NATIONAL PROGRAM FOR
Sustainable Irrigation

Open Hydroponics : Risks and Opportunities

Stage 1

General Principles & Literature Review

By
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June 2005, LWA DAN 22

Acknowledgements

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Thanks are given to the many people who provided their valuable time and cooperation for this project. (Alphabetical order) : John Chavarria (Mildura Fruit Company), Arthur Edwards (Yandilla Park), Pablo Liguori (Yandilla Park), Japie Kruger (OHS Solutions) and Trevor Slugget (Yandilla Park).

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Project Funded by : Land and Water Australia through the National Program of Sustainable Irrigation

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Scope

The following report is a brief study and interpretation of the publicly known principles and theories of Open Hydroponics (OH). Scientific validation of the principles of OH, productivity gains from OH and in-field assessment of the practicality of OH was not a part of this study. Published information on OH was reviewed, however very little published information was available and therefore a considerable amount of information was also sourced from OH public presentations, OH seminars, personal field visits to OH orchards and communications with various OH consultants.

Summary

Open Hydroponics (OH) is a management practice recently introduced into Australian tree crop production. The system was originally developed by Professor Rafael Martinez (Spain). A number of commercial OH management programs have been adopted in Australia and a number of orchards are using variations of its principles (intensive fertigation practices). Higher productivity is reported in orchards using OH both in Australia and overseas. Aspects of OH management principles could be incorporated into conventional production systems to improve productivity.

The aim of OH is to increase productivity by continuously applying a balanced nutrient mixture through the irrigation system, limiting the root zone by restricting the amount of drippers per tree and maintaining the soil moisture near field capacity. The combination of these practices is claimed to provide a greater control and manipulation of nutrient uptake at specific physiological stages and improved water uptake. The principles of OH are based on soil, water and nutrient interactions and crop physiology. Validation of these principles and the assessment of their impact in field situations needs to be undertaken.

OH can increase orchard productivity but also increases management risks. Risks identified include the ability to maintain water supply to the orchard and nutrition and irrigation management skill levels. OH orchards have restrictive root zones that may hold only a day supply of readily available water (RAW). If water supply is cut for a number of days during peak demand periods, this could impact significantly on the productivity of the orchard. On-farm water storage may be required to reduce the risk. OH requires a higher level of management skill for both nutrition and irrigation management. A misjudgement in irrigation scheduling or nutrient application rates could impact on productivity and returns. Important factors for the success of OH is the improvement of management skills by growers and the use of professional OH consultancy services.

The principles of OH could have potential benefits in conventional production practices. An increasing number of growers are using intensive fertigation programs (IFP). IFP is a fertigation program that has similar principles to OH, but is less intensive than OH. IFP has a greater level of adoption than OH. Further studies using commercial OH orchards backed up with scientific trials on targeted issues at research stations are recommended to investigate OH practices in relation to other intensive management practices and to develop a knowledge-base in Australia.

Introduction

Commercial Hydroponics

Hydroponics is the growing of crops in a soil-less nutrient enriched water solution. Some hydroponic systems grow crops only in a nutrient solution whilst others use an inert media to provide an anchor for the plant roots (i.e. rock wool). The inert media does not provide or store nutrients. All nutrients are provided in the water solution.

The advantages of hydroponics are:

- it eliminates many of the management issues faced with conventional soil production. These issues include soil borne diseases, unfavourable soil characteristics (soil compaction, infiltration, structure, etc), unfavourable soil chemical characteristics (fertility, salinity, contaminants, CEC, nutrient balance, pH etc);
- crop water stress is reduced or eliminated;
- a high degree of nutrition control can be achieved. Nutrient ratios are able to be controlled to match and manipulate physiological growth stages. Nutrient concentrations in the water solution can be up to 10-50 times greater than in a soil solution (Epstein, 2004).

With improved water and nutrition management, annual crops are able to reach maturity faster. Multiple cropping is able to occur on one site (numerous crops in one season).

Figure 1: Outdoor hydroponic strawberry production (Photo: R.Wier)

Open Hydroponics (Soil hydroponic production)

Open Hydroponics (OH) adapts the principles of commercial soil-less media hydroponics to soil based production. The adaptation involves reducing the influence of the soil as a nutrient and water storage medium and using it as a medium to anchor the roots and deliver nutrient solutions to the roots. The key principles of this adaptation are:

- reducing the size of the root zone by reducing the wetted soil volume, and
- the continuous application of a balanced nutrient solution that is pH buffered to about 6.5 pH. The wetted soil volume is always maintained near field capacity (above and below).

The advantages of OH claimed by management consultants over conventional production systems (i.e. sprinkler or non intensive fertigated drip) include:

- Improved productivity;
    - Higher more even bearing yields;
    - Improved tree health and vigour;
- Greater control of nutrition through the ability to manipulate the concentration and uptake of nutrient in the root zone environment;
- Overcome some water quality issues (i.e. high pH water)

The concept of OH has been used for many years in glasshouse production (vegetables and ornamentals) by supplying a balanced nutrition program at regular intervals (intensive fertigation program). Aspects of OH including intensive fertigation and restricted root zone have been investigated and used in orchards in the past. However Professor Rafael Martinez Valero, (University Miguel Hernández, Alicante, Spain) was the first to bring all of the concepts together to develop OH in the early 1990's . The original incentive to develop OH was to address low fertility soils (i.e. gravel base soils) and poor quality water (i.e. saline water) for some regions of Spain, however OH is now used in a wide variety of situations and soil types including clay and sandy soils. Professor Martinez then commercialised his OH program to be known as the Martinez OH Technologies (MOHT).

Since the inception and adoption of MOHT into horticultural industries around the world, other consultants have developed their own OH programs. These other systems claim to be providing OH management programs and some issues have been raised regarding the validity of a program claiming itself to be OH. This issue is complex and contentious and will not be addressed in this report. This report will only discuss the core principles of OH and discuss some of the strategies used by two OH management programs used in Australia. These programs are the MOHT program currently coordinated by Yandilla Park and OHS Solutions program currently coordinated by Mr Japie Kruger. Mr Kruger is a consultant from South Africa that has been working with OH since the late 1990’s. A number of growers have installed and are currently installing OH programs by Mr Kruger. Other consultants are providing consultancy services on Intensive Fertigation Practices (IFP). IFP are adaptations of OH program that use similar principles to OH, but at a less intensive level.

The concept of OH was first introduced to Australia in 1999 with the installation of a MOHT system by Yandilla Park on their Farm 8 citrus orchard in Sunraysia (Yandilla, 2004). Although the general concepts of MOHT are widely known, the detailed information of the management plan and nutrient solution mixtures are intellectual property and are not publicly available. Only growers that purchase the MOHT system are privy to details of the program and as such are required to sign a confidentiality agreement.

The Farm 8 MOHT citrus orchard has generated much interest in OH. Numerous growers have visited the Farm 8 orchard and have been impressed with the increased vigour and productivity of the orchard. A number of MOHT systems have since been installed in Australia. MOHT is used in Spain, South Africa, Chile, Argentina, Morocco and California (Yandilla, 2004).

Since the majority of information about OH and some IFP is intellectual property owned by the commercial proprietors of individual systems, very little information is published about OH and IFP. Only two publications were sourced that dealt with OH (see literature review).

Restricted root zone

OH aims to reduce the influence and interaction of the soil as a media to store water and nutrients by reducing the size of the active root zone. This is achieved by reducing the size of the wetted soil volume by reducing the number of drippers per tree. The principle of restricting the root zone by reducing the wetted soil volume would work successfully in an arid climate; however its effect may be reduced in a high rainfall climate.

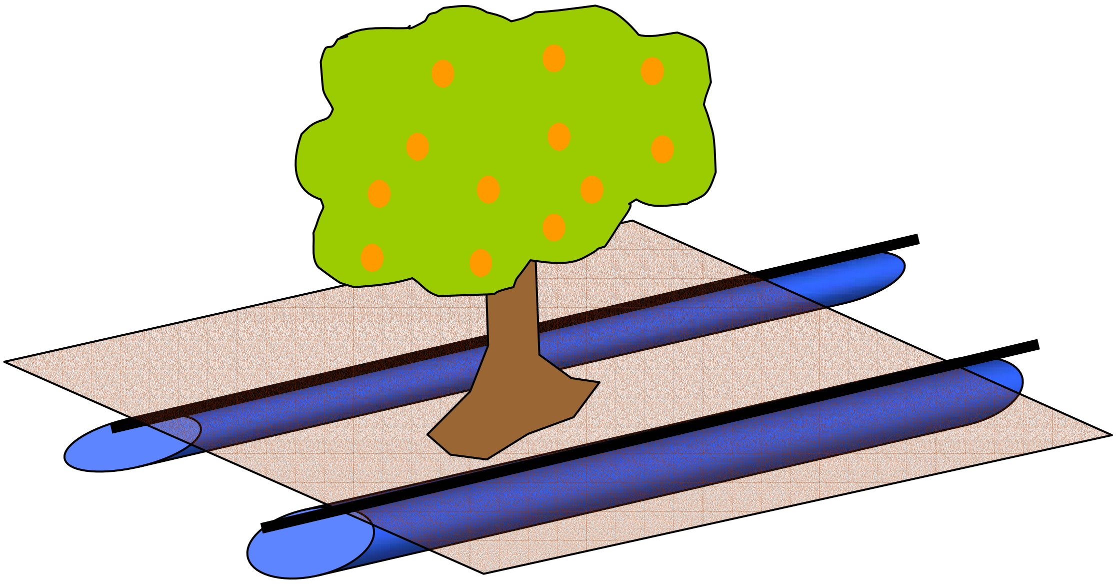

Figure 2 : Conventional twin line drip irrigation system where the wetted pattern from each dripper join to form a continuous wetted strip along both sides of the tree

