Sector: Hardy Nursery Stock (HNS)

1. Introduction

This sector covers a wide range of crop species (including trees, shrubs, herbaceous perennials and nursery production of fruit plants) with a diverse range of production techniques and cycles (duration and timing), some field cultivated others container grown (or combination during production cycle). The intensity of cropping and levels of technology employed cover a wide spectrum from extensive field plantings to intensive sophisticated protected cropping. Benchmarking water use cannot be generalised in this sector without taking into account these factors.

Irrigation and water management is very different for container produced crops compared to field scale cropping. Factors such as restricted root volumes, absence of a large soil water reservoir, growing media characteristics and sometimes difficulties getting water to the root zone all tend to increase rates of water use. However, there are also opportunities for enclosed or semi-enclosed systems, water re-capture and other novel irrigation technologies that can help reduce water consumption.

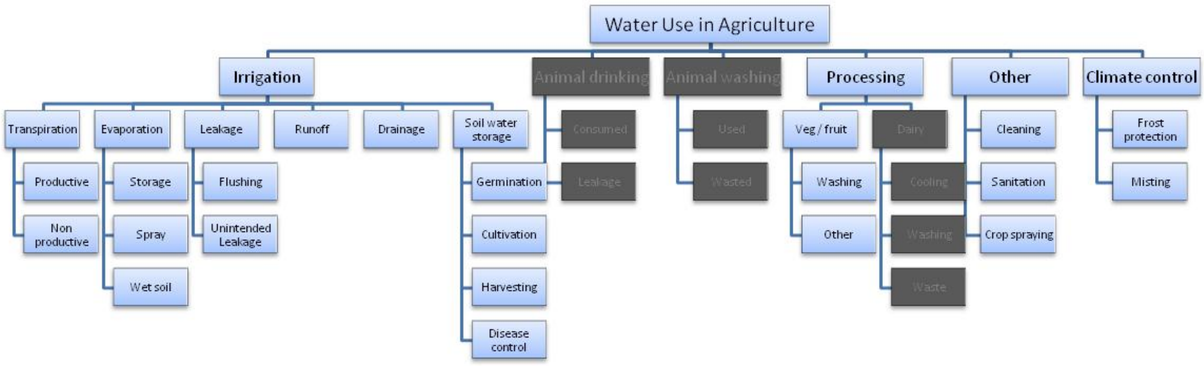
HNS are high value crops. All container production and much field production is entirely reliant on a guaranteed irrigation supply. Rainfall will only provide between 20 – 50% of water needs for outdoor container production (Grant and Burgess, 2007). Interruption of supply for more than a few days during critical times can lead to total crop loss and economic disaster for the business. Irrigation is for quality assurance of HNS rather than yield. Correct irrigation management and scheduling is of increasing importance in this sector (including avoiding over-irrigation) to maintain crop quality. Water management is also linked with pest, disease and weed control, efficient labour use in addition to making best use of limited water supplies.

Water is thus vital for the HNS sector, particularly as container growing and containerisation forms such an important part of total production. The sector is becoming increasingly open to the uptake of new technology relating to irrigation and water use. This is being driven partly by legislation and restrictions on obtaining or extending abstraction licences in some areas, the increasing costs of mains water, and the need to demonstrate better water use efficiency as a requirement of quality assurance schemes demanded by customers. There is also an increasing realisation of the other advantages that better irrigation management can have economic benefits to businesses. While the level of water management varies greatly within the sector, most nurseries are open to improvements provided they can see the potential benefits to their business.

2. Hydrological pathways

Water use in HNS production is primarily for irrigation, with much smaller volumes used for 'other' uses including crop spraying, cleaning of protected cropping structures, containers, cropping beds and machinery (Figure 1). Water use for processing will be relatively small, but will include some washing of bare root stock for pre-pack marketing. Climate control also consumes little water with negligible frost protection use (unlike protection of top fruit crops during blossom). Removal of excessive atmospheric heat by misting is rarely used for protected cropping in UK climates, but control of propagation environments by mist or fog is important in this sector, albeit a minor consumption.

Figure 1 Possible water use pathways in hardy nursery stock production.



