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MANGO WATER RELATIONS AND IRRIGATION SCHEDULING

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ABSTRACT

Irrigation management is critical to the success of mango production. This paper presents recent developments in techniques for assessing the water status of mango trees and understanding mango physiology. Water status in trees is commonly studied by measuring leaf water potential, but due to mango's excessive latex exudation, leaf water potential measurements can not be reliably measured. We have employed xylem sap flow in the tree trunk, micro-variation of branch diameter (microdendrometry), leaf gas exchange and other techniques to study mango water relations.

The main Australian mango cultivar Kensington Pride is very sensitive to air dryness, more so than most Florida cultivars. Stomatal conductance in mango is negatively correlated with air dryness and the severe reduction in photosynthesis in mango during the dry season could not be overcome by ample irrigation.

Both sap flow (tree water use) and twig/branch shrinkage have been shown to be good plant-based indicators of plant water status and been successfully used to control irrigation. However, at the present time, both techniques are far from being practical or economical enough to be used by growers for their irrigation scheduling.

A low cost, farmer friendly tool for irrigators, FullStop, was developed by CSIRO in Australia. FullStop is a simple device buried in the ground in the rooting zone, which will tell the irrigators when to switch off irrigation. This system has great potential to be adopted by many growers.

The Pakistan mango industry, especially in the sub-tropical region, is looking for the introduction of a drip irrigation system. In tropical regions in Australia, almost all mango growers use under-tree micro-sprinkler systems. There were a number of growers who trialled drip irrigation, but sooner or later they all changed to a micro-sprinkler system. The driving forces for the change have been ease of field management and reduced need for water filtration and treatment when using sprinklers.

Key words: Whole-tree water use, sap flow, shrinkage, photosynthesis, irrigation scheduling, drip irrigation, plant-based water status indicator, FullStop.

1. INTRODUCTION

Irrigation management is critical to the success of mango production. Irrigators are faced with two questions: when to irrigate and how much? In order to maintain an optimal water status and prevent trees from a significant loss of productivity under limited water availability, water relations of mango trees (water requirement-time and quantity, physiological response to water deficit, etc) need to be understood.

Water status in trees is commonly studied by measuring leaf water potential, but excessive latex exudation in mango prohibits reliable measurements of leaf water potential. Alternative methods such as xylem sap flow in the tree trunk, micro-variation (shrinking and expansion) of branch diameter (microdendrometry), leaf gas exchange and other techniques have been employed to study mango water relations.

There is a large range of irrigation scheduling tools in the market, from the simple to the more sophisticated, but most of them are still too expensive for farmers in the developing countries. A low cost, farmer friendly irrigation scheduling tool (FullStop) for small growers was developed by CSIRO in Australia. It is a simple device buried in the ground in the rooting zone, which will tell the irrigators when to switch off irrigation. This system has had much success in South Africa and is now being trialled by many horticultural industries in Australia.

This paper highlights recent development of mango tree water relations, its application in irrigation scheduling and to introduce the FullStop to mango growers.

2. MANGO WATER RELATIONS: STOMATAL CONDUCTANCE, WHOLE-TREE WATER USE, ORGAN SHRINKAGE

2.1. Photosynthesis and stomatal conductance

Since 1990, we have been extensively studying photosynthesis and stomatal conductance of several mango cultivars grown in the seasonally wet-dry tropical region of northern Australia. During the wet season, all five mango cultivars performed similarly at their highest photosynthetic capacity (Figure 1a). As the dry season progressed and a soil water deficit developed, all mango trees progressively decreased their photosynthesis rates but to different degrees. The Australian mango cultivar Kensington Pride (KP) had significantly lower photosynthesis rates than other cultivars. Ample irrigation at the peak bloom did not significantly improve photosynthetic performance of the mango trees. Even under adequate irrigation, high levels of air dryness (as indicated by leaf-air vapour pressure deficit, LAVPD) significantly reduced stomatal conductance of mango leaves and KP was more sensitive to air dryness than Irwin (IR) (Figure 1b).

