Soil Moisture Monitoring
HOW and WHY?

Adrian Orloff.

What does irrigation farming mean? It means applying water to a crop in order to supplement water requirements not met by rain, in order to grow the maximum yield and quality of the desired plant product.

Knowing how much water to apply and when to apply it is a fundamental management decision on which effective water management practices should be based. However very few irrigation farmers are using such technology. About 4% in Australia.

Before we discuss some of the issues about soil moisture monitoring and irrigation scheduling, lets look at some important points when understanding the importance of water for plant production. There has been a considerable amount of research into the general relationships between plant responses and soil moisture conditions. It is important to understand that the various stages of growth, for example vegetative growth, flower-bud initiation, fruit development, etc., are a function of the moisture supplies, (and other factors), and that the total growth and yield of a crop will be a combination of the effects of soil moisture conditions (among other factors) at each growth stage.

When considering a watering regime for a crop, it is wise to understand the various growth stages and the water requirements of the crop in order to achieve maximum yield and quality potentials. In perennial crops, the future growth and cropping efficiency of the plant has to be safeguarded at all stages by preventing drought conditions. However, if one particular stage of growth has a more significant influence on yield, for example the flowering stage of a crop where fruit is to be marketed, then water supply conditions to the plant during flowering may need to be managed more carefully than at other stages of growth. Maintaining adequate soil moisture conditions during moisture-sensitive stages of growth will have a significantly beneficial effect on plant growth. Significant reductions in yield will result from restricted water supply during these moisture-sensitive stages because the provision of adequate water at other (not so moisture-sensitive) stages will not compensate for the harm sustained.

Most annual crops exhibit a differential response to moisture supply because they are especially sensitive to water shortage from the time of flower initiation, during flowering and, to a lesser extent, during fruit and seed development. Perennial crops are sensitive to a restricted water supply generally at the same periods and in precisely the same way, but it is doubtful whether the sensitivity during fruit development is more pronounced than it is during vegetative development, and in particular when fruit development and vegetative growth occurs at the same time or when the rate of growth during a particular day length period or temperature period determines the yielding capacity of the crop.

Research has proven that the organs growing most actively during moisture stress periods suffer the greatest check to growth. Consequently, it has also been suggested that the process of cell division (reproduction) appears to be less affected by moisture shortage than that of cell elongation (cell expansion).

<u>The importance of high soil moisture supply at certain growth stages are illustrated below:</u>

Development effects

- Vegetative growth of perennial crops is sensitive to soil moisture stress.
- Optimum soil moisture conditions help to maintain cell division and expansion, and transport nutrients to the actively growing sites of the plant.
- Maintain vegetative growth phase for the yield and quality of successive crops in both young and mature perennial plants.
- Example of how the vegetative growth phase is important for high yields can be illustrated in crops such as sugar cane, which benefits from severe moisture stress prior to harvesting; avoidance of moisture stress during the vegetative growth phase considerably reduces the time taken to reach maximum productivity. Mature mango trees may also be irrigated to encourage a particular growth flush so that they can bear flowers and fruit at the desired time.

Internal water relations

- There is a change in the internal water relations of both annual and perennial plants during the transition from vegetative growth to reproductive development. Transpiration requirements are reaching a maximum at a stage where water absorption may be reduced by a depletion of soil moisture reserves as well as reduced root growth. The net result may be a lowering in the water content of the plant, which in certain crops may favor flower-bud initiation. During flower-bud differentiation, when the sexual organs are formed, and during subsequent flowering, most crops, both annual and perennial are particularly moisture-sensitive.
- Floral organs in many annual and perennial plants are extremely sensitive to water stress. Water shortage at this time may result in defective floral organs, sterility, reduced numbers of flowers formed and failure of flowers to open. Therefore, during the period from the development of the reproductive organs and until fertilsation has occurred, plants require optimum water supplies and are particularly responsive to irrigations.