3. HNS – cropped areas, water sources and value

Defra no longer publish detailed statistics regarding HNS areas and crop value. However, the reported area of HNS in England and Wales from the most recent survey (2005) is 8850 ha (excludes cut flowers and bulbs, pot plant production and bedding) worth £452 million. Of this, the number of HNS containers produced was about 267 million worth about £281 million. In addition, the area for bulbs and flowers grown in the open was 4660 ha worth £27 million (BHS, 2005). The June 2007 census data for England reports an HNS area of 6170 ha comprising 2179 holdings (mean 2.83 ha).

From surveys by ADAS of 50 HNS and 25 ornamental nurseries (in 2000 and 2008) about 50% of holdings rely on mains water (Briercliffe *et al,* 2000; Brough and Drakes, 2008). Of the nurseries surveyed in 2000, 90% of smaller nurseries with <1 ha production used only mains water. However, larger nurseries will have a higher proportion of abstracted water from boreholes and rivers. An increasing proportion of nurseries are collecting roof water from glasshouses and tunnels, and also surface run-off water from cropping beds and hard standing areas. Rainwater (which is free of dissolved salts) is usually preferable to hard water supplies for HNS to avoid deposits on leaves.

Knox et al (2010) collated data on cropped and irrigated areas, and amounts of water applied across the seven Horticultural Development Company (HDC) crop sectors, drawing on information from King *et al* (2006), Weatherhead (2006), Defra censuses and other industry sources. Of the 6200 ha estimated for HNS in England and Wales in 2005, 5000 ha (81%) was reported to be irrigated (accounting for an abstraction volume of 25 million m^3).

The Environment Agency (EA) has records of licensed and abstracted water volumes used for horticulture and nursery irrigation, but this cannot be disaggregated into different types of nursery production so only totals for nursery stock, pot plants and bedding plants are available. In 2003 (a dry year), the total abstracted volume nationally was 1.555 million m^3 out of a total licensed volume of 4.197 million m^3, i.e. an abstraction of 37% of the licensed volume from a total of 336 licenses. However, there were large regional variations in the amounts and proportions abstracted; the South West had a lot of small volume licences with only 7% abstraction of that licensed that year, whereas the Southern region abstracted over 30 times the amount of water as the South West representing almost 50% of the licensed availability from about half the number of licence holders (Knox, Weatherhead and Rodriguez-Diaz, 2008).

Clearly there is a large discrepancy between the abstracted and irrigated volume estimates from the different data sources which cannot be fully explained. Even allowing for some rainwater harvesting, recirculation and storage contributing to the irrigated volume total, it doesn't explain the 15-fold difference between the 25 million m^3 estimate and the abstracted estimate of 1.6 million m^3. Although about 50% of nurseries are mainly reliant on mains water, these will include a large proportion of smaller size holdings. A significant proportion of the total HNS area will therefore be irrigated by abstracted water. Some of the discrepancy in the statistics will be because abstractions less than 20 m^3 per day do not require licensing and NALD also excludes small abstraction licences which will include a significant number of nurseries. Also, many multiple use extractions may not be reflected in the NALD database.

4. Irrigation

A wide range of application technologies are used in nursery stock, as in some other horticultural sectors, but there are no reliable statistical data available of the areas of production under different water application methods. Even in the relatively comprehensive 2005 survey of agricultural irrigation (Weatherhead, 2006) statistics from only about a quarter of the outdoor irrigated area could be collected, and within this, Nursery Stock irrigation was grouped along with other ornamentals, herbs and miscellaneous crops within ‘other’.

Overhead irrigation

Despite the lack of detailed statistics, it is clear that forms of overhead irrigation remain the most widely used method for both outdoor and protected, field and container grown nursery stock. Some agricultural hose-reel rainguns and booms will be used for some field grown shrubs and roses, but portable or solid-set impact or rotary sprinklers are also popular where field irrigation is required. Outdoor container grown stock is typically laid out on beds and irrigated by semi-solid set impact sprinklers (e.g. Naan, Rainbird, Pope Premier) or a wide range of rotary sprinkler heads (e.g. Pope Rotoframes, Naan-Dan and Eindor mini and micro sprinklers, Nelson MP Rotators).