2.2. Whole-tree water use

Whole-plant water use provides a baseline for a plant's irrigation requirement. The measurement of whole-plant water use in trees is much more difficult than in field crops, owing mainly to their large size (Wullschleger et al., 1998). For large trees, measurement of the flow of xylem sap is the most common approach to estimate whole-tree water use. The development of thermo-electrical methods for the direct measurement of xylem sap flow in tree trunks or branches over the last two decades has provided tree physiologists with an accurate and convenient tool to study whole-tree water use and water relations. Granier's heat dissipation method (Granier, 1985; Lu et al., 2004) with the potential to integrate the axial sap flux density along its 2-cm-long probe, thus reducing the measuring error due to microvariation in the wood structure, is becoming popular among tree physiologists and hydrologists (Kostner et al., 1998, Wullschleger et al., 1998).

Figure 2 summarises the spatial variation in sap flux density (Fd, kg dm^{-2} h^{-1}) within sapwood. Mango trees have a very large sapwood width, exhibited as Gaussian/decreasing or even/decreasing patterns (Figure 2a). Substantial sap flow at the centre of the trunk of these large trees distinguishes mango from other diffuse-porous species studied so far, e.g., *Citrus* and

Populus. It highlights the importance of studying radial trends in sap flow in mango trees (Lu et al., 2000). Sap flux density measured at different aspects around the stem varied substantially and without a constant pattern in orchard mango trees (Figure 2b). To cover these variabilities, a new sap flow measurement system was developed (Lu, 1997). Using this technique we have extensively studied mango water use in Australia.

An irrigator constantly faces two questions: when to irrigate and how much? Sap flow measurements can provide answers to both these questions. Figure 3 shows the general correlation between whole-tree water use (sap flow) and tree size (trunk diameter) for mango trees grown in the Darwin region. Based on the whole-tree sap flow measurement we can quantitatively estimate the whole-tree water use and use it as the baseline to determine the irrigation requirement. The idea is to match the irrigation input as closely as possible to the actual transpirational water loss (estimated by sap flow) by improving the efficiency of water delivery. Readers are cautioned to multiply it with a factor (say, 1.3) to take account of water losses due to wind, evaporation, deep drainage and surface runoff.

Sap flow was also found to be an indicator for plant water status. On mature KP mango trees grown on deep sandy-loam soil in the field (Figure 4), the ratio of the daily sap flow (Dry/Control) repeatedly fell to about 0.85 when volumetric soil moisture fell to 15% and other indicators (microdendrometry, stomatal conductance) revealed signs of stress (see figure 7 for the period between 26 August to 2 September when the twig shrinkage index also revealed signs of stress). This suggested that the sap flow may also reliably indicate the onset of the plant water stress for field grown mature trees.

2.3. Branch/twig and fruit shrinkage

Branches or twigs and fruits generally shrink while actively transpiring during the day time, but expand during the night time (Figures 5 a & b). Figure 5b shows variation in twig diameter (pointed line) and in fruit diameter (solid line). Although fruit showed rapid net increase in diameter (size) as a result of net increase in carbohydrate storage, it still showed diurnal shrinking/expanding cycles. As a soil water deficit developed on 25 September (26/9), a sudden reduction in diameter was observed in both fruit and twig. It is easier to monitor twigs than fruits so our research was subsequently concentrating on twigs.

Figure 6 shows diurnal changes in branch diameter (black line) and sap flow (red line) of a group of well watered (“Control”) and water stressed (“Dry”) mango trees. For the controls, diameter variation and sap flow both exhibited normal patterns, but the “Dry” trees, on day 3 after the last irrigation, showed significant reduction in both diameter and sap flow, clearly indicating the onset of a tree water deficit.

3. TWIG SHRINKAGE AS AN INDICATOR FOR IRRIGATION SCHEDULING

The above results have showed the ability of the two plant-based measurements to indicate the onset of plant water stress/deficit. In a field trial, we compared three irrigation scheduling methods: control (irrigated according to local authority’s recommendation), microdendrometer (changes in twig diameter as an indicator of the time when irrigation is required) and soil water monitoring (farmer’s own irrigation schedule based on soil moisture measurements using a capacitance probe).

