful ANOVA of these data revealed no statistical effect of irrigation (p > 0.15).



Figures 4. A. Yield, B. Average fruit weight, C. Number of fruits per plant and D. Total soluble solids content. Fruits were collected twice a week and both samples from the same week were pooled. Yield and

number of fruits are calculated as the sum of both harvests, fruit weight and TSS as their average. Irrigation in the ”control" treatment was managed using the WFD. The “deficit", and" excess" treatments corresponded to irrigation levels of 25% lower and 25% higher respectively than the “control”.

The irrigation affected fruit yield (Figure 3.A), as the repeated measures ANOVA revealed a significant interaction ($p < 0.05$) between the date and irrigation factors. Over the whole cycle, the cumulative yield in irrigation the “deficit” irrigation was 12.5 t ha^{-1}, against 14.3 and 15.4 t ha^{-1} in the “control” and “excess” irrigation respectively. This amounted to a 16% yield reduction in the “deficit” irrigation treatment, while no significant difference were found between the “control” and “excess” irrigations. This yield decrease was not due to a reduction if the number of fruits produced (Figure 3.C), where no significant effect of irrigation was found, but rather by their size (Figures 3.B), as indicated by a highly significant interaction ($p < 0.001$) between the date and irrigation factors.

Fruit quality was also affected (Figure 3.B.), with a significant effect of irrigation ($p < 0.05$). The average TSS was higher in the “deficit“ irrigation treatment, while no differences were observed between “control” and “excess” irrigation. It is interesting to note that the effects of irrigation on fruit yield, size and quality were noticeable only after mid February, that is during the period of peak production and/or higher evaporative demand, while no difference in were observed at the beginning of the cycle.

Conclusions

From a practical point of view, the Wetting Front Detectors worked as expected under our local conditions (furrows and swelling clay soil). The irrigation management protocol applied in the control achieved its objectives: it was easy to adapt irrigation time to maintain the depth of the wetting front around 45 cm. However, the proportion of detectors responding at 30 and 45 cm depths appeared to decrease slowly during the whole cycle. Apart for the clogging of the filters, an explanation of this decrease in the response of the detectors may be that during the last three month of the experiment, while the evaporative demand increased quickly, the adjustment of the irrigation time was done only twice a week, so that irrigation lagged behind the increase of evaporative demand by 3 to 4 days.

The protocol implemented to install the detectors and interpret their response was quite different from the one proposed by the inventors of the technique (Stirzaker at al., 2004). They suggested managing irrigation to keep the wetting front between two detectors installed approximately at half the depth of the root system, and immediately below the root system. For strawberry, with a root depth around 35 to 40 cm, this would have implied installing the detectors at 20 and 40 cm and maintaining the wetting front around 30 cm. However, previous experience with strawberries on the same soil has shown that this protocol led to insufficient irrigation. In the present experiment, the depth of the wetting front was maintained around 45 cm, which proved to be adequate. The reason why wetting fronts deeper than the root depth are needed is likely to be that the soil is a swelling clay with cracks and high macroporosity. During irrigation, the water infiltrates quickly through the macropores, and later redistributes by capillarity. In this situation, the water that will be used by the plant is likely to infiltrate deeper than the root zone before reaching the roots by capillarity.

When comparing “deficit” against "control" and “excess” irrigation treatments, a lower fruit yield was observed, while the “excess” irrigation did not significantly differ from the “control”. The fruits from the “deficit” irrigation, in addition to being smaller, also had a higher TSS content. In this case, higher TSS content should not be mistaken with higher fruit quality but rather revealed drier and less juicy fruits (as observed by tasting the fruits). These results confirmed that irrigation managed using the wetting front detector actually met the demand of the crop, at least within the +/- 25 % range tested: reducing irrigation affected yield and quality, while increasing it didn't bring any improvement.