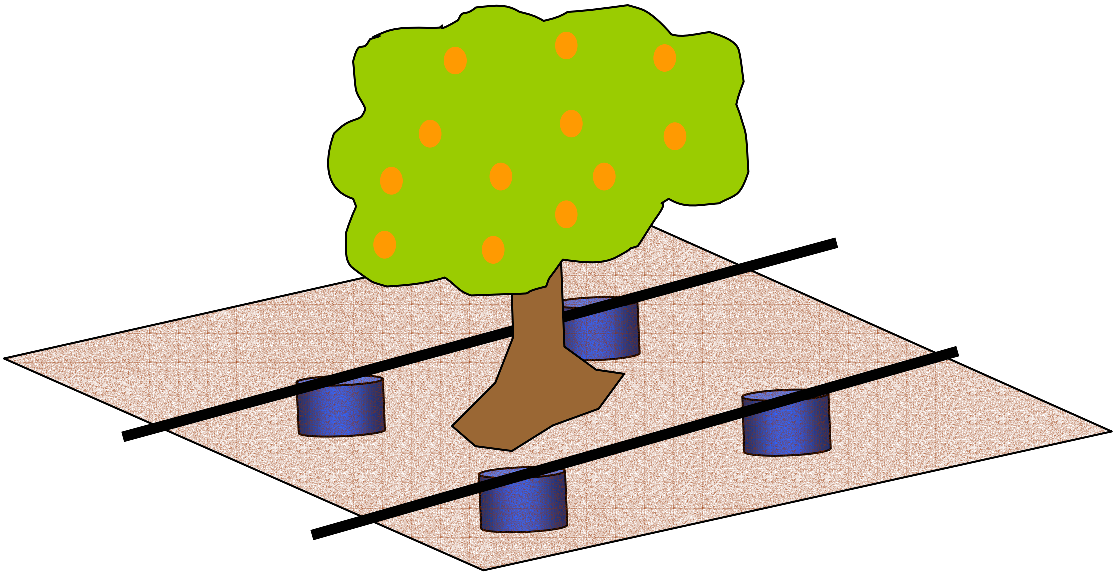

Figure 3 : A restricted root zone whereby an individual wetted ball of soil is formed. The diagram depicts a twin line drip irrigation system however a single line can also be used.

A restricted root zone system is achieved by limiting the amount of drippers per tree. Some OH programs calculate the number of drippers required for a restricted root zone by using an equation that uses the size of the tree canopy as an important parameter. This calculation generally works out to be about 22,000 drippers per hectare for a 2.3L/hr dripper output (0.5mm/hr application rate over the orchard). There is no published information on the definition of a restricted root zone in OH and the best estimate to date is that it occupies about 8-15% of the total available soil volume. A standard conventional twin line drip irrigated orchard would wet about 25 to 35% of the total available soil volume.

Reducing the size of the root zone has numerous advantages for OH production including;

- reducing the influence of the buffering capacity of the soil
- greater manipulation of the nutrient concentrations in the soil and subsequent improved nutrient uptake

The pulsing, or continuous, application of water and nutrients is an important aspect of OH. Roots generally focus their growth where the greatest nutrition and water supply occur which is directly underneath the dripper. A concentration of roots under drippers is commonly observed in conventional citrus orchards using drip irrigation in the Sunraysia district on sandy loam soils. The continual application of nutrients and water to match daily water use by OH may further encourage roots to grow in a more concentrated ball around the dripper (Figure 5) than a conventional drip irrigation management system (Figure 4).

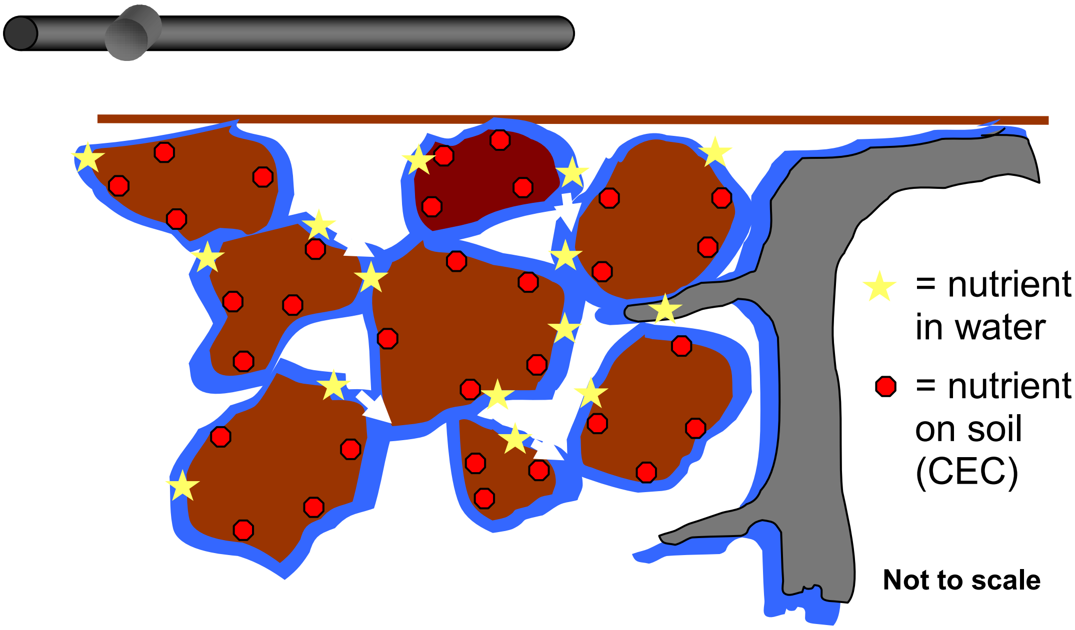

Figure 4 : A diagrammatical depiction of a conventional drip system root zone. The soil moisture is depleted to the readily available water (RAW) refill point before irrigation occurs. As soil moisture is depleted discrete films of moisture form around the soil particles and the roots. As nutrients are added to the soil they are adsorbed to the soil surface and are released into the soil solution through an equilibrium. Some nutrients move quickly through mass flow to the roots (i.e. calcium) and other nutrients move very slowly through diffusion to the roots (i.e. phosphorous).

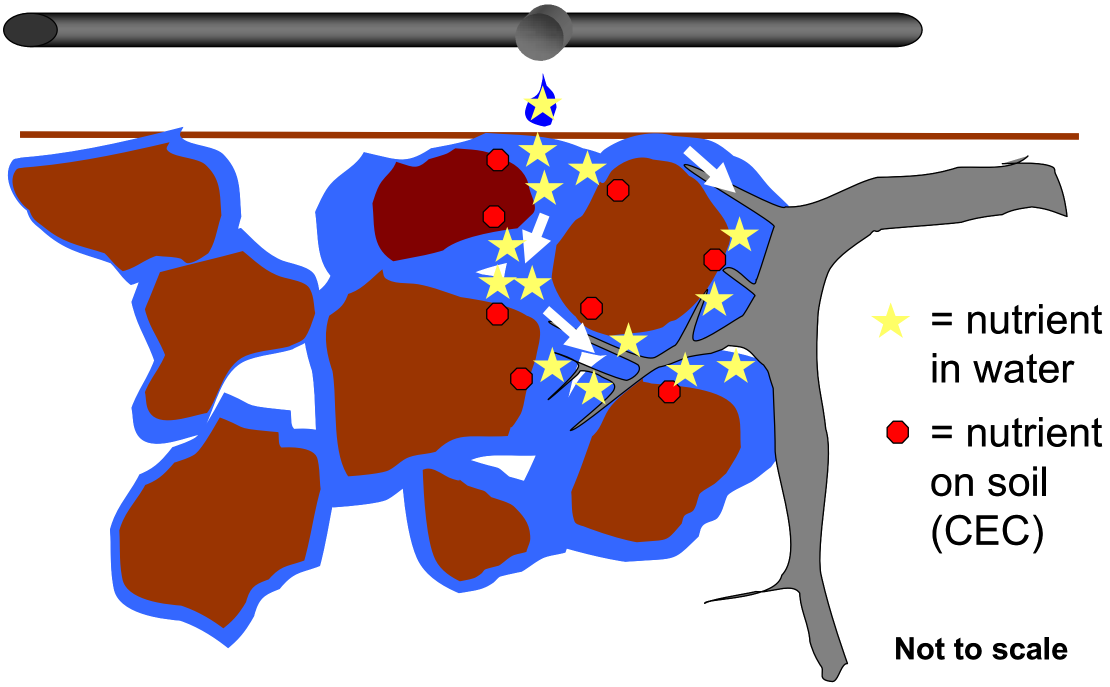

Figure 5 : A diagrammatical depiction of a restricted root zone. The concentrated root zone and high soil moisture status improves delivery of nutrient to the roots and attempts to reduce the influence of the buffering capacity of the soil.