To utilise the information of microdendrometers to control irrigation on mango, we developed a “shrinkage index” to quantify the plant water status. This index was reliable over two growing seasons: the index of the control trees never rose above 25 (Figure 7), while the microdendrometers piloted trees (“Dendro”) showed sign of stress when the index hit a threshold of 30. We purposely withheld irrigation when the index reached 30 for the first time to determine that this index value of 30 or above remained until re-watering. Comparing the soil moisture and sap flow data during the first drying cycle in Figure 4 with the change in Dendro’s shrinkage index values, it showed to be an excellent indicator of the onset of water stress.

However, a comparison of the sensitivity of the indicators examined (sap flow, microdendrometry, stomatal conductance and soil moisture) showed that sap flow was not as sensitive as other indicators such as the microdendrometry. From well watered to stressed conditions, a range of changes in sap flow ratio was only 15%, while microdendrometers exhibited a change of 30%. Furthermore sap flow was a less sensitive indicator of water stress under field conditions in soil with high water holding capacity.

Results from the two year field trial showed that trees under irrigation controlled by the dendrometers using the shrinkage index as indicator had better water use efficiency than fully-irrigated trees at 80% evaporation replacement (Control) and farmer's own method (Table 1).

Both the dynamics of sap flow (tree water use) and twig/branch shrinkage have been shown to be good plant-based indicators of plant water status and have been successfully used to control irrigation. However, at the present time, both techniques are far from being practical or cheap enough to be used by growers for their irrigation scheduling (Lu, 2002; Yunusa et al., 2004).

3. FULLSTOP, A PROMISING, CHEAP IRRIGATION SCHEDULING TOOL FOR MANGO GROWERS

There are already many tools and services available for monitoring soil water levels, but around 90% of irrigators do not use them. Low cost and simplicity are essential if more farmers are to use these devices. However simplicity cannot be at the expense of accuracy, so we need to find the balance between simplicity, accuracy and cost for improving water and nutrient management from a low base (Stirzaker et al., 2004).

CSIRO scientists developed and introduced a wetting front detector "FullStop" for farmers and the performance of this detector was evaluated on a range of farms under surface drip, buried drip, fixed sprinkler, centre pivot and mini-sprinkler irrigation on a variety of annual and perennial crops (including mango). FullStop is a funnel-shaped instrument that is buried in the soil (Figure 8). The funnel concentrates the downward movement of water so that saturation occurs at the base of the funnel. The free (liquid) water produced from the unsaturated soil activates an electronic or mechanical float, alerting the farmer that water has penetrated to the desired depth and it is the time to "stop" irrigation. The FullStop system has had much success in South Africa and is now being trialled by many horticultural industries in Australia.

Several studies have shown that the wetting front detector helps irrigators to evaluate their own practices and challenges their perceptions of what is happening in the root zone. Detectors do not provide quantitative data, but help irrigators to move in the right direction; after all, the soil is a buffer and it is not important to be right every time – just important not to be consistently wrong, as errors in water application accumulate over time (Stirzaker et al., 2004).

4. IRRIGATION DELIVERY: DRIP IRRIGATION OR MICRO-SPRINKLERS IRRIGATION

The Pakistan mango industry, especially in the sub-tropical region is looking for the introduction of a drip system. Drip irrigation is not commonly used for mango trees in Australia. In tropical regions in Australia, almost all mango growers use under-tree micro-sprinkler systems. There were a number of growers who trialled drip irrigation, but sooner or later they all changed to a micro-sprinkler system. The driving forces for the change have been ease of field management (spot the failures of the drippers from a motor-bike) and reduced need for water filtration and treatment when using sprinklers.

Most of the published studies on drip irrigation on mango were made in India in the last decade and mainly from a group at Gujarat Agricultural University (Desai et al., 1999). However, there is a decline in published works on mango since the beginning of year 2000. Desai and his colleagues discussed the major constraints faced by mango growers in adoption of the drip system (Desai et al., 1999). Economic constraints were the high cost of spare parts, heavy initial expenses for installation of a drip irrigation system, the lack of capital for covering an entire area under drip irrigation. Technological constraints were frequent clogging of drippers and microtubes, minor repairs, damage caused to the system by rodents and jackals, difficulties in maintaining water pressure for a long period, and lack of technical know-how (Desai et al., 1999).

