WATER STRESS AND APPLE FRUIT QUALITY

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ABSTRACT

Regulated Deficit Irrigation (RDI) has been used successfully in dry climates to control vegetative growth of fruit trees during the early part of the growing season without seriously disadvantaging fruit growth or quality. This project was undertaken as part of a study to investigate the feasibility and practicality of using the RDI concept in a humid fruit growing environment using Royal Gala apple trees.

Treatments consisted of a lucerne cover crop, black polyethylene undertree covers and a within-row herbicide strip which is the normal commercial practice in New Zealand orchards. A full irrigation treatment (FI) was used on half the experimental trees and an RDI treatment was used on the other half of the trees. The RDI treatment consisted of withholding water until 105 days after full bloom, then using a full irrigation for the remainder of the season.

Integration with depth of the soil moisture content (θ) (measured with a neutron probe) at the commencement of the experiment revealed 230 mm of water was stored in the top 900 mm of soil. Full irrigation resulted in θ increasing, with storage of about 250 mm 83 days after bloom and remaining at this level for the remainder of the season.

The storage in the RDI treatments decreased in a linear manner until 58 days after bloom, after which it remained constant until irrigation was started 105 days after bloom. The lucerne RDI (LRDI) treatment had a lower storage (105 mm) during this constant period than plastic RDI (PRDI), or herbicide (HRDI) treatments which both had a storage of

130 mm. The amount of water in the soil at this time for LRDI and for PRDI/HRDI was 42% and 52% of the total available capacity. Immediately after irrigation commenced on the RDI treatments, profile water storage returned to the values of the FI treatments remaining at these values for the rest of the season.

Removal of water from the soil profile was not uniform. It appeared that lucerne removed moisture from the upper horizons first, before extracting it from the zone below 500 mm.

Leaf water potentials (ψ_e) were lower in RDI treatments, when measured at midday, (but not pre-dawn), than in FI treatments. Leaves from LRDI trees had lower ψ_e values than did leaves from PRDI and HRDI trees.

Rate of fruit growth was reduced in all RDI treatments during the early part of the season, but returned to the same value as FI fruit once irrigation was resumed; except for LRDI fruit which did not attain the same growth rate of FI fruit. There were less large fruit and more small fruit from LRDI treatments than from other treatments where no significient effects on fruit size were measured. Fruit from RDI treatments were firmer, less mature and contained more soluble solids at harvest than FI fruit; some of these differences were maintained through 12 weeks storage at 4°C. There was no consistent effect of irrigation or cover treatment on fruit colour, mineral content or disease incidence at harvest or after storage.

Vegetative growth, measured as pruning weights and the increment in trunk diameter, was significantly reduced by RDI treatments with LRDI causing the greatest reduction in pruning weight and PRDI inducing the smallest trunk diameter increase.

The combined lucerne cover crop and RDI treatment was the most successful method found for reducing soil moisture in a humid climate. It also resulted in the greatest amount of stress being induced in these trees, reducing both vegetative growth - a desirable effect; but also fruit growth, a commercially undesirable effect. It is suggested that different methods of managing lucerne, or the use of less successful water extracting plants will need to be evaluated before recommending a successful, yet practical method of using the RDI concept in apple orchards growing in humid environments.

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INTRODUCTION

1.1 INTRODUCTION

Water constitutes one of the most important constraints to increasing food production worldwide; and in some parts of the world irrigation is the only way to make sure any food can be produced. The amount and rate of water uptake depends on the ability of the roots to absorb water from the soil with which they are in contact, as well as the ability of the soil to supply and transmit water towards the roots at a rate sufficient to meet transpirational requirements (Hillel, 1980). These depend on properties of the plant such as its rooting density, rooting depth, and rate of root extension, as well as upon the physiological ability of the plant to continue drawing water from the soil at the rate needed to avoid wilting, whilst maintaining its vital functions. The properties of the soil, such as its hydraulic conductivity, diffusivity, matric suction and their relationship to soil water content are also important. Soil water uptake by plants is also due to a considerable extent on the meteorological conditions which dictate the rate at which the plant is required to transpire and hence the rate at which it must extract water from the soil in order to maintain its own water status.

From a physical point of view, evapotranspiration can be viewed as a continuous stream of water flowing from a periodically replenished source of limited capacity and variable potential, namely the reservoir of soil moisture, to a sink of virtually-unlimited capacity - the atmosphere. As long as the rate of root uptake of soil moisture balances the rate of canopy loss by transpiration, the stream continues unabated while the plant remains fully hydrated. The moment the uptake rate falls below transpiration, the plant itself begins to lose moisture. This imbalance cannot continue for any length of time without resulting in loss of turgidity and wilting of the plant.