Several of the mini and micro sprinklers and a few other rotary sprinkler heads such as MP Rotators and Pope Browning nozzles are also suitable for use under protection – single or multispan polythene tunnels, or glasshouses. These may be mounted on laterals and risers from ground level, but more normally overhead sprinkler or spraylines, supported by the tunnel or glass structure, are used. Micro sprinkler or heavy mist nozzles that would be unsuitable for outdoor use due to wind drift, are also used indoors, including the widely used ‘pinjet’ nozzles.

With many overhead sprinklers, a range of nozzle sizes (often colour coded) can be used, which will vary output and spread at a given pressure. It is imperative that, to achieve uniform irrigation deposition from overhead systems, the most suitable nozzle size and associated sprinkler spacing at the correct pressure and minimum height above the crop is used to match the particular bed, tunnel or glasshouse bay layout for the crop. Uniform water application to the crop is one of the most important factors to optimise first to improve water use efficiency. Sprinkler manufacturers and irrigation consultants use design software to ‘test’ layout options before installation, but this is no substitute for on-site uniformity and output measurements of systems to check performance and make adjustments if necessary (Burgess, 2005).

Mobile gantry irrigation designed to run over cropping beds offer many advantages over conventional overhead sprinkler systems. They are not yet widely used for HNS in the UK, but are more widespread on the Continent. Crop spraying and even crop handling can sometimes be integrated into gantry functions. Gantries are available for both outdoor and protected crops. In the UK, most uptake has been by vegetable transplant raisers and some pack bedding and pot plant producers, but interest by HNS growers is increasing, particularly following a recent HortLINK project where remote sensing of plant water need through infra-red sensing, and precision application with gantries was explored, along with other novel water saving technologies (Davies, 2010).

Drip and trickle irrigation

For container-grown nursery stock, drip irrigation is mainly used on larger pot sizes of 5 litres and above (especially trees and large specimen shrubs and stock plants), because crop handling becomes too difficult with higher labour and equipment costs for smaller pot sizes. However it is used more frequently in protected pot plant production on raised benches where crops are more standardised and pot handling is less of an issue. Trickle irrigation lines are not often used for soil grown nursery stock, except for some field tree production and stock beds for propagation. Trickle lines are often used in conjunction with capillary matting and some sand beds for container sub-irrigation systems.

Sub-irrigation

These systems are used for container crops only and deliver water by capillary action through the bottom of the pot (Hewson, *et al* 2006; Burgess, *et al* 2003). Systems fall into 3 groups:

1. *Sand beds*. The classic Efford Sand Bed is the most sophisticated requiring construction with a very level surface. A sand mix with a specified grade of particle sizes, to a depth of 75 mm or more is enclosed within a polythene liner with typically raised board edges. The base is sloped to the centre to accommodate a slotted central irrigation / drainage pipe connected to a sunken header tank with ball cock valve. A water table is maintained some 25 mm below the sand surface in summer, but in winter, or after high rainfall, the tank can be emptied and the water tension in the sand layer has the advantage of pulling surplus water out of the pots.

Less sophisticated versions of sand beds are also found that may not be perfectly level, and rely on periodic wetting up via trickle lines on the surface, rather than a sunken header tank.

2. *Capillary matting*. This is sometimes laid on the surface of container beds as a secondary system to improve redistribution and retention of water delivered by overhead systems. More rarely for nursery stock it is used as primary irrigation, using periodic pulses of water via trickle lines to maintain capillary contact with and a supply of water to the growing medium through the pot base. This system is more frequently used for pot plant crops on bench systems under protection. It doesn't have the advantage of a deep sand layer to provide 'positive drainage' in winter unless overhanging 'tails' of matting on benches are used, and so is also less suitable for outdoor beds.