Root growth and availability of water

- Studies have demonstrated that during certain growth stages, especially flowering and the formation of fruit, root growth is retarded or ceases completely.
- For annual crops in particular, there appears to be an increased risk of water stress during the development of reproductive organs, when root growth ceases.
- Reduced root growth, especially in annuals, is likely to be a contributory factor causing marked sensitivity to soil moisture conditions at certain stages of growth, and hence explain the beneficial effects of irrigation at such times.

Availability of nutrients

- Soil moisture status and mineral nutrition of plants are interrelated.
- Irrigation or rainfall at a specific growth stage may facilitate nutrient uptake by plant roots by increasing the availability of nutrients or by providing suitably moist conditions for root activity in the nutrient rich topsoil.
- The beneficial effect of rain or irrigation at certain growth stages may be caused primarily by an increase in the availability of nutrients rather than by the increased water supply.
- Evidence has shown that enhanced availability of nutrients is particularly beneficial for annual crops at certain stages of growth and also for perennial crops, notably during the periods of vegetative growth, flower development and fruit setting. The beneficial effect of a plentiful supply of water at certain growth stages is partly the result of the increased or sustained availability of nutrients to the plant, especially when the period for maximum nutrient requirement coincides with the stage of maximum moisture sensitivity.
- Excess soil moisture conditions, above field capacity can result in excess drainage, leaching nutrients below the active root zone of the crop.

The importance of low moisture supply at certain growth stages are illustrated below:

Development effects

- A low soil moisture supply in the early stages of growth of an annual crop can influence the earliness of flowering through a reduction in the number of nodes formed before flowering occurs.
- Similarly, flower-bud initiation can be encouraged or hastened in perennial fruit crops by restricted soil moisture supply at the time that flower-bud initiation should occur. Drought may be used to ensure satisfactory flower-bud initiation in citrus and mango trees.
- There are periods during the development of perennial crops when a certain degree of moisture stress may not appear harmful when considered over only one or two seasons. However successive short periods of moisture stress during the vegetative growth phase will have a cumulative effect on growth and therefore cropping potentials.

Drought hardening effects

- Results have proven that a reduced water supply in the early stages of growth encourages the development of a large, deeply penetrating root system, (where soil structure is not limiting), which is considered a desirable buffer against drought.

Alterations in the chemical composition and physical characteristics of plants

- An internal water stress in plants alters the balance of the various physiological processes, and as a result the chemical and physical composition of the plant or its parts can be altered.

- Sometimes a water deficit produces desirable changes in composition. For example, water shortage before harvest improves the sugar content in sugar cane and can be used to increase the concentration of sugars in wine grapes. Holding water back from other crops, such as tomatoes prior to harvest can also increase the sugar concentration and increase the solid contents of the fruit, or in apples, can be used to increase sugar concentration or harden fruit by concentrating the cells, by reducing water content prior to picking.

The time when water shortage begins to influence plant growth will be related to the volume of soil available per plant. Providing adequate soil moisture reserves, while annual plant roots are actively growing into fresh regions of soil, sufficient water can usually be obtained to satisfy transpiration requirements and maintain unchecked growth. When, however roots can no longer extend into a fresh volume of moist soil, the plants become more dependant on and therefore respond more to rainfall and irrigation.

There appears to be two distinct phases of root development for annual plants. Phase 1, when roots are still extending strongly into new soils, and phase 2, when the available soil has been fully occupied by roots. The time at which phase 1 ends will be related to the activity of the roots and their spatial distribution, the plant spacing and depth of soil for rooting. Research has shown that responses by annual crops to irrigation may have been related to the time when the available soil volume becomes fully occupied by roots and only by chance to a particular stage of growth.

Many perennial crops appear to be more sensitive to soil moisture conditions during the establishment period, while their roots are developing into and colonising the available soil volume, than when their permanent roots have occupied the soil volume. Soil volume differences will often be reflected in the final size reached by the mature perennial plant; a larger shoot system will be carried on a tree in deep soil than on one in shallow soil and a larger root/shoot ratio will be developed where soil moisture supply conditions are least favorable.