Studies into restricted root zones using physical constraints have shown a reduction in yield in fruit and vegetables (Boland et. al 2000, Ismal et. al 1996, Bar-Yosef, et al 1988 & Kharkina et. al. 1999). The yield reduction was mainly attributed to reduced canopy growth. A relationship between root volume and canopy size has been observed in many crops. Reduced canopy growth or a reduction in yield per tree has not been observed to date in OH. The wetted soil volume in OH is considerable greater than the restricted root zones studies mentioned above where significant reductions in vegetative growth and yield have been reported. For example the study by Boland et al. (2000) on peaches showed a reduction in growth and yield when the root zone was restricted to 3 % of its potential. By comparison the wetted soil volume in OH is approximately 8% to 15% of the potential root volume. It is possible that in an OH situation the roots are redirected to grow more densely in a smaller volume of soil, but the soil volume is sufficiently large enough to support active root growth and a productive tree. More work is required to understand restricted root zone dynamics in OH.

Figure 6 : Professor Rafael Martinez Valero (MOHT) showing the intensity of root growth from a sample of citrus roots taken from underneath a dripper of an orchard (Farm 8) using the MOHT program.

Soil Buffering Capacity and Nutrient Uptake

As the nutrient solution is applied to the soil by the dripper, it must travel through the soil to reach the roots. As the nutrient solution travels through the soil profile (macro and micro pores) the soil will buffer and alter the nutrient solution (Brady 2001). In a restricted root zone the roots are highly concentrated in a smaller area of soil that is near the dripper. Therefore the applied nutrient solution will have to move and interact through less soil to reach the roots in a restricted root zone.

OH provides nutrients on a short time scale (daily supply) rather than using the soil as a storage medium to release nutrients as required throughout time (monthly, quarterly). A restricted root zone may make the soil behave more like a root anchoring medium rather than a nutrient buffer and storage medium. Some nutrient buffering by the soil will occur in a restricted root zone environment.

As nutrients move through the soil via the soil solution they interact with the soil and are adsorbed on to the soil particles through anion and cation exchange capacity. In some cases they are fixed onto the soil particles and made unavailable for exchange. The movement of some of these nutrients from the soil surface to the roots will partially (potassium) or wholly occur (phosphorous) through diffusion (Havlin 2004). Diffusion moves nutrients very slowly and over very short distances measured in millimetres (Barber 1995). A high concentration of roots in a small volume of soil increases the root to soil ratio and may increase the ability of roots to seek out and take up nutrients that are supplied through diffusion mechanisms.

Nutrient Manipulation

The application of nutrients to a small volume of soil allows greater ability to change the concentration of nutrients in the soil solution. For example spreading 20 kg of potassium sulphate on 1/10 of a hectare will have a greater effect on changing the concentration of potassium in the soil solution than if it was spread over the entire hectare. The ability to reduce nutrient concentrations in the soil is also possible because only a small store of nutrients is available in the soil volume in an OH program using a restricted root zone. This manipulation of nutrition can be important for some physiological stages (for example reducing nitrogen in the maturation phase of citrus).

Nutrient Uptake

Roots are selective in their uptake of nutrients. In other words, they can exclude or preferentially take up certain nutrients regardless of the difference in the concentration of these nutrients. However the uptake of nutrients is also affected by the concentration of the nutrient in the soil solution (Epstein 2004). Therefore increasing the concentration of a nutrient in the soil solution will increase uptake. However this increase in uptake is not the same proportion as the concentration increase (i.e. doubling the potassium concentration in the soil solution of a soil with naturally good levels of potassium may not double the amount of potassium uptake by the roots). OH attempts to increase and decrease the uptake of nutrients at particular physiological stages by having a greater control of changing the concentration of these nutrients in the soil solution.

Water Management

Maintaining high soil moisture is an important aspect of OH. It is used for improved nutrition management and water uptake. OH irrigation management programs try to maintain soil moisture near field capacity and/or within at least 10% of the readily available water (RAW) in the soil.

Conventional water management irrigate within RAW (Figure 7 & 8). An advantage of maintaining soil moisture near field capacity is that the risk of water stressing trees is greatly reduced. Conventional orchards that irrigate to RAW may sometimes misjudge when RAW is reached and may cause water stress. Conventional drip irrigation system operators may choose a 50% to 75% RAW refill point to ensure that trees are never water stressed, whilst a sprinkler irrigator would use a 100% RAW refill point because of practical difficulties in conducting very frequent irrigations.

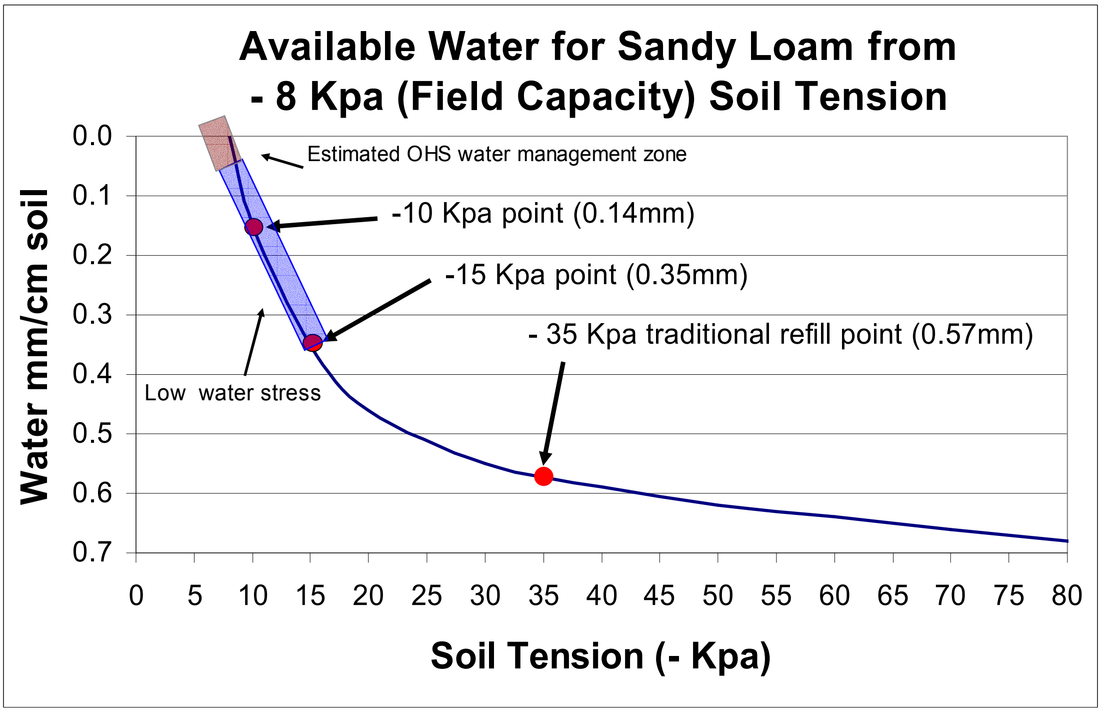

Figure 7: Water content and soil moisture relationship for a sandy loam soil

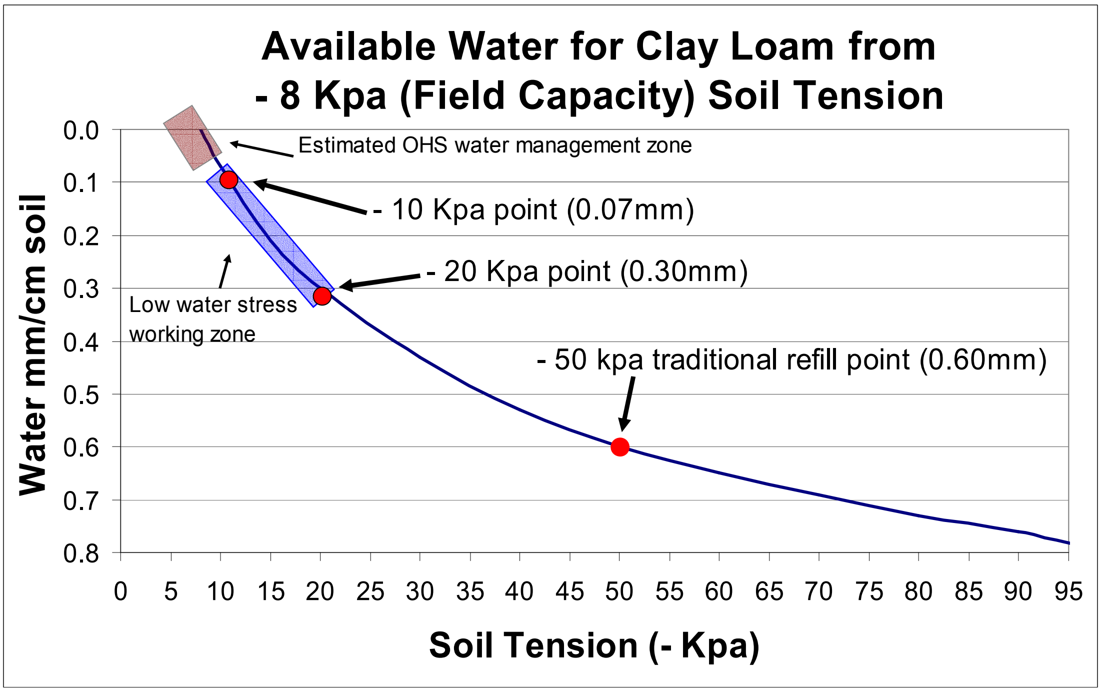

Figure 8 : Water content and soil moisture relationship for a clay loam soil:

Maintaining soil moisture near field capacity requires the use of an irrigation system and management program that can top up soil moisture very frequently or continually throughout the day. The practical implications of irrigating very frequently or continually are demonstrated in the following comparison of a conventional drip irrigation wetted zone and a restricted root zone. The calculations are sourced from a drip irrigation RAW calculator spreadsheet developed for this project (Figures 7 to 10) which will be soon published on the Australian Citrus Growers web site.