3. *Flood and drain or Ebb and flow*. Again, this is more commonly used for pot and bedding crops under glass, with either specially constructed concrete floors or benches. Pots are enclosed in large shallow troughs and water is flooded in to a depth of 20 – 30 mm, held for several minutes and rapidly drained out again to be cleaned, nutrient levels adjusted, and held in tanks for re-use. There is some interest in this technique for nursery stock, notably a nursery near Spalding produces over 2 million hardy perennial containers a year on a 7 ha site all down to flood and drain capillary irrigation. Most is outdoors but 0.5 ha under protection. This sort of irrigation is also particularly appropriate for module raised tree production in deep cells, where it is difficult to achieve uniform wetting from overhead sprinklers.

4.1 Drainage and runoff

For irrigation of field-grown crops of nursery stock, whether by sprinklers or drip irrigation, many of the same considerations relevant to field vegetable production for example apply here and need not be discussed again in detail. These include choosing appropriate application rates to match soil infiltration and avoid runoff, scheduling irrigation doses to match rooting depth and soil moisture deficits to minimise drainage losses and understanding crop physiological responses so that for example water is not wasted encouraging late season soft growth before plant harden up in the autumn or before lifting.

Overhead sprinkler layouts and design

As overhead irrigation remains the most widespread method of watering container crops, the potential for greatest water savings in the HNS sector can be made by the way overhead systems are designed and managed. Most of the technology is already well established, so while recent innovations in scheduling technology discussed later are very valuable, the biggest gains in water savings can be made from more nurseries understanding and adopting current best practice.

Achieving uniformity of application through correct system design (as described previously) is necessary before trying to implement more effective scheduling and growers should avail themselves of the training courses, workshops and factsheets are which are available (Burgess, 2005). Of the many different types of sprinklers available, most are capable of giving good results if they are installed and used appropriately. A frequent mistake is that bed edges and corners are not sufficiently covered with full overlap of sprinkler patterns because lines of sprinklers are set in from the edges of the cropped area. While all parts of the crop may still be wetted, bed edges receive much lower doses. Irrigators then tend to apply up to 2 or 3 times the amount of water necessary for the majority of the crop to wet up the driest zones. Although counter-intuitive to many growers, because edge sprinklers are apparently wasting water on to non-cropped areas, the better uniformity results in much reduced irrigation times, an overall saving in water, and some buffer from the effects of wind on coverage.

Excessive application rates also encourage water losses from drainage and runoff because water is applied faster than the absorption rate of the growing media. This applies particularly to peat based media that have dried too much and become hydrophobic. Choice of appropriate nozzles and sprinkler design so that application rates do not exceed 15 – 25 mm/hour can help – some pin jet nozzles systems tested have exceeded 75 mm/hour application rates. Most modern irrigation timer controllers can also be set up to apply water cyclically around irrigation zones as a series of smaller split or pulsed doses allowing soak-in time in-between. This can significantly improve water use efficiency and should be utilised more.

The multiplicity of crop types and container sizes in nursery stock production often means it is difficult to group crops for similar irrigation requirements within an irrigation zone. Even different cultivars of a subject in the same pot size may vary in water need, so irrigation scheduling is inevitably compromised. Having smaller irrigated zones or stations, using sprinklers with a smaller throw, allows for greater flexibility, but usually bed sizes and layout are designed more for ease of plant handling, layout and economy of scale as an overriding priority. Increasing irrigation zone subdivisions also increases the size controllers and plumbing costs required, and the complexity of irrigation management. The need for sprinkler overlap also means that irrigation of zone edges can be compromised by an adjacent zone running a very different schedule, as it is usually uneconomic to have large uncropped buffer zones or pathways in between. This is often clearly seen in glasshouse bays where sprinkler lines have been installed to give overall uniformity across the width of the house. To achieve uniformity in the central bay, adjacent bays need to be irrigated for the same time. Designs are possible using sprinklers such as some Dan types, incorporating an 'anti mist' device, which throw more heavy droplets to the edge of the output pattern. This means that 80 - 90% of the output from that bay's sprinklers remains uniformly distributed over the bay with little overspill, and that bays can be irrigated more efficiently with independent scheduling. It is important that growers are aware of these considerations when planning new or upgrading installations. Altering existing layouts typically involves changing sprayline and nozzle spacings which can be costly.