The crop coefficient applied in the “control” irrigation treatment increased from Kc=0.66 two months after planting to Kc=0.8 at the end of the cycle. The only recommendations found in the literature for a fully developed strawberry crop vary between 0.6 in Florida (Clark, 1993), 0.7 (McNiesh, 1985; Snyder and Schulbach, 1992; Hansen and Bendixen, 2004) and 0.95 (AgriMet, 1975) in California. The value of Kc=0.8 we found for the fully developed crop under our conditions fits well inside this range. In contrast, the value of Kc=0.66 we found at the beginning of the experiment, when the crop was only two months old, seems quite high compared to crop coefficients of 0.2 to 0.4 given by the same authors in the early stages. The explanation may be in the principle of the wetting front detector itself: smaller irrigations (in the early stages of the crop) lead to weaker wetting fronts that are more difficult to detect than with bigger irrigations. Therefore, the detectors may have underestimated the presence of the wetting front and overestimated the irrigation requirement in the early stages of the crop.

In conclusion, the wetting front detector proved to be a viable alternative to other more complex and/or expensive techniques for the management of irrigation in strawberry, and in horticultural crops in general. In this experiment, irrigation was managed using only a set of 9 detectors installed at 45 cm depth. From our practical experience with the detectors, we suggest that a set of 4 to 6 detectors installed between 40 and 50 cm of depth should provide enough information to manage irrigation in a small field (up to 1 ha) with the protocol applied in this experiment. However, additional studies to further refine the interpretation of the wetting front detections and to validate these recommendations in commercial conditions.

References

AgriMet. 2006. AgriMet Crop Coefficients: Strawberries. The Pacific Northwest Cooperative Agricultural Weather Network. http://www.usbr.gov/pn/agrimet/cropcurves/SBRYcc.html.

Cadahia L.C. 1998. Fertirrigación. Cultivos hortícolas y ornamentales. Ediciones Mundi-Prensa. España. 475 pp.

Clark, G.A. 1993. Water requirements for drip irrigated strawberries in South Central Florida. Document EA 253, Agricultural and Biological Engeneering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Services, University of Florida. http://edis.ifas.ufl.edu.

Hanson, B., Bendixen, W. 2004. Drip irrigation evaluated in Santa María Valley strawberries. California Agriculture 58(1):48-53.

Hochmuth, G.J. 1995. Manejo de fertilizantes con riego por goteo para hortalizas. In: Uso de la plasticultura para la producción intensiva de hortalizas. pp 17-24.

Hochmuth G J, E E Albregts, C C Chandler, J Cornell, J Harrison. 1996. Nitrogen fertigation requeriments of drip-irrigated strawberries. J.Amer. Soc. Hort. Sci. 121:660-665.

Hutchinson PA and Stirzaker RJ. 2000. A new method and device for scheduling irrigation. Irrigation Association of Australia, May 23-25, 2000 National Conference, p 584-592.

McNiesh, C.M., Welch, N.C., Nelson R.D. 1985. Trickle irrigation requirements for strawberries in Coastal California. J. Amer. Soc. Hort. Sci. 110(5): 714-718.

Miner G S, E B Poling, D E Carroll, L A Nelson. 1997. Influence of fall nitrogen and spring nitrogen-potassium applications on yield and fruit quality of 'Chandler' strawberry. J.Amer. Soc. Hort. Sci. 122:290-295.

R Development Core Team. 2004. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org.

Snyder, R.L.; Schulbach, K.F. 1992. Central coast crop coefficients for field and vegetable crops. Drought Tips 92(45).

Stirzaker RJ Hutchinson PA and Mosena ML. 2000. A new way for small farm irrigators to save water. (in: proceedings of the 6th International Micro-irrigation congress, 23-26 October, 2000, Cape Town. South African National Association of Irrigation and Drainage, Cape Town, p. 4.3, 1-10.

Stirzaker RJ. 2003. When to turn the water off: scheduling micro-irrigation with a wetting front detector. Irrigation Science. 22: 177-185.

Stirzaker RJ and et Wilkie J. 2002. Four lessons from a wetting front detector. The Irrigation Association Of Australia, 2002 National Conference And Exhibition.

Sitrzaker, RJ, Stevens J, Annandale J, Maeko T, Steyn M, Mpandeli S, Maurobane W, Nkgapele J, Jovanovic N. 2004. Building Capacity In Irrigation Management With

Wetting Front Detectors. Water Resarch Comission report, University of Pretoria Report to the Water Research Commission. Research Project No 188.

Voth V. 1991. Pomology strawberry research. Australian Berry Fruit Growers Federation. National Conference, Hobart, Australia.