Conventional Twin Line Dripper RAW Calculation

Average water application requirements for medium sized mature oranges in Sunraysia using drip irrigation during summer is about 5.5mm per day or about 105L per day per tree (520 trees/ha). A twin-line dripper (60cm emitter spacing) in a sandy loam soil with an effective wetting diameter of one meter and an effective wetted soil depth of 55 cm (broad ellipsoid wetting pattern) would hold about 206L at 100% RAW (note: this example is only for one situation and there can be variation in wetted soil depth and width between orchards). Therefore this soil would have about 2 day's supply of water for 105L per day water use conditions. If the refill point was set at 50% RAW, then there would only be about 103L of water available per tree, or about one days supply of water. At a 50% RAW refill point, a tensiometer might fluctuate between 10 to 15 Kpa in a sandy loam soil (Figure 7). A 10% RAW refill point would have one fifth of a days supply of water and irrigation pulsing (about 4 pulses per day at 1mm application rate), or a continuous form of irrigation application (eg. low output drippers) would be essential to maintain the desired soil moisture level. At a 10% RAW refill point, a tensiometer might fluctuate between 5 to 10 Kpa in a sandy loam soil (Figure 7).

Restricted Root zone RAW Calculation

A single-line dripper (95cm dripper spacing) in a sandy loam soil with about four drippers per tree (520 trees/ha) with a 1m diameter effective wetted zone and an effective wetted soil depth of 55 cm (broad ellipsoid wetting pattern) would hold about 70L per tree per day of 100% RAW, or about two thirds of a days water supply in summer (5.5mm per day water application requirement – 105L per tree). A 50% RAW refill point would have one third of a days supply of water and a 10% RAW refill point would have one fifteenth of a days supply of water in summer (about 9 pulses per day). Therefore a restricted root zone management system with a 10% RAW refill point, would have to have an irrigation design to either apply water continuously at a low output rate throughout the day or to pulse irrigate throughout the day.

Irrigation scheduling

As demonstrated in the calculations in the previous section, an intensive form of irrigation scheduling is required for OH. To maintain soil moisture near field capacity requires continuous or regular application of water throughout the day during typical summer water use conditions. During low water use conditions such as winter, the intensity of irrigation scheduling could be reduced to one application per day or even less depending on the situation.

There are currently two main types of irrigation scheduling principles and programs to cope with the irrigation demands of OH. These are pulsing irrigation and continuous irrigation. Pulsing irrigation management program involves short pulses of irrigation provided to the trees throughout the day to maintain soil moisture within a 10% RAW refill point (Figure 7 & 8). This type of irrigation management program is currently used by OH consultant, Japie Kruger (OHS Solutions). The number and timings of pulses are based on a calculation of RAW and average tree water use along with monitoring of irrigation scheduling devices. In a restricted root zone situation up to nine or more pulses of irrigation could be scheduled throughout the day in summer (Figure 9). The spreadsheet used to generate the graph in Figures nine and ten was sourced from a drip irrigation pulse frequency model spreadsheet developed for this project and will soon be published on the Australian Citrus Growers web site. An irrigation system designed for pulsing irrigation may apply between 1 to 1.5 mm of water over the orchard area per hour and requires an irrigation design that would prevent leakage of water from the main lines and dripper lines once the irrigation ceases (tube non leakage valves, non leakage drippers, non return valves).

A continuous irrigation management program uses low output rates to match water use conditions in summer. Pulsing is also used in this system to better match water application rates to the crop's water requirements. This type of irrigation management program is currently used by the MOHT system. Irrigation systems using this method may use application rates of about 0.5mm/hr (0.40 to 0.55mm/hr). The main principle of this system is that the irrigation operates continuously throughout the day to approximately meet summer water use demands. During summer conditions a general strategy is to commence irrigation before peak daily water use conditions occur. The soil moisture profile near the dripper is initially brought to above field capacity. The MOHT system aims to maintain soil moisture levels above field capacity (controlled saturation) throughout the majority of the day (Figure 10). MOHT (Martinez 2004) suggests that roots are able to take up more water and nutrients at soil moisture levels above field capacity near to saturation point (near to zero soil moisture tension). Therefore at peak water demand periods the stomata may stay open longer which would allow the leaves to photosynthesise longer and produce more carbohydrates to increase productivity. Martinez also suggests that less energy is required by the tree to uptake water closer to a free state (above field capacity) than at higher soil moisture tensions (Martinez 2004). The soil moisture levels above field capacity are managed so adequate oxygen levels are available to maintain root function. Martinez termed this principle as "controlled saturation" (Martinez 2004). This principle should not be confused with roots in an anaerobic waterlogged, or saturated soil environment of stagnant water, but a defining zone of high soil moisture with constant water flow maintaining adequate oxygen levels. In milder climatic conditions where the tree water use is less than the dripper application rate, a form of irrigation pulsing is used to match the water application rates to tree's water use needs. Pulses could be up to three per day and are dependant on the tree water use rates for the day. During the middle of winter when water use rates are very low only a short single daily irrigation could be applied.

Concerns have been raised about the risks of root asphyxiating effects of water logging. The MOHT programs attempts to overcome this risk by monitoring and regulating water application to ensure adequate oxygen levels are maintained to reduce the risk of root asphyxiation. Soil excavation under the drippers of the farm 8 MOHT citrus orchard have shown an extensive and dense root growth directly under the dripper.

Infield measurements of the soil moisture status of a root zone using a MOHT controlled saturation irrigation management program, or any other OH program was not conducted. The degree, volume, timing and intensity of soil saturation underneath the dripper are not known. Further in-field investigations are required to provide a better understanding. Some possible theories on how a MOHT controlled saturated soil management system is able to maintain adequate oxygen levels are:

- At low water application rates there is a continuos flow of water into the soil profile throughout the day and continuous uptake by the plant. Oxygen may move in with the water and assist to maintain oxygen levels in a saturated, or near saturated root zone.
- The infiltration rates of the soil might be greater than the application rates and hence total saturation may never be reached.
- Soil saturation may only occur in a small zone directly under the dripper. By the actions of drainage, capillary action and root water use, soil moisture levels may not be saturated within the main body of the root zone where adequate oxygen levels can be maintained.
- Irrigation does not normally occur at night and the soil would drain to field capacity.
- Mounding may assist to over come some soil saturation issues.

A soil moisture depletion model for a MOHT continuous irrigation program (Figure 10) demonstrates that as peak water use conditions occur during the middle of the day in peak summer conditions (~ 5mm/day), soil moisture levels in the soil are reduced below field capacity. Soil moisture levels recover in the late afternoon when water use demands decrease and the application rate is greater than the water use rate. During days of less water use demand (i.e. 3mm per day). The system will over supply the amount of water required if continuously applied. Irrigation pulsing is adopted in these circumstances.

Scheduling of irrigations for OH (pulsing or continuos) requires a higher level of skill and management than using the conventional irrigation programs using a 50% or 100% RAW refill point. All operators using OH principles in Australia use a soil capacitance probe to assist in scheduling irrigations and to closely monitor soil moisture status. Growers monitor the lower soil depth sensors of their soil moisture monitoring devices (i.e. 100cm) to check that only a minimal amount of water passes beyond the root zone. Annual water use figures of orchards using OH irrigation practices have not been significantly different to those using conventional drip irrigation practices.

Growers using OH may be scheduling irrigations better that conventional drip operators because the adoption of OH requires growers to improve their irrigation management practices. There is a reduced margin of error for irrigation scheduling with OH and a more rigorous irrigation scheduling regime is generally adopted. Nutrient leaching beyond the root zone through excessive irrigation is a risk with OH but there is also a risk of insufficient salt leaching by scheduling too efficiently.