Agronomic implications

The sensitivity of the flower development process to water conditions has emerged as a common phenomenon in both annual and perennial plants. Many annual crops have also shown to be moisture-sensitive during flowering, while perennial crops appear to be moisture-sensitive during the period of maximum vegetative growth and probably again immediately after their flowers have been fertilised. Water supply for perennial crops should be adequate to maintain, at all stages of growth and development of the crop, an effective and healthy foliage able to utlilise as fully as possible the incoming energy. Thus any stress condition that is required to suppress or restrain growth or to favor crop quality should lie within the range of stress that the plant can tolerate without detrimental effects to its overall health.

The agronomic implications of moisture-sensitive stages of growth are of considerable importance. Irrigation practice needs to be made as efficient as possible in terms of water use, not only because water for irrigation purposes are often in short supply, but because the returns per unit cost of irrigating are reduced by using excessive quantities of water. The aim should be to obtain the maximum possible yield of marketable produce from a given quantity of water supplied to a crop. The practical application of such management strategies can be used to apply water at any sensitive stages of growth, and to postpone irrigating at other stages, until the estimation of soil moisture deficits from monitoring show that a predetermined limiting deficit (refill point) has been reached for a given crop on a particular soil.

So what does this mean? It means that a greater understanding of the relationship that water has with plant growth needs to be attained. Soil moisture monitoring does not simply mean measuring how wet or dry a soil is. Objective soil moisture monitoring can enhance water management strategies to improve crop yield and quality potentials. "Irrigation scheduling" can be defined as applying the correct amount of water at the correct time to a crop in order to maintain optimum soil moisture conditions to produce the maximum yield and quality of the desired plant product. Objective soil moisture monitoring allows the manager to plan irrigations according to soil water holding capacities, plant water use, prevailing weather conditions and quantified management decisions.

How do you decide when to water and how much to apply?

- Historic information
- What the neighbours do
- Look at the crop for signs of water stress
- Set routine
- Dig stick
- Evaporation pan
- Soil moisture monitoring
- "Guesswork"

Principles of irrigation scheduling

The basic issues to be considered and monitored to develop and manage an irrigation schedule are outlined below

- **Positioning monitoring sites**

Monitoring sites need to be selected carefully in order to allow for soil and crop variations. Positioning monitoring sites within the average soil types will reduce the risk of the better soils being under-watered and the worse soils being over-watered. Ideally, a soil survey at the time of the irrigation development will provide you with the information on soil variations. The information collected from the survey will allow you to plan the irrigation system according to soil variations, and position monitoring sites in representative locations.

Positioning monitoring sites in relation to the crop and irrigation system are also important considerations. Care should be taken to ensure that the site will record both representative water use of the plant(s) and wetting from the irrigation system. There are a number of factors that need to be taken into account such as plant spacing, crop type and soil type.
Care should be taken when installing the sensors, to ensure that soil and crop disturbance while monitoring sites is minimised. Ensure that you do not compact the soil near the site, or destroy the plants (annual crops generally) by stepping on them while installing the sensors. Considerable site disturbance will effect the representativeness of the data you are collecting.

1. Depth at which sensors are installed

The number of sensors, and depth at which they are installed is an important issue to be considered when establishing a monitoring site. This will depend on the sensors being used, as some systems utilise individual sensors buried at certain depths while other systems operate on a single sensor lowered down access tubes, which can measure multiple depths.

The issue for consideration is to be able to differentiate between water use and drainage. If only one sensor is buried, you will be able to monitor wetting and drying patterns, however it is difficult to distinguish whether the drying is caused by water use, by drainage or a combination of both. That is why it is advisable to measure at least two depths, if not three within the profile, (preferably one at the top, one near the middle, and one below the root zone), thus ensuring you are able to differentiate between water use and drainage.