In addition to direct water savings from improving sprinkler layouts, considerable labour savings can be expected from easier irrigation management of irrigation schedules, and less time spend spot watering dry areas by hand.

Gantry irrigation

Gantry irrigation can apply water very uniformly to an area provided its fan nozzles are working correctly and above a minimum height, much as a crop spray boom would be. It has the advantage that irrigation is restricted to the strip (e.g. glasshouse bay or outdoor bed) along which it is travelling. Irrigation doses can be varied by a combination of travel speed, choice of nozzle, and number of passes over the crop, and for nursery stock it has the significant benefit that different irrigation rates can be applied to blocks of different subjects laid out down a run. Various methods of automating and programming different irrigation schedules can be achieved. This type of irrigation clearly requires a substantial capital investment, but a cost-benefit of a gantry installation in a glasshouse bay at Hillier Nurseries as part of the recent 'Water LINK 2' project gave a positive 24% IRR benefit over a 10 year planning horizon using a generous 15% discount rate to allow for any over optimism with predicted benefits, when compared to an already uniform overhead pinjet irrigation system. This sort of investment is quite sensitive to the area over which the gantry is being used – in this case a bay of 1550 m^2 gave a payback period of 6 years. Benefits were mainly reduced labour for maintenance of overhead nozzles, less need for hand watering and improved crop quality (Davies, 2010).

Drip and trickle irrigation

Pot drippers and trickle irrigation can avoid runoff wastage by placing water directly into containers. However it is essential that low application rates or pulse irrigation is used to avoid significant drainage losses from run-through. Growing media designed for good water retention and lateral distribution of water should be chosen over very open structures, and multiple drippers used in large containers. Wetting agents or the addition of small proportions of e.g. coir, loam or composted green waste to media can also help.

Sand and capillary matting beds

Sand beds have been in use in the horticulture industry for about 30 years and are suitable for irrigating a wide range of container sizes up to about 250 mm in height. The classic Efford sand bed is inherently extremely efficient using only 25 – 30% of the water of even a well managed overhead system, and requires less attention during busy summer months because the header tank automatically controls supply. Although suitable for most species, sand beds are particularly useful for subjects susceptible to diseases and other disorders encouraged by overhead watering. An important reason why sand beds have not been adopted much more widely by the industry, is the relatively high capital cost of installation at some £10 – 12 / m^2 compared to about £2 – 3 / m^2 for a simple overhead system on a free draining gravel or permeable groundcover base. Capillary matting systems can also give similar water savings to sand beds at lower cost, but are not as popular for HNS for the reasons above.

Financial incentive for water efficient investment

The Enhanced Capital Allowances (ECA) scheme makes provision for items in its water technology list such as efficient boom irrigation, drip systems and control equipment. For approved items, nurseries can claim 100% of the capital invested against tax in the first year (instead of 25%p.a write down) thus making the investment a more attractive proposition. Unfortunately, some relatively simple but high capital cost technologies that can be implemented, that would have the biggest impact on water savings, such as capillary sand beds and impermeable bed lining and drainage collection infrastructure, are not currently permissible under this scheme. This may be because they are not items that can be 'bought off the shelf' from a particular manufacturer, or connected with the definition of what constitutes 'plant and machinery'. However, some mechanism for enabling these to qualify for ECA should be sought if wider uptake of such water efficient technologies is to be encouraged.

Recapture and re-use of drainage and runoff

Increasingly, nurseries are incorporating water recapture onto new container bed constructions or upgrading of existing ones. In addition to recapturing a large proportion of the irrigation which misses the pot or drains from it, a significant amount of surplus rainwater can also be harvested on outdoor bed. Combined with rainwater harvesting from glasshouse, tunnel and other roof structures, very significant savings in overall water consumption can be made. Some nurseries, particularly with a large area of glass, and a sufficient size reservoir for water storage, can become almost self-sufficient. Often runoff water is collected in a lake or reservoir constructed for the purpose at a low point on the nursery. Provided the water is collected via impermeable (e.g. concrete) channels, and does not pass through the soil, it remains the property of the nursery and can be reused without classification as an abstracted source. The recaptured water is filtered and typically cleaned of potential plant pathogens by e.g. chlorination, slow-sand filtration or UV treatment, before being pumped into clean water holding tanks at a higher level on the nursery.