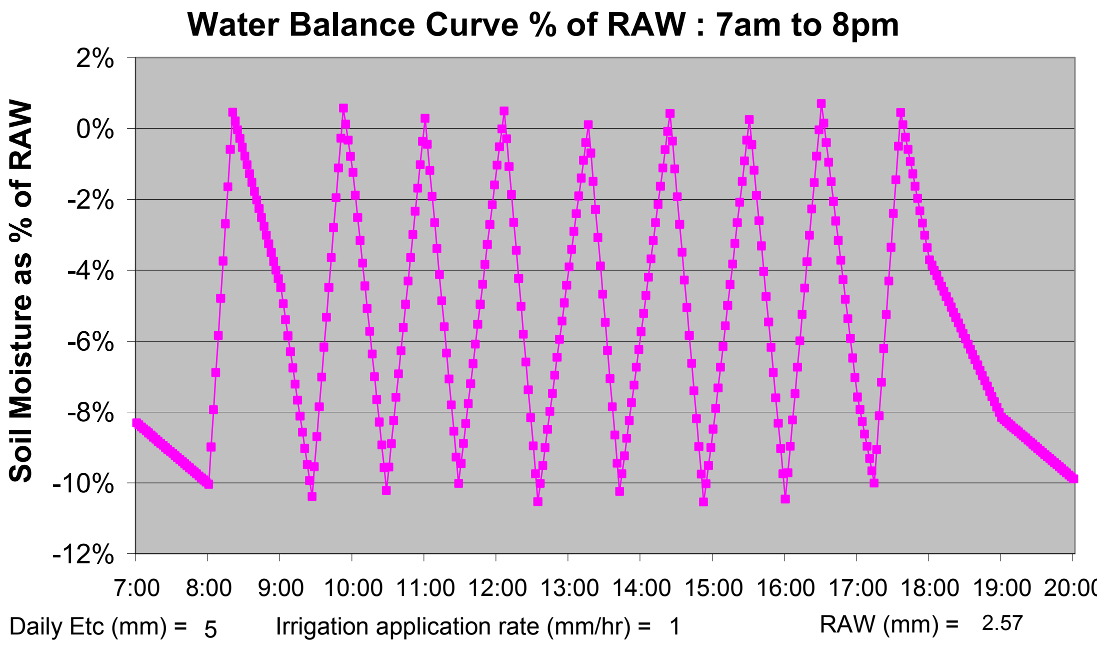

Figure 9 : Soil moisture curve for a pulse irrigation system using a restricted root zone with a 10% refill point. The curve was generated from a soil moisture profile model. A decrease in the curve indicates water use and an increase in the curve indicates an irrigation. 0% is field capacity.

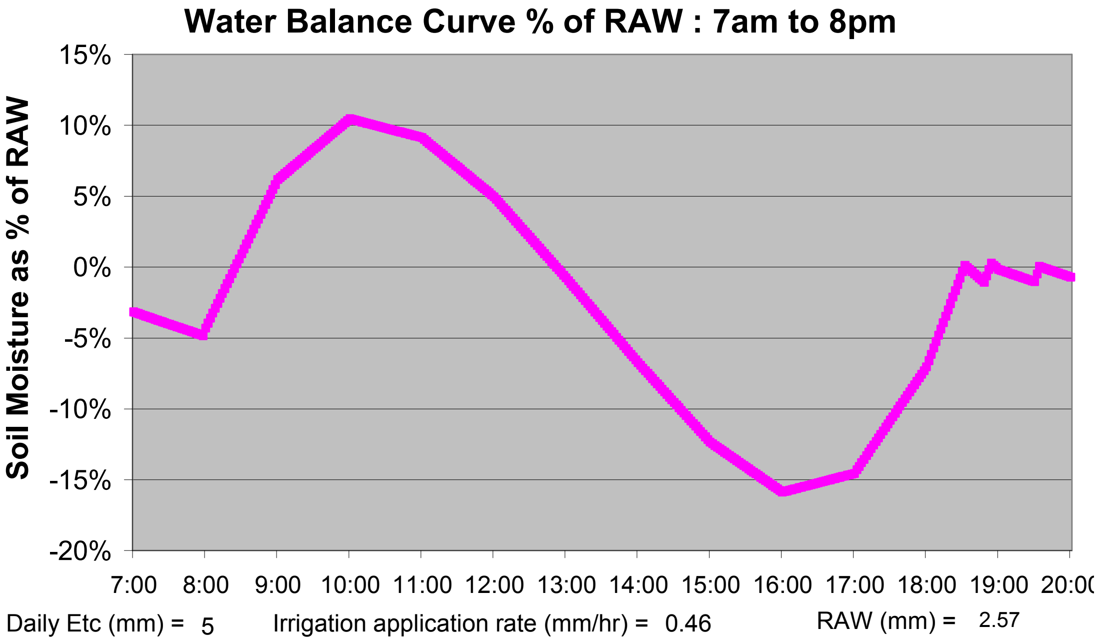

Figure 10 : Soil moisture curve for a continuous irrigation system using a restricted root zone. The curve was generated from a soil moisture profile model. The graph depicts continuous irrigation from 8:00am to 6:30pm.

Growers using OH irrigation practices in Spain have realised the importance of irrigation scheduling to maintain optimum soil moisture levels. Soil capacitance probes are used to monitor soil moisture levels. Some growers have purchased other irrigation scheduling devices including a trunk diameter measuring device (Figure 11). When the device detects a contraction in the trunk this indicates that irrigation is required.

Figure 11: Soil capacitance probe (left) and a trunk diameter measuring device (right) used by a grower in Spain to assist in irrigation scheduling.

Pulsing or continuous irrigation is reported to have two effects. The first effect is that it maintains the root zone soil moisture levels closer to field capacity and it also bring the main core of the wetted zone closer to the soil surface (Charlesworth, 2004). This increase in height is reported to result in less movement of water past the root zone. The second effect is that it allows time for some lateral movement of water thereby increasing the volume of the wetted soil zone. However pulsing irrigation trials have produced conflicting opinions on lateral water movement. Some trials have reported an increase in the width of the wetted zone, and others have reported no increase (Charlesworth, 2004).

The soil surface remains wetter longer in a pulsing or continuous irrigation program. This encourages the roots to grow closer to the soil surface. However on some soils the roots may not grow in the immediate area directly under the dripper (3-10cm) since this area could be experiencing too high moisture levels (saturation). Since the soil surface remains wetter longer this might increase possible losses by evaporation.

Intensive Fertigation Practices

Since the introduction of OH to the Australian citrus industry in 1999 there has been an increasing interest into OH. However some growers have been deterred because of its high initial capital costs, consultancy cost and lack of Australian experience. This resulted in some growers adopting a variation of OH. This variation of OH is called intensive fertigation practices (IFP).

It is sometimes difficult to differentiate OH and some IFP because IFP uses many of the same principles of OH. Both use a nutrient solution containing various macro and micro nutrients, proportional injection of the nutrients into the water supply, pH adjustment of the irrigation water and a high level of irrigation scheduling and monitoring. The most obvious difference is that IFP uses a larger conventional root zone volume (twin line continuous wetted strip: figure 2) and a refill point that is set lower than OH. The practical implication of using a conventional root zone is that the physical and chemical properties of the soil are more utilised. This can lower the application rates of some of the macronutrients (eg calcium, magnesium and potassium). Utilising some of the nutrients available in the soil reduces fertiliser costs when compared to a restricted root zone OH program. The larger wetted soil volume provides a bank of available water to the tree thereby reducing the management risks associated with restricted root zones. The majority of growers using IFP would irrigate only once a day to maintain soil moisture at a good level (generally not exceeding 50% RAW) whilst OH would be focusing on maintaining soil moisture levels near to field capacity. IFP is an intensive form of fertigation whilst OH uses fertigation as a part of a hydroponic management strategy.

There are more citrus growers in Australia using and adopting IFP and general fertigation practices than those adopting OH. Some grower's skill levels and orchard situations may not be suitable for OH and these growers may be able to implement IFP. The principles of OH are an important influence in IFP. The possible benefits of IFP to Australian horticulture should not be underestimated or ignored.

Nutrition

Application Rates

The restricted root zone used in OH does not hold a large store of nutrients therefore the application of a balanced nutrient solution must be on a very regular basis. This is achieved by injecting fertiliser proportionally with irrigation. An adaptation of a standard hydroponic solution is fed to the trees on a daily basis. A standard hydroponics solution (eg modified Hoagland solution – Epstein 2004) would not be suitable for OH because the residual salts not used by the tree will remain in the root zone. These residual salts is could build-up and cause toxicities and salinity issues. In a commercial soil less hydroponic situation the old nutrient solution is eventually discarded and replaced with a fresh batch. The concentration of salts in the nutrient solution for OH is less than a commercial soil-less hydroponic nutrient solutions.

Nutrient solutions are developed by establishing the nutrient requirements of the trees for a particular growth period and calculating the appropriate solution concentration and injection rate to achieve the targeted annual application rate. Nutrient application rates for the majority of OH and IFP in citrus can be about 20% to 50% higher than conventional practices. Two possible reasons are higher productivity levels and a lower nutrient bank in the soil. OH and IFP use a more intensive nutrition program that may push the trees into a higher level of vigour and productivity requiring higher nutrient application rates to maintain production. The soil is no longer a bank of nutrients and the majority of nutrient removed by the crop needs to be resupplied. The macro nutrient rates applied by OH and IFP are reasonably consistent to estimated tree and crop nutrient removal rates. Application rates of micro nutrients are significantly higher than crop removal rates because of fixation issues of these micro nutrients in some soils. **These higher application rates carry a risk and if not done correctly and introduced gradually, nutrient imbalances may occur which could have serious implication on productivity and fruit quality**.