It is more likely that drip-irrigated plants will suffer from more severe water stress than plants under other systems when a failure of the irrigation system occurs. This is because drippers wet a much smaller volume of soil (thus a smaller buffer) than other irrigation systems, such as micro-sprinkles. Growers planning to adopt new irrigation systems are advised to be fully aware of the advantages and disadvantages of different systems and should make careful decisions according to their particular growing conditions and financial situations.

5. CONCLUDING REMARKS

Both the dynamics of sap flow (tree water use) and twig/branch shrinkage have been shown to be good plant-based indicators of plant water status and have been successfully used to control irrigation. However, at the present time, both techniques are far from being practical or cheap enough to be used by growers for their irrigation scheduling (Lu, 2002; Yunusa et al., 2005).

Sap flow measurements may be used to refine irrigation management in a trial involving several irrigation regimes. The regime with the minimum irrigation input that maintains yield and fruit quality as the well-watered control trees should be the most efficient irrigation regime. In the case of regulated deficit irrigation, sap flow measurement should also permit us to gain an insight into a tree’s reaction to various deficits at different phenological stages.

More fundamentally, measurements of whole-tree transpiration (sap flow) together with micrometeorological and canopy variables should permit us to better understand the whole-tree processes involved in controlling canopy water loss and its relationship with whole-canopy photosynthesis, especially under different canopy or irrigation management regimes.

The Fullstop wetting front detector is simple and cheap and has great potential to be adopted by many growers worldwide.

Drip irrigation is not commonly used for mango orchards in Australia. The Pakistan mango industry should seek more information from Indian mango growers/researchers and carefully adopt the most suitable irrigation system which is best for their own growing conditions and financial situation.

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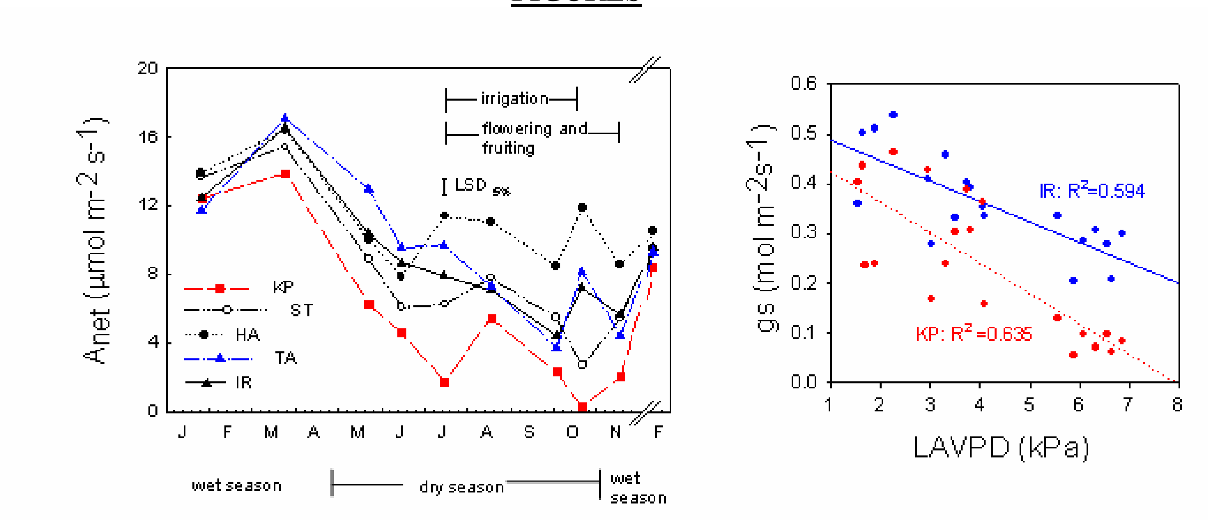
TABLES

Table 1: Performance of three irrigation scheduling methods (Control: irrigated at recommended rate (NTDPIF); Farmer: controlled by the farmer using soil water monitoring tool; Microdendrometer piloted: irrigated when daily shrinkage index increased to 30. Water used (sap flow) was measured with 5 replicates per treatment and yield with 6 replicates per treatment).