1. Taking readings

Depending on the system that you are using, (manual versus automatic), readings should be taken on a regular basis, so that you are able to interpret wetting and drying patterns to assist with data interpretation. With manual systems, it is ideal to ensure data is collected before irrigations, to see how dry the soil is, after irrigations, to see how effective the irrigation was, and ideally between the irrigation cycle to monitor if there was any excess slow drainage of water below the roots or to measure the depth and rate of water extraction.

Another consideration is to ensure that you do not compact the soil or destroy the plants that you are monitoring when you take the readings. This is of more concern with annual crops, where you may need to walk out into the crop. Continual monitoring at such a site can lead to soil compaction and potentially unrepresentative crop growth. This issue is not of major concern with automatic logging systems, as data is generally collected from a central logger away from the site or even at the PC in the office, if a telemetry system is used. Even though the data is being continually recorded, it is wise to view the data at least a couple of times a week so that you can make immediate management decisions, rather than collecting historical data.

- **Establishing the depth of the root zone**

To calculate the frequency and duration of irrigations, the depth of the active root zone of the crop being monitored must be determined. The volume of soil that the roots of the plants are occupying will effect the volume of water that is available to the plants and the volume of water needed to be applied to replenish the profile.

Quantifying the depth of the root zone can be achieved in a number of ways. If a soil survey has been conducted, root zones can be estimated if a crop has not been planted, or visually inspected if plants are growing. Data collected can provide information on the depth of water extraction by the plants. As mentioned above, if individual sensors are being used, care should be taken to ensure that at least one sensor is positioned within the root zone of the crop and one below the root zone.

- **Establishing the full point**

In simple terms, the full point can be defined as the wettest the soil within the root zone of the crop can be before there is through drainage. This will depend on the soil texture, as clays, loamy clays and clay loam have a greater water holding capacity than lighter textured soil such as sands and sandy loam. The depth of the root zone will also have bearing on the full point of the site, as obviously a deep rooted crop on a heavy textured soil will require more water less frequently, and a shallow rooted crop on a light textured soil will require less water more frequently.

By measuring soil moisture before and after an irrigation, (generally six to twenty four hours after, depending on soil types), you are able to quantify the depth to which the irrigation event wetted. The data collected between irrigations should provide information on the depth of the active root zone. By comparing the depth of the irrigation compared with the depth of the root zone, you are able to determine whether sufficient or excess water has been applied to adequately replenish the root zone of the crop to the full point. Excess water moving below the root zone (above full point), will result in wasted water, increased pumping costs, leached fertlisers (lighter soil generally), and in heavier soils, potential water-logging. Insufficient water applications, that do not replenish soil moisture levels to the full point can result in more frequent irrigations than what is required or a gradual depletion of the soil moisture within the root zone of the crop.

- **Establishing refill point**

The refill point can be defined as being the driest a soil can be for a given soil and crop type before there is a decline in water use resulting in inadequate reserves of water for optimum growth to be maintained. The moisture level at which the refill point is set will depend on a number of factors including soil type, crop type and management strategies. There is a direct relationship between crop water use and yield, therefore if a crop is unable to use water to its full potential, yield and quality potentials can be reduced especially if the period of low moisture conditions corresponds with a moisture-sensitive growth stage.

As soil moisture levels fall below the true refill point, two physiological processes can be measured using soil moisture sensors. Firstly, crop water use declines (if weather conditions have remained constant), and the depth of water extraction increases as the readily available water within the active root zone falls below a critical level, and the crop searches deeper into the profile for moisture.

The refill points for specific crops may be adjusted during various growth stages of crop development in order to modify or promote various plant characteristics, as discussed earlier in this paper.

- **Effectiveness of irrigation or rainfall events**

For accurate irrigation timing, it is critical to be able to identify the effectiveness of irrigation and rainfall events. This will have bearing on when and how much water needs to be applied. The difference between actual and effective irrigation or rainfall events must be identified when developing and managing an irrigation programme. The “actual” irrigation or rain event is the volume of water either measured in a rain gauge or flow meter, whereas the “effective” amount is that which has infiltrated into the root zone of the crop and is available to the plant.