Growers using OH and IFP are also able to time the application of nutrients to suit physiological growth stages. The majority of growers in Australia would probably require an upgrading of nutrition management skills to manage an intensive OH nutrition management program and also use a professional consultant to assist in management. All OH users and a high majority of IFP users use a consultancy service. The consultancy services also provide advice on the installation of the fertigation system and other best management practices.

Since the soil is not used as a source of nutrients, the majority of macro and micro nutrients must be supplied by the nutrient solution. Soils used for citrus production in the southern growing regions of Australia generally contain adequate levels of calcium, magnesium, and moderate levels of potassium. Conventional fertiliser practices do not apply significant amounts of calcium or magnesium since they are available in adequate amounts in these soils. For a restricted root zone as used by OH, these nutrients may no longer be sufficient supply and may need to be supplemented. The concentration of nutrients in the irrigation water would also be considered when developing a nutrition program. The application of nutrients such as calcium can be expensive and is considered one of the disadvantages of adopting a restricted root zone program.

Nitrogen application rates for citrus used in Spain are about 1.5 to 3 times higher than conventional rates used in Australia (Augusti, 2003; Falivene, 2004). The application of other macro nutrients is also higher than conventional rates used in Australia. Research trials at Dareton, NSW, in the 1970's on Valencia orange trees have demonstrated that high nitrogen application rates, such as those used in Spain, could cause a serious decline in fruit quality (unpublished). Reports (personal communication) from Australia and Chile indicate that some growers have adopted high rates of fertilisers in some OH and intensive fertigation programs. Some growers report (personal communication) the use of high nitrogen application rates (i.e. 250-350 kg/ha of N) have resulted in poor fruit quality and a reduction in returns as a result of a nutrient imbalance. It is possible that the high fertiliser rates used in Spain could be related to the use of high salinity water containing high chloride levels (EC 2000-3000) (Falivene, 2004)and/or a problem with of nutrient leaching. In response to problems with high fertiliser application rates, nitrogen rates used in Australia by OH and IFP growers are now not as high as in Spain, but more reasonable and more closely aligned to crop removal rates.

Ionic Balance

An ionic balanced nutrient solution in commercial soil-less hydroponic systems assists in maintaining the pH of the nutrient solution (Burt, 1997; Huett, 1993). An ionic balanced nutrient solution has equal numbers of positive and negative charges of nutrients that are actively taken up by the roots (Lopez, 2000). When roots take up nutrients they must balance their electrical charge to be neutral. A simplified explanation of this process is as follows. If a root takes up a cation (positive charged ion, for example calcium : Ca^{+2}), it can balance the electrical charge by also taking up and an anion (negatively charged ion) or anions to provide the equivalent negative charge (for example two nitrate ions : $2 \times NO_3^{-1}$). If a root is unable to balance the charge by taking up an anion, or anions, of equal negative charge, then the root will exude two positively charged hydrogen ions. The hydrogen ions exuded from the roots will lower the pH of the soil thereby causing acidification of the rhizosphere.

Ionic balance is an important consideration, but not a critical factor for soil-less hydroponic production. Only Spanish literature (Lopez, 2000) and one English fertigation paper (Burt, 1997) explain in detail the principles of ionic balance. One Australian book discussed the principles of ionic balance in relation to pH control (Huett, 1993). Many other publications do not mention the importance of ionic balance and only mention the need to check the pH of the solutions (Jones, 1997, Mason, 1990 and Resh 2001). A possible reason for not discussing ionic balance is that many of the hydroponic nutrient solutions recommended in the books are already ionic balanced. If the solutions are not perfectly balanced, the addition of an acid or alkaline to the nutrient solution during production will alter the pH to the desired level.

Martinez (2004) claims that energy savings from an electrically balanced nutrient solution can contribute to increases in productivity. The theory is that as anions and cations are taken up in balanced pairs the root does not have to waste energy in maintaining electrical balance within the root cells. A tool to manipulate the ionic balance of a nutrient solution is the use of nitrate instead of ammonium as the main form of nitrogen. Although nitrate in a balanced nutrient solution may assist to reduce the energy required for ion uptake by the roots (Matinez 2004), energy will be required to reduce it back into the ammonium form where it can be utilised by the tree. Ion uptake is a complex topic and further investigation need to be conducted to assess if the overall energy savings are sufficient enough to impact on productivity. The Japie Kruger OH system does not heavily focus on an ionic balanced nutrient solution, but considers it as a consideration when developing a nutrient solution.

Preventing soil acidification is an important consideration in OH. An ionic balanced nutrient solution can assist in reducing soil acidification. Although much is discussed about ionic balance there is not much that operators can practically do to change the ionic balance of a solution other than to replace the ammonium forms of nitrogen with nitrate which provides more negative ions in the nutrient solution. If nitrate is the sole form of nitrogen, then the only other tools available to manipulate ionic balance are to increase phosphorous application rates or reduce the application rates of other cations, however this could cause a nutritional imbalance. The other advantage of not using ammonium forms of nitrogen is that as ammonium converts to nitrate (through the natural processes of nitrification) it releases hydrogen ions in the soil further contributing to soil acidification. The nutrient buffering capacity of the soil may also change the concentration of nutrients in the nutrient solution as it enters the soil.

Water pH Correction

pH adjustment of the irrigation water is used by many OH and IFP management programs. It is a standard practice in soil-less hydroponic production. Phosphorous and calcium are mixed together in OH nutrient solutions. Phosphorous and calcium can form a precipitate if mixed together in solution, however the risk of precipitation is significantly reduced if the pH of the water is slightly acidic (6 to 6.5 pH). Phosphorous and a number of micro nutrients are more available at slightly acidic pH levels. The pH trimming of nutrient solutions may assist in the uptake of these nutrients. However the buffering capacity of a soil can change the pH of a nutrient solution entering the soil to be similar to the soil pH. The extent of a soil to buffer a nutrient solution in an OH situation was not investigated.

Soil Solution Analysis

Since the soil solution is the focus of OH and some IFP programs, analysing the soil solution can be a useful nutrient monitoring tool. This tool has been used in Spain and is also currently being assessed in Australia on a number of citrus orchards in Sunraysia and the Riverland. A soil solution extract is removed from the soil at specific crop stages and analysed for its nutrient content (Figure 12). Nutrient application recommendations are then made based on these results.

Figure 12: Soil solution extraction tube. Tubes are installed at varying depths to measure the amount of nutrients in the soil solution in the root zone and below the root zone. The tube pictured is manufactured by SARDI for the tri-state salinity project.

Current Literature

There is a significant amount of literature dealing with research on irrigation frequency and fertigation, but conclusions about OH cannot be drawn from these research papers because OH is a different management technique. However the information can provide a general insight and a better understanding into some of the principles involved with OH. Only two papers were sourced that dealt directly with OH (Kruger[2], 2000, Martinez 2004) and two research trials dealt with certain aspects of OH (Kruger[1], 2000 and Bravdo, 1992).

Fertigation and Irrigation Frequency Research in Citrus

Research into irrigation frequency and fertigation have produced mixed results. Some research trials into fertigation have reported benefits in yield and the nutritional status of trees, whilst others have reported no significant differences. These mixed results are well summarised in a paper by Intrigiolo et al:

> *"the beneficial effects of fertigation, as compared to conventional methods, are evidenced not only by a productive parameters (Koo and McCornack, 1965) but also by vegetative responses (Koo, 1979). Koo (1980), investigating nutritional aspects, reported differences in leaf contents, particularly of N, P and Mg between trees which received liquid and trees which received dry fertilisation. These differences were not found by Scuderi and Raciti (1980). Furthermore, Koo (1980) and Koo and Smajstral (1984), in trials carried out on sandy soil, reported increased leaf nitrogen content proportional to the extent of ground covered by irrigation. They found no different effects due to fertigation frequencies (3 or 10 times a year)."*

Bester et al., (1977) reports an increase in leaf nitrogen levels of young trees fertigated frequently with an NPK solution when compared to a broadcast fertiliser application using a sprinkler irrigation system, however there were no significant increases in leaf potassium or phosphorous levels. Similar results were also reported by Intriglio et al., (1992) when comparing a single annual application of NPK to a continuous fertigated application. A trial conducted by Syversten (2001) comparing daily fertigation to weekly and monthly fertigations could not find any difference in yield, fruit size or the growth of young trees. However leaf nitrogen levels were higher for the daily fertigated treatments.

Mixed results have also been reported with irrigation frequency. The majority of papers reviewed provided positive responses to the use of drip irrigation as compared to sprinklers and to the increased frequency of irrigation. The majority of papers also report a significant increase in water use efficiency with drip irrigation compared to sprinkler irrigation. An irrigation frequency trial conducted by Bowman (1996) reported increased fruit size and yield in sprinkler irrigated grapefruit trees when the refill point was set to about 10-15kpa compared to about 35-45kpa. These soil tension readings would correspond to about a 50% RAW refill point and a 100% RAW refill point. A comparison of drip irrigation to sprinkler irrigation by Rodney et al (1977) reported a significant increase in yield during the first six years after planting. Productivity improvement with the use of drip irrigation compared to conventional sprinkler irrigation is a generally accepted principle in the citrus industry. No significant differences in yield and quality were reported (Yagev, 1977) in the use of drip irrigation applied twice per week compared to once every second week.