Treatments	**Water provided (L/tree/day)**	**Water used (L/tree/day)**	**Fruit yield (kg/tree)**	**Irrigation efficiency (%)**
Control	170	53	64	31
Farmer	125	47	60	38
Dendrometer piloted	79	61	58	77

FIGURES



(a) **(b)**

Figure 1: Seasonal variation in net photosynthesis rates (Anet) of five mango cultivars in Darwin, northern Australia (KP: Kensington Pride, ST: Strawberry, HA: Haden, TA: Tommy Atkin, IR: Irwin) and (b) correlations between Stomatal conductance (gs) and air dryness (LAVPD: leaf-air vapour pressure deficit).

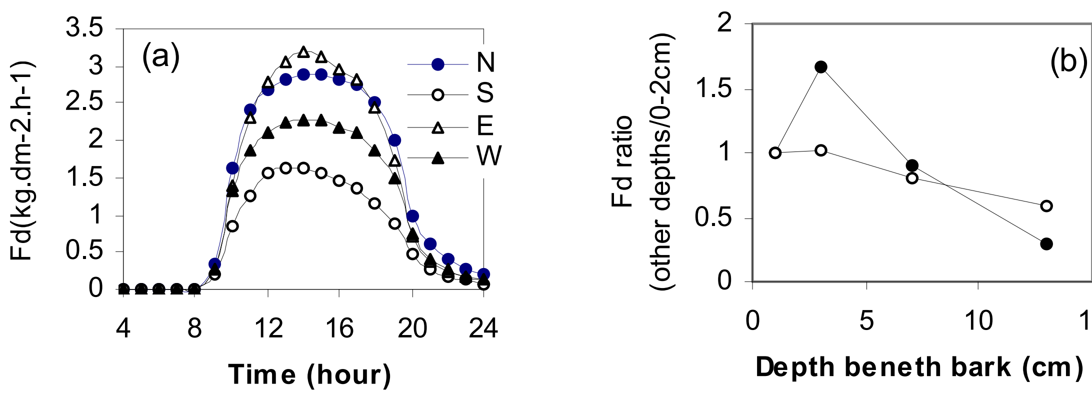


Figure 2: (a) Circumferential variation in trunk sap flux density (Fd) and (b) depth profiles of sap flux density at 0-2 cm versus other depths (Fd ratio) in trunk of mango trees (after Lu et al., 2000). Legends E, S, W and N represent east, south, west and north.

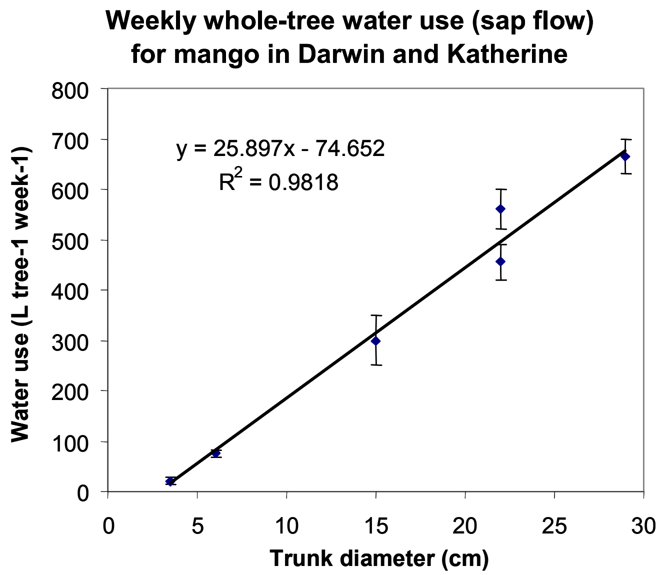


Figure 3: Relationship between tree size (trunk diameter) and whole-tree water use measured by sap flow method on mango trees grown in Darwin and Katherine areas in northern Australia.