There can be water quality advantages too from using a high proportion of soft rainwater for irrigation in hard water areas.

Significant recapture systems need space on nurseries for a 'dirty water reservoir' or alternatively a large drainage channel in which bed drainage can be collected before being cleaned and stored in tanks for re-use. On sloping sites, terracing can be used to create level areas for cropping beds.

Overhead irrigated containers were often stood on gravel beds with a layer of permeable woven ground-cover underneath to keep them free from the soil. While they had the advantage of helping to prevent 'puddling' and waterlogged containers in low areas, any water which misses the pot, or surplus run through, is lost. Beds constructed for water recapture require a carefully graded and firm base, often with a layer of firmed scalpings or gravel over which is laid an impermeable layer such as thick polythene. A woven ground cover geotextile is then often used on top to provide a hard wearing and easily cleaned surface for the containers. Beds must be free of bumps and hollows and are sloped at about 1 – 2% to one side or to the middle to a drainage pipe backfilled with gravel or an open lined channel. Full circle or part-circle overhead sprinklers are often run along bed edges to overlap from both sides.

Work in recent HDC and Water LINK projects has demonstrated that between 10 to 50% of water getting into a container is taken up through the pot base on this type of bed, depending on the stage of the crop, foliage interference and pot spacing (Grant et al., 2010). This is because quite a lot of water falling onto the standing base during and shortly after irrigation can be intercepted and absorbed by the pot before running off the bed. Even where recapture systems are used, excessive irrigation is undesirable. Growers can determine appropriate irrigation doses and improve their scheduling by weighing samples of pots before and after irrigation. Also they can test if doses are excessive by placing a sample of pots in a slightly smaller pot lined with polythene to catch drainage water. Measurements of weight gain from these pots compared with those stood directly on the bed, with leachate volumes, can be used to determine what proportion of overhead irrigation is being lost as by drainage or run-through from the container (Burgess, 2006).

Recent advances in irrigation scheduling technology

Through recent Horticulture LINK and HDC projects (Harrison-Murray, 2003; Grant and Burgess, 2007, Davies, 2010), two important pieces of technology have been developed that are now available for commercial uptake by the HNS industry.

Soil moisture based scheduling. The first uses a soil moisture probe and controller to enable in-pot moisture content to be measured, and a standard irrigation valve opened and closed according to user adjustable set points to automatically schedule irrigation. This 'closed-loop' feedback approach takes account of all the complex of factors affecting water uptake into the pot, including rainfall, and varying water use by the plant as it grows. The SM200 moisture probe developed by Delta-T Devices from the project, is a smaller and less costly version of their theta probe. The GP1 logger and controller makes use of software that can control irrigation from one or more moisture probes and other inputs such as temperature or a rain gauge if required. Irrigation can also be pulsed from within the software. The logged data provides useful information for the grower to observe the effect of irrigation settings on moisture status and helps inform fine adjustments to settings. It was found that provided irrigation uniformity is reasonable, only a single pot in a large cropping bed requires monitoring because wet / dry cycles of the control pot remain in proportion to the rest of the bed. Extensive trials on commercial beds of over 500 m^2 have shown that GP1 scheduling can use less than 50% of water than on comparably cropped beds that are manually scheduled. Currently multiple controllers and probes would be needed to achieve closed loop feedback control on each cropping bed or irrigated zone, but controllers with several relay outputs are being developed. Another useful development would be wireless linkage of a network of probes around a nursery to centralised irrigation controllers. Such technology exists, but has yet to be tested or developed further in the UK. This may be examined in a Horticulture LINK project on vegetable crop irrigation due to commence shortly, and may have application to other sectors.