The mixed results of research in fertigation and irrigation frequency may possibly highlight the effect of site (i.e. soil, climate, water quality) and treatment factors (i.e. fertigation frequency, nutrient mixtures). Particular treatments may operate well in one soil type or climate, but may not produce the same results in another. Modification, of a treatment to suit local conditions may be required to properly assess a treatment.

Restricted Root-zone and OH Research in Citrus

A trial conducted by Bravdo et al., (1992) in Israel compared the use of restricted root zone practices for citrus. The trees were maintained at a high moisture status (8-12 kpa) and were fertigated proportionally with a macro and micronutrient solution. The trial is similar to an OH program. A sprinkler and drip irrigation treatment and three fertiliser rate treatments were used in the trial. For the lowest and medium fertiliser application rates there was no significant difference in yield between any of the treatments for both drip irrigation and sprinkler irrigation. However there was a significant increase in yield in the restricted root zone drip irrigation treatment using the highest rate of fertiliser application. This treatment produced the highest yield, but the smallest fruit size in the first year of cropping. However in the following two years of cropping, high yields were maintained with no difference in fruit size compared to other treatments. The highest fertiliser rate equated to an annual application of 400kg of nitrogen per hectare. The other two fertiliser rates equated to an annual application of 240 and 120kg of nitrogen per hectare. 400kg of nitrogen per hectare would be considered as excessive in Southern Australian citrus growing conditions. Such high rates of nitrogen can have negative affects on fruit quality. It is possible that the high fertiliser application rates may have been required because of water salinity issues. The paper did not indicate the salinity levels of the irrigation water. These trial results may indicate that there could be a transitional phase when converting from conventional practices to an intensive OH program. Productivity might be reduced during the transitional phase. High rates of fertiliser may also be required to fully utilise the potential of an OH program.

A trial conducted by Kruger[1] et al (2000), compared drip irrigation fertigation to conventional broadcast and fertigation micro sprinkler irrigation. The fertigation treatments were daily, weekly and fortnightly for the drip irrigation system and weekly, fortnightly and once every two months for the micro sprinkler system. There was no difference in the returns between the micro sprinkler system and drip irrigated system. However the drip irrigation system using a restricted root zone yielded less than the other treatments. The paper stated that the reduction in yield from the restricted root zone treatments was probably due to the inability of irrigating at sufficiently frequent rates to meet the water use needs of the trees. This emphasises the need for correct water scheduling practices for a restricted root zone and drip irrigation system.

The trial also showed a trend of lower returns from the fertigated sprinkler treatment when compared to the broadcast fertiliser application sprinkler treatment. Mr Kruger indicated (personal communication) that the regular fertigation of nutrients through a sprinkler system may dilute the concentration of nutrients in the soil where it may not have a significant impact on nutrient uptake as compared to a more concentrated broadcast application. Mr Kruger does not advocate the extensive use of high frequency fertigation with sprinkler systems. Although the results showed no significant difference between micro sprinkler and drip irrigation systems, it must be noted that the drip irrigation treatment was not an OH program, but a general fertigation treatment. Only the restricted root zone treatment was approaching OH.

The trials conducted by Kruger[1] et al (2000) and Bravdo et al., (1992) may also indicate that a very well managed sprinkler irrigation system can perform equally as well as a drip irrigation system. However in reality, sprinkler irrigation systems may not be as intensively managed by growers as those managed in research trials. There could also be different system design application and distribution efficiencies. A well designed drip irrigation system has good distribution efficiency and is easier to implement optimum irrigation scheduling practices. The inefficiencies of a commercially managed sprinkler system could be restricting full production potential and could be the cause of the reported improvements when growers convert to a more efficient drip irrigation system.

Mr Kruger conducted an OH trial on Clementine mandarins in 1999 in South Africa (Kruger[2] 2000). The trial was a non replicated demonstration trial. The OH treatment increased yields by 19%. The yield increase was attributed to an increase in fruit numbers, but as a consequence fruit size was slightly decreased. However in financial terms, the higher yield compensated for the smaller fruit size by approximately 31%. The trial indicated a positive response to OH for both yield and economic return. The paper also indicated that further productivity improvements are expected with some fine tuning of the system.

The paper written by Martinez et.al 2004 provides yield results of some orchards using OH in Spain and discusses some of the principles involved with ion balanced solutions and maintaining soil moisture at saturation. Nova, Marisol and Delite mandarins were planted at high-density (1000 trees per hectare) and grown using the MOHT system. The first six years of results were presented in the report. Yields in the sixth year were about 65 to 75 tonnes per hectare. These yields are definitely higher than a conventional orchard using medium density plantings (i.e. 550 trees per hectare). However it is difficult to assess if the MOHT program was any better than an IFP orchard at a similar planting density because there is no control treatment presented in the data. Some reports from Spain indicate that orchards using IFP are also achieving similar yields when planted with mandarins at high density (Falivene 2004), but the long term yield data is not available for these orchards to adequately assess the difference.

The paper discussed the advantages of controlled saturated soil moisture management and ionic balance. This was previously discussed in the irrigation scheduling and the nutrition and application rate section.

Equipment

A variety of equipment can be used for OH, but the minimum requirement is the ability to conduct proportional fertigation from a multi-tank system. A minimum of two nutrient tanks are required with the possibility of an acid tank and acid injection unit depending upon irrigation water quality. A sansitisation tank and injection system would also be required.

Some of the cheaper systems are unable to interface with a personal computer and require a higher management input to keep track of application rates and timings. A small display panel on the controller displays all the data to be read. Although it is possible to conduct an OH program using these injection systems, it is not generally recommended because of the management issues involved in keeping track of application rates and nutrient ratios. The preferred fertigation injection system is able to interface with a personal computer and provide real time information on injection rates and record cumulative application rates. It is easier to manage information through a personal computer rather than manually transferring the information to a record sheet from a small display panel.

The cost of fertigation systems vary considerably. As a guide fertigation systems that are capable of interfacing with a personal computer cost between $50,000-$100,000, this includes the injection system, three tanks and housing facility. The cost estimates do not include filtration, piping and the irrigation lines. Further information about fertigation equipment is available from Citrus Fertigation Systems workshop notes (Falivene et.al 2004)

Figure 13: A centrifugal bypass fertigation system used for an OH program

Grower interest in OH & Fertigation

There has been an increase in interest in OH and fertigation practices in the citrus industry over the past couple of years. This has been reflected by the increasing number of growers investing in OH and other fertigation systems, and by the attendance of growers at numerous field days and seminars dealing with fertigation. For the purpose of simplifying discussion in this section, the term "fertigation" refers to all practices and programs involving fertigation including OH and IFP.

Fertigation is not to new to agriculture. Many of the fertigation programs currently being adopted involve the use of best management practices and especially irrigation and nutrition. Some possible reasons for the increased rate of interest and adoption of fertigation and best management practices included:

- Higher productivity and profitability of these management programs;
- Good marketing of an integrated management program;
- Greater control over the orchard ;
- Consultancy services.

Higher Productivity and Profitability

Many of these systems are promoted as increasing yields of marketable fruit, thereby increasing profitability. Growers that have adopted these management programs are reporting improvements in productivity. Expectations of increasing returns are always a strong driver for change.

Good Marketing of an Integrated Management Program

Many fertigation programs provided by consultants are an integrated management program. These programs deal with all aspects of best management to improve orchard profitability. Traditionally information has been packaged and delivered separately, for example field days workshops and fact sheets that have delivered information on pest, disease, nutrition, irrigation, soil management and canopy management individually.

An integrated management program provides recommendations on all aspects of the orchard system. It provides the grower with a vision of success.

Control Over the Environment

It is recognised that intensive fertigation practices and OH can give growers a greater sense of control over their orchard by being able to more accurately manipulating water and nutrient levels.

Consultancy Services

In the past few years the availability of consultancy services has increased.

Significant recognition is given to Yandilla Park for introducing and promoting OH into Australia. In the past few years they have conducted a number of field days and seminars that have increased grower awareness of OH. They continue to provide a consultancy service on the installation and management on a variety of fertigation systems including OH.

Mildura Fruit Company (MFC) is a large citrus packing house in Sunraysia. MFC have a grower services section that provides advice to contracted growers. In recent years they have sponsored grower tours to study fertigation practices in Spain. These tours have significantly increased the knowledge and confidence of growers in fertigation practices. The significant number of growers that are using intensive fertigation practices in Sunraysia are associated with MFC and have attended a Spain tour. The consultancy services provided by MFC also advise on the installation and management of fertigation systems.

Japie Kruger (OHS Solutions) commenced providing his OH and fertigation consultancy services in Australia in 2004. Japie has made a number of OH information presentations to citrus growers around Australia. A number of growers have adopted his OH system and program.