The water that has either run-off, evaporated or drained below the root zone of the crop is not available to the plants. Without objective soil moisture data, it is very difficult to quantify the volume of water available to the plants, which has either been applied through irrigation or has fallen as rain.

- **Plant water use**

Plant water use will vary according to growth stages, prevailing weather conditions and soil moisture status. The rate of soil water depletion by the crop will affect the frequency of irrigation events. Through soil water monitoring, the rate of soil water depletion can be measured and predictions on when and how much water to be applied can be calculated.

Plant water usage is a good indicator of the soil moisture status. As soil moisture within the root zone falls below the refill point, plant daily water use generally declines (when weather conditions have not changed). A decline in water use, caused by inadequate water reserves, generally occurs before any physical symptoms of water stress are observed. The ability to identify the critical lower limits of soil moisture (refill point) within the root zone is invaluable in maintaining optimum soil moisture conditions for maximum growth potential. Once the crop displays visible symptoms of water stress, water use rates will have declined, and if this water stress occurs at periods of high moisture demand, significant reductions in potential yield and quality may result.

The ability to establish, monitor and manage the above parameters is critical in developing and managing an irrigation programme. Evaporation data can be used, however with this technique, you are measuring the rate of evaporation from a surface of water, multiplying this value by a crop factor, and then applying this value as crop water use to determine when and how much water needs to be applied. This management tool does not take into account such issues as:

- Soil water holding capacity
- Effectiveness of irrigation or rain events
- Depth of water infiltration
- Depth of plant water extraction
- Effects of plant health on water use
- And others.

In cases where soils are compacted, where there are problems with surface sealing or where there are clay pans which restricts the movement of water into and through the soil profile, soil moisture monitoring should be implemented; not only to identify, but to implement management practices to rectify these problems.

The three main driving variables on which irrigation management decisions are based upon are:

- How much water the root zone of the crop can hold
- How much water infiltrates into the soil
- How much water is the crop using?

The basis of irrigation scheduling is using objective measurements in conjunction with plant inspections to eliminate the guesswork involved in estimating how wet or dry the soil is in order to decide when and how much water to apply. Irrigation management varies from property to property and field to field. Data collected on one property, or even field, is not relevant to another, therefore farmers must develop and manage their own scheduling programmes based on their soil and crop types.

Soil water management can make a dramatic difference to the profitability and sustainability of an irrigation enterprise. Making informed irrigation decisions based on accurate data can maximise the income per unit of water and capital. New irrigation delivery systems provide growers with the ability to apply the correct volumes of water to the correct areas in order to increase potential returns per unit of water applied to a crop.

Water management is the “missing link” with many irrigation enterprises. Unfortunately, too many growers are investing considerable capital and resources into areas of management such as pruning, soil preparation, sap and tissue analysis, fertliser application and improved irrigation systems. For example, incorrect timing of irrigations can promote excessive vegetative growth that needs pruning. Capital invested in sap, tissue or soil analysis, and consequently fertliser applications, can be literally washed down the drain through over-watering. Investment in upgrading or developing new irrigation systems, such as drip, mini jets or mini sprays can be negated by not understanding how to manage these water delivery systems. I have seen cases where growers have upgraded their flood irrigation systems to mini jets, and have been using the new system as an easier way to flood irrigate, by running the new sprinklers for up to 16 hours, when 6 hours would have been sufficient to wet the root zone. Crop health and vigor, in these cases have declined as a result of poor water management causing a perched water table within the root zone of the trees. Poor water management can negate the resources committed to these management issues.

Water has to be considered as a management input, just as fertlisers and sprays are. Irrespective of how well all other farming practices are managed, without soil or water, there is no crop to manage.

Adrian Orloff
MAIT industries
P.O.Box 1093
Shepparton, Victoria, 3632
Phone 03 9873 7712
Fax 03 9873 7713
Mobile 0438 655 350
Email adrian@mait.com.au