Evaporative demand based scheduling. The other important innovation has been the development of the Evaposensor for use in irrigation scheduling. The Evaposensor was invented at East Malling Research, originally as a research tool for controlling mist propagation environments (Harrison-Murray, 1991a and 1991b). A wet and dry 'leaf' each contain a temperature sensor. The temperature difference between the two 'leaves' is directly proportional to evapotranspiration (ET) losses by cuttings or crops. The sensor is sensitive to the key drivers affecting evapotranspiration: solar radiation, temperature, humidity and wind. Its integrated output (°C h) was shown to have a very high correlation with conventional calculations of ET using the Penman-Monteith equation from meteorological station data. In the HNS 'Water LINK' projects, Skye Instruments made the Evaposensor available commercially and also developed a meter capable of integrating and logging the data so that daily degree-hour totals could be easily read and then used for irrigation scheduling with an appropriate crop calibration factor. The Evaposensor and Evapometer is a relatively inexpensive method of collecting ET data on farms and nurseries compared to the use of an automatic weather station. A major advantage is that a suitably sited Evaposensor will monitor ET for all outdoor crops, and another can be used for all crops under similar protected environments.

A recent breakthrough in the use of the Evaposensor was being able to link it, via another interface developed by Electronic and Technical Services (ETS), to a range of irrigation control panels (e.g. those by Heron Electrical). This partly automated the scheduling process, making it much easier for nurseries to adopt. Many irrigation controllers can contain interfaces that integrate solar radiation levels for adjusting e.g. mist bursts for propagation. The Evaposensor / ETS output has been integrated in a similar way by the controller and used to adjust irrigation programs. Normally, irrigation programs consist of timed irrigation doses to a series of valves or stations around the nursery. Times for each station can be varied according to crop type and need, but day to day variations in the weather which affect ET and thus scheduling, require the operator to make manual adjustments to times. In practice, this is never achieved adequately by growers. The integrated ET values are either used to increase or decrease the number of short irrigation cycles the controller applies, or adjusts base times in a program by a given percentage. Because there is no closed-loop feedback from the actual moisture status of the crop, the base times for irrigation need to be established either by a formal calibration or trial and error. Adjustments will also be needed to allow for changes in ET with crop growth and stage of development. However, the Evaposensor greatly eases the irrigation manager's task because day to day variations in irrigation requirement caused by the weather are taken care of automatically, and adjustments made following crop inspections are a slower and much more manageable process.

Scheduling based on remote measurement of plant stress. In the recently completed HNS 'Water LINK 2' project, the use of infra-red sensing of foliage canopy temperatures as a means of identifying either individual water-stressed plants, or areas of a bed, was developed (Davies, 2010). This is based on the principle that most plants close down their stomata when soil water is limiting, as a way of minimising further water loss which would lead to wilting and tissue damage. Foliage then becomes warmer relative to a well watered plant, because it no longer loses as much heat through evaporative cooling. Temperature differences vary with species and degree of stress, but can be as much as 4 °C. An array of inexpensive thermopiles mounted along an irrigation gantry boom were used to scan a bed of plants. Individually controlled nozzles (or groups of nozzles) on a second boom behind the sensors could then apply differential quantities of irrigation to drier areas of the bed as required. Potential difficulties, such as differentiating between foliage and background growing media in pots/bed surface and empty bed areas, were overcome. A three-sensor system to measure the red and near-infrared incident and reflected light, so the proportions of plant and background in the viewed area could be measured and thus plant temperature estimated. The gantry system combining scanning and water delivery is ideal for this approach, and would enable a high degree of automation and control. Delivery of water to individual containers would be desirable, but fraught with practical difficulties from an overhead system, particularly with smaller containers typical in much HNS production. Nevertheless, the ability to partition an irrigation boom into sections, and apply differential irrigation along and across a bed has the potential for significant water and labour savings in an automated system. Further development is required before this method of infrared irrigation scheduling can be adopted by the industry. The scope for uptake will be linked to the willingness of nurseries to also adopt gantry irrigation. Initially, it will be of interest to larger nurseries with a significant area of suitable glasshouse production, but could be adapted for outdoor gantry systems. It is also likely to be of interest to pot and bedding producers.