Risks

Water Supply

The calculations presented in the irrigation scheduling section highlight the importance of having a reliable water supply to ensure that the trees obtain adequate water during the peak summer demand periods. OH require water on demand. If the irrigation system is shut down for more than a few days during peak summer conditions it could have minor to moderate implications on a standard drip irrigation orchard and major implications on an OH orchard using a restricted rooting zone.

Pressurised piped supply does not always mean guaranteed supply. Circumstances could arise where breakdowns and extended delays could occur (i.e. floods, lightning strike to pump stations, burst mains etc). Some supply schemes close down channels for extended periods during winter. Private diverters may not have guaranteed supply in the future. Water supply risk reducing strategies may need to be implemented. This includes the installation of a back-up diesel pump and on-farm water storage. A more in-depth discussion of water supply is provided in the Water Supply Infrastructure report.

Soil acidification and salinity

An important aspect to consider for drip irrigation systems is soil acidification and salt accumulation around the root zone.

An intensive drip irrigation fertigation program could increase the risk of soil acidification. This is an important issue with a restricted root zone system. Soil acidification has already occurred in drip irrigation systems using standard twin line drippers in alkaline soils. Commercially available liquid lime solutions that are compatible for use with drip irrigation systems can be used if pH levels drop below desired levels.

Salts are known to accumulate at the edge of the wetted zone of a drip irrigation system. Management practices have to be implemented to ensure that the salts do not move back into the root zone and cause short term salinity issues. Management practices to reduce salt movement back into the root zone include using a leaching fraction to push salts to the edge of the root zone and controlled irrigation during rain to ensure that salts are not pushed back into the root zone. Work is currently being conducted to investigate the best strategy to leach salts from root zones in drip irrigation systems (Tri-state salinity project).

Nutrient Leaching

Maintaining a soil profile constantly near to field capacity increases the risk of nutrient leaching. The gradual draining of the soil may occur which may move nutrients past the root zone. However nutrient leaching is a risk in any production system whether applying the bulk of fertiliser in three main applications for a sprinkler irrigation system or in small daily doses over a growing season for a drip irrigated fertigation system. Nutrient leaching is a complex issue and is dependant on soil type, climate, management and the regularity of significant rainfall events.

A practice adopted by OH and IFP growers to reduce the risk of nutrient leaching is to use soil capacitance probes to monitor low level soil moisture levels (70 to 120 cm). If soil moisture levels below the root zone begin to increase then irrigation applications are reduced. To validate soil probe readings growers occasionally soil auger under the root zone of trees. Annual water usage rates have not been radically different from conventional drip irrigation practices. Although these management practices significantly contribute to reducing nutrient leaching, other factors can increase this risk. Further discussion on nutrient leaching is discussed in the Water Nutrient and Salt balance report.

Management Skill

OH can provide higher levels of production in optimum situations, however it can also cause rapid decreases in production if not managed correctly. Restricted root zone, intensive nutrition programs and high soil moisture scheduling practices have a reduced margin for error and **require a higher degree of skill and management**. As the root zone becomes more restricted a higher level of control over the nutrient soil solution can be achieved, but margin for error with soil moisture levels decreases. Higher nutrient application rates can cause nutritional imbalances if not conducted correctly. Waterlogging a root zone by over irrigating can have a major impact on reducing production. Waterlogging may also bring a higher risk of disease (i.e. root rot : phytophthora). Irrigating with an inadequate leaching fraction may cause salinity issues in the root zone.

All OH growers in Australia currently use a professional consultancy service to advise on nutrient programs and mixtures. The consultants also provide equipment installation advice. The use of these consultants is an important aspect in the success of OH because the majority of growers do not have the knowledge, experience or skills in OH management. Even though consultants provide management guidance, in the course of daily OH operations the grower still needs to make management decisions. The training of growers to a higher level of management for OH would complement a consultancy service and provide a higher degree of confidence to both consultant and grower.

An additional risk is that the long term implications of restricted root zone practices are not fully known under Australian conditions.

Productivity Gains

Consultants and users of OH from Australia and overseas have been reporting (personal communication) an increase in production from 20% to 40%. The increase in yield may not require any additional water and therefore the weight of fruit per unit of water applied has increased. Observations of OH in Australia clearly demonstrate improvements in the vigour and health of the orchard along with signs of improved productivity. However it has been difficult to establish the relative nature of some of these figures (compared to other systems that implement best management practices). The adoption of OH in Australia is still in the early stages. It can take an orchard a few years of transitional change to settle into an improved bearing capacity and then a further few years for results to give a true picture of yield improvement. Preliminary observations and yield indications from orchards currently using OH are that there is a definite positive response in the vigour and health of the trees with a higher bearing capacity of trees. Young trees are responding especially well with good levels of growth. The Yandilla park orchard (farm 8) has been using OH for about four years and is reporting a general trend of more consistent cropping that has increased average yields. Similar improvements in productivity and tree health have also been observed in IFP orchards

Some of the productivity information quoted for OH is from overseas. Some production figures quoted are from orchards using high-density plantings (i.e. 1000 trees/ha), high yielding varieties (i.e. mandarins), vigorous rootstocks and from warmer climates (semitropical) that have quicker growth rates. Arguably a well-managed orchard using any type of production system in these circumstances would have higher production levels compared with orchards with a moderate yielding citrus variety (midseason naval oranges), in a standard planting density (i.e. 520 tree/ha), medium vigour rootstock and in a Mediterranean type climate (Southern Australia).

OH uses an irrigation scheduling program that ensures that the trees never experience water stress. It is difficult to establish what portion of the productivity gains reported are due to an improvement in irrigation practices or a combination of best management practices or as a result of OH principles.

Further Research

Although some of the general principles and theories of OH are understood, the practical implications of the system are still being investigated for Australian conditions. OH requires a higher level of inputs (management and raw materials) compared to conventional practices. Although early indications are that increases in productivity are likely to increase orchard profitability, no published data or studies are available that indicate that these productivity increases are sufficient to compensate for the increased inputs. No data is published that compares OH to other similar production systems such as IFP.

The main hypothesis identified in this study is;

- Does OH provide the greatest net returns as compared to other forms of productions systems (intensive fertigation systems and conventional production systems) in Australian conditions?
    - Comparison using the same varieties, rootstocks, planting densities, soil and climate etc.

Numerous theories of soil nutrient and water relations in an OH situation was presented in this report. This study only presented and interpreted these theories and principles, but did not to investigate or validate them. Field trials and investigations are required to validate these theories and principles. Further hypotheses identified in dealing with OH theories and principles are;

- Does precise manipulation of nutrient ratios during physiological growth stages have any practical advantage over current practices? If so, what degree of nutrient manipulation provides the greatest economic return?
- What is the buffering capacity of the soil in the restricted root zone compared to a larger more conventional root zone?
- Does a conventional drip irrigation root zone (20-30% soil volume) have similar or acceptable capabilities to manipulate the soil solution as a restricted root zone (8-15% soil volume) and does a restricted root zone produce higher returns?
- Are there any differences in evaporative losses from an OH soil surface that remains wet longer as compared to an IFP or conventional drip system?
- Does soil moisture levels near or above field capacity provide greater returns compared to conventional practices that set a refill point at lower soil moisture levels?
- Does an ionic balanced nutrient solution save significant amounts of energy that will impact on increasing orchard productivity?

The ecological impacts of OH were not assessed in this report would require further investigation. See Ecological Risk Assessment report for more information.

Conclusion & Recommendations

OH can potentially improve the productivity of Australian perennial Horticulture. It is a highly intensive form of production that requires a high level of inputs and management skills. There are infrastructure (water supply) and management risks involved, however these can be managed with good planning, professional OH consultancy providers and training. An important factor in the success of OH is the need for growers to use a professional consultant to train, advise and guide them through the use of the program. Many growers would also require an upgrade in management skills to operate OH in conjunction with a consultant. OH may not be suitable for all growers (skills, financial situation, infrastructure) and other less intensive programmes similar to OH might be more suitable (IFP and general fertigation). There is a need to provide growers with information and training in OH and IFP. The information needs to outline the variety of choices available for management programs using fertigation practices (i.e. OH and IFP) so growers can select a program that suits their skill level and circumstances.

Further work needs to be conducted to assess the potential benefits and impacts of OH. The assessment could investigate some of the questions raised in the previous section (Further Research) and include an economic analysis of the production systems. The potential benefits of OH could also identify new practices that could benefit conventional production systems.

Further work should first focus on collecting field data from commercial OH orchards. However since many OH programs are protected under confidentiality agreements, data collection on commercial properties may pose some difficulties and may not provide sufficient information to make an adequate assessment. Since controls or alternative treatments are difficult to impose on a commercial situation, will information will only provide anecdotal information on a few situations. To adequately analyse aspects of OH research stations trials are required where controls and various treatments can be implemented. The research station trials would be conducted in consultation and co-operation with commercial OH providers on identified knowledge gaps. The research station trial would complement and enhance the commercial field data collection assessments to provide more conclusive results.

The research station trial could also be an excellent resource for Australian research and extension officers in the use and application of OH principles. This resource could be used as a foundation to develop specialised skills training workshops, field days and other extension material. The training of growers would provide a higher degree of skills confidence to both consultant and grower.

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