The concept of potential transpiration (Penman, 1949) is an attempt to characterise the evaporative flux extracted from a stand of plants fully covering the ground surface when the supply of soil water is not limiting. It is the meteorological conditions rather than soil or plant conditions which exercise the greatest influence on the transpiration rate as long as the soil is wet enough. However, as soil wetness is diminished, even though not completely depleted, actual transpiration begins to fall below the potential rate either because the soil cannot supply water fast enough, or because the roots can no longer extract it fast enough to meet the meteorological demand. The point at which this condition is reached depends in a combined way upon the weather, the plants and the soil. The best method to analyse all this in the soil is through the water balance. Irrigation is a means to keep soil wetness high.

1.2 WATER BALANCE OF THE ROOT ZONE

The water balance states that in a given volume of soil (V, m^3), the difference between the amount of water added (W_{in}, m^3) and the amount of water withdrawn (W_{out}, m^3) during a certain period is equal to the change in water content δW during the same period (Hillel, 1982).

$$\delta W = W_{in} - W_{out} \qquad 1.1$$

This change results in a change in the volumetric water content of the soil (θ, m^3m^{-3}).

$$\delta W = V\delta\theta \qquad 1.2$$

When gains exceed losses, the water-content change is positive, and conversely when losses exceed gains, δW is negative. Rain or irrigation water applied to the land may in some cases infiltrate into the soil as fast as it arrives. In other cases some of the water may pond over the surface. Depending on the slope and microrelief, a portion of this water may exit from the area as surface run-off while the remainder will be stored temporarily as puddles in surface depressions. Of the water infiltrated, some evaporates directly from the soil surface, some is taken up by plants for growth or transpiration, while some may drain downwards beyond the root zone and add to soil moisture storage. Additional water may reach the defined soil volume by run-off from a higher area, or by upward flow from a water table or from wet layers present at some depth. The pertinent volume of depth of soil for which the water balance is computed is determined arbitrarily. From an agricultural or plant ecological point of view, it is generally appropriate to consider the water balance of the root zone per unit area of field. The root zone water balance is expressed in integral form thus:

$$\text{Change in storage} \;=\; \text{gains} \;-\; \text{losses}$$

$$\delta S \;=\; (P + I + U) \;-\; (R + D + E + T) \qquad 1.3$$

where δS is change in root zone soil moisture storage, δF increment of water incorporated in the plants, P precipitation, I irrigation, U upward capillary flow into the root zone, R run-off, D downward drainage out of the root zone, E direct evaporation from the soil surface, and T transpiration by plants (Hillel, 1982).

The time rate of change in soil moisture storage can be written as follows:

$$ds/dt \;=\; (p + i + u) \;-\; (r + d + e + t_r) \qquad 1.4$$

where t = time and t_r = transpiration rate. Each of the lowercase letters represents the instantaneous time rate of change of the corresponding integral quantity in equation 1.1. The change in root zone soil moisture storage can be obtained by integrating the change in soil wetness (S) over depth and time as follows:

$$S = \int_o^z \int_o^t \frac{d\theta}{dt} \, dt \, dz \qquad 1.5$$

where θ is the volumetric soil water content, measured by gravimetric sampling or by means of a neutron probe and z is the lower boundary of the water extraction by roots and is assumed constant with time (Sharma, 1985).

Evapotranspiration from a well-watered field depends primarily on the energy supplied to the surface by solar radiation, which is characteristic for each location and varies little from year to year (Hillel, 1982). E + T are generally designated E_{to} representing the climatic demand for water. Evapotranspiration also depends upon surface roughness and soil thermal properties, characteristics which may vary in time (van Bavel and Hillel, 1976). As a first approximation, and working hypothesis, it is assumed that E_{to} depends entirely on the external climatic inputs and is independent of the transient properties of the field itself (Hillel, 1982).

Actual evapotranspiration, ET_a is generally some fraction of E_{to} depending on the degree and density of plant canopy coverage of the surface, as well as on soil moisture and root distribution. E_{ta} from a well-watered stand of a close growing crop will generally approach E_{to} during the active growing stage, but may fall below it during the early growth stage, prior to fully canopy coverage, and again towards the end of the growing season, as the matured plants begin to dry out (Hillel and Guron, 1973). For the entire season, E_{ta} may total 60-80% of E_{to} depending on water supply: the drier the soil moisture regime, the lower the actual evapotranspiration.

Another important item of the field-water balance is the drainage out of the root zone. A certain amount of drainage is required for aeration and for leaching out excess salts so as to prevent this accumulation in the root zone.

1.3 SOIL WATER AND LEAF WATER POTENTIAL

The balance between water loss through transpiration, and water uptake via roots, controls the plant water status which is usually related to the plant water deficit (Boyer, 1969).

Water movement through the soil-plant-atmosphere is best treated as a series of interrelated, interdependent processes. Rate of water absorption is affected both by the rate of water loss and by the water balance. Rate of transpiration depends not only on stomatal aperture and atmospheric factors affecting evaporation, but also on the rate of water absorption which is governed by the water balance (Kramer, 1983).

To characterise the soil-plant-atmosphere continuum, it is important to evaluate components of the energy potential of water and the effective potential gradient as it varies along the entire path of water movement. This includes liquid water movement in the soil towards roots, absorption into roots, transport in roots to the stem and through the stem to