Weather forecasting and scheduling

Using accurate weather forecasting to avoid wasting irrigation on outdoor crops shortly before heavy rainfall, could save significant volumes of water, because of the large areas involved, and that often heavy irrigation doses are used to restore soil water reserves, and there is less opportunity to recapture drainage water. Forecasting is less relevant for container crops because lighter and more frequent scheduling patterns are typical. However, rain gauges linked to irrigation controllers can automatically reduce or avoid applying irrigation to pots shortly after or during rain. Although this has been available for some years, there is scope for more widespread adoption by nurseries.

4.2 Transpiration

Regulated deficit irrigation (RDI)

This is a technique that exploits the plant's stomatal response to water stress, which slows down transpiration, and hence photosynthesis and growth. Often in HNS production, encouraging maximum growth rate is not desirable, and slowing growth to produce 'bushier' looking plants with more compact internodes gives a better quality product. Reducing surplus growth, without the use of chemical growth regulators, is possible through applying a controlled stress irrigation regime (RDI). Other advantages include reduced pruning requirements, thus saving labour, and flower bud development may also be enhanced in some species. Although RDI regimes can save up to 50% water, the motivation for using RDI, is usually less about water economy and more about improving plant quality and reducing labour cost. The irrigation infrastructure needs to be able to apply irrigation uniformly, and a precise scheduling strategy is needed to avoid overstressing plants and causing plant damage, or conversely over-watering and reducing the growth control effect. Trials have given promising results for a range of crops (Harrison-Murray, 2003). In future, this approach had potential for crops under protection, but will only be suitable for a proportion of HNS crops. It is also being trialled with pot plant crops (e.g. Poinsettia) that normally require growth regulator sprays.

Buffer sprays and bacteria

These are two other novel techniques with water saving potential that were investigated in the HNS 'Water LINK 2' project (Davies, 2010).

Applying growth control through RDI can be risky, as leaf damage can occur if plants are dried down to the extent that severe wilting occurs. The LINK project identified that alkalisation of xylem sap can occur after plants are exposed to drought, and this increases the concentration of the stress hormone ABA transported in plants, and which is associated with stomatal closure. Sap pH can be manipulated in HNS species by the application of alkaline potassium phosphate buffer sprays. This can then cause increased ABA delivery and induce responses that mimic those found in water deficit plants. It was found that the potential for restricting excessive growth could be demonstrated through using buffer sprays, but without the need to dry down the growing medium, and thus risk wilting or scorch damage to plants.

Inoculation of growing medium with bacteria (*Variavorax paradoxus*) has been shown to have a number of potential benefits for the production of HNS plants. Plants that are stressed (e.g. due to drought or wounding) can generate ethylene to excessive levels, leading to leaf drop and other senescence symptoms. Certain bacteria, including *V. paradoxus*, synthesise the enzyme ACC deaminase, which cleaves ACC, the precursor of the plant hormone ethylene. This reduces the ethylene generated in plants inoculated with these bacteria. In that project, inoculation of plants lowered ethylene emission from leaves, reduced leaf drop, and promoted flowering in *Cytisus* plants experiencing drought. Late season senescence in *Aquilegia* was also reduced. These results showed that ACC deaminase containing bacteria have real potential for use on nurseries where production stresses (e.g. caused by drought) are unavoidable.

Currently both buffer spray and bacteria technologies have further need for development, practical evaluation and possible licensing / regulatory hurdles to overcome before they can be commercially adopted.

4.3 Evaporation

Many of the ways of reducing evaporation losses considered for other crop sectors will be applicable here. For example, coverage of storage reservoirs and tanks, use of wind breaks, and use of low level irrigation such as drip instead of spray, where applicable.

For container grown crops, a 1.5 – 2.0 cm depth of a coarse mulch (such as cocoshell and bark) resulted in only 60% of the water loss from peat media filled containers in controlled tests (without plants) over a month drying down from well-wetted, compared to non-mulched pots (Burgess *et al.*, 2004). Mulches rely on a trapped air layer to break the capillary link with the medium underneath, so finer materials that still allow ‘wicking’ of water to the surface are much less effective. The water conservation benefits from mulching pots, however, declines as plants grow, and transpiration accounts for nearly all water loss from containers at 100% leaf cover. Mulching containers is also an extra production operation and expense that has had limited widespread uptake, but with continued restrictions on herbicides, growers are increasingly turning to pot