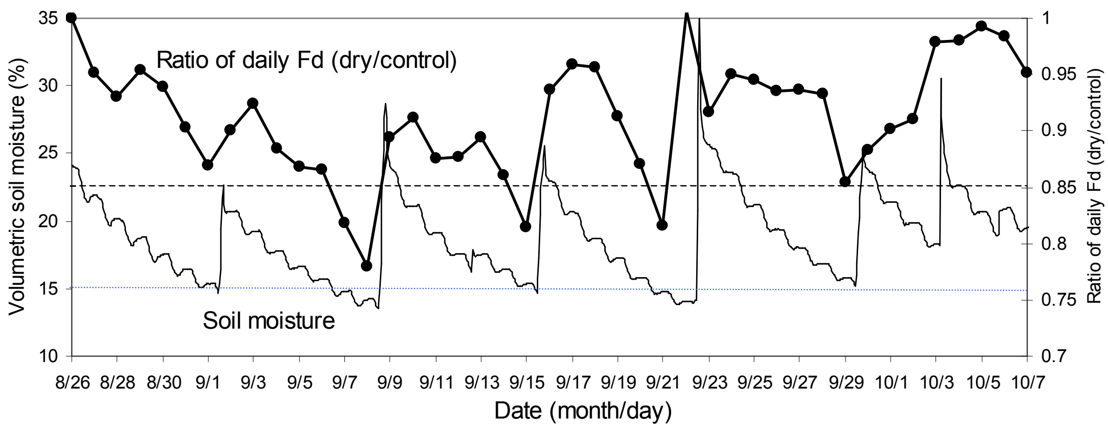


Figure 4: Ratio of the daily sap flow measured on well-watered control trees vs. dry trees over several irrigation cycles as indicated by variation in volumetric soil moisture in the top 30 cm soil profile. (7-year-old Kensington Pride trees on sandy-loam soil in an orchard near Darwin).

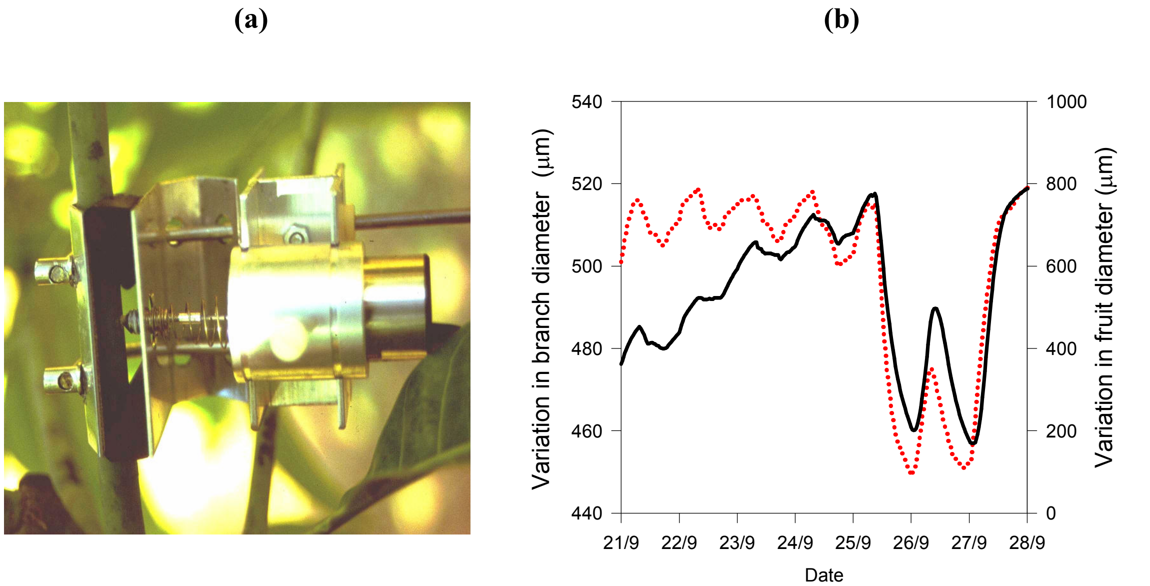


Figure 5: (a) A microdendrometer installed on a twig of mango tree, (b) diurnal changes in diameter of branch (red, pointed line) and fruit (black unbroken line). Irrigation was stopped from 23 Sep. onwards.

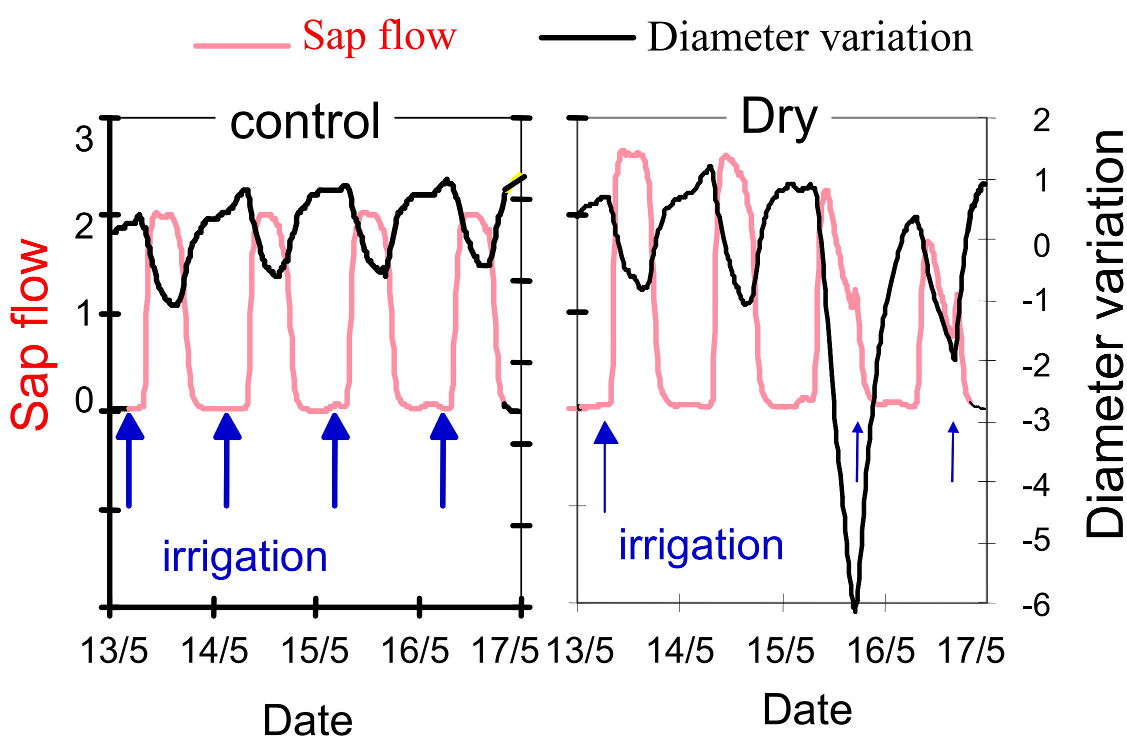


Figure 6: Diurnal changes in sap flow and branch diameter of Kensington mango trees grown in 100 L plastic drums. On the nights of 15 and 16 May, only 10% of normal irrigation amount was applied to the 'dry' trees.

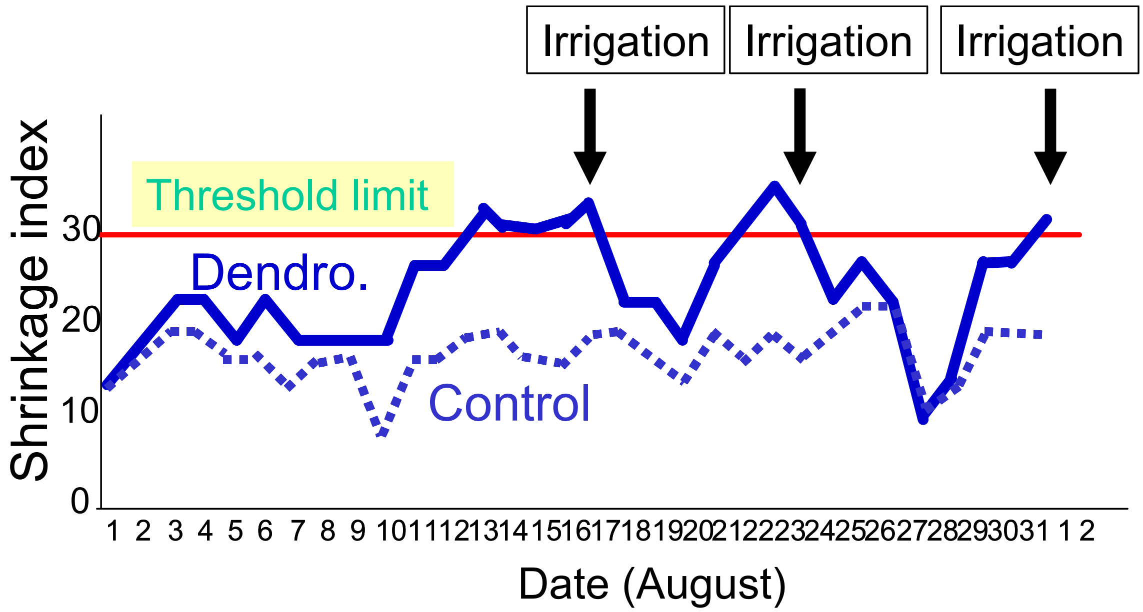


Figure 7: Daily changes in Shrinkage index of a group of trees which were irrigated at local authority recommended rate (Control) and of a group of trees received irrigation only when the Shrinkage index hit the threshold limit of 30 (Dendro.). Irrigation events for the 'Dendro.' trees are indicated by arrows.

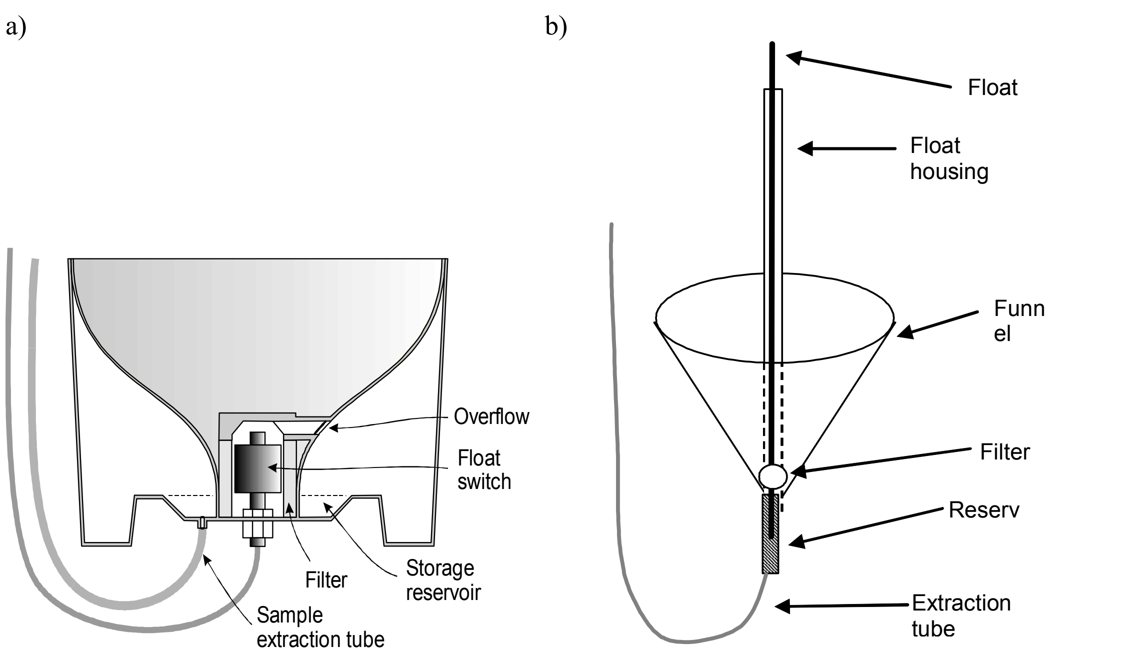


Figure 8: a) The electronic prototype contains a float switch behind the filter. If the cell containing the float fills completely, water overflows into a storage reservoir and this sample can be extracted for nutrient or salt monitoring. Water around the float switch is withdrawn back through the filter by capillary action as the soil dries, thus resetting the detector. b) The mechanical prototype has a narrow reservoir below the filter which houses a styrofoam float. As the reservoir is filled the float moves up the float housing and protrudes above the soil surface. The reservoir is emptied by syringe through an extraction tube (Stirzaker et al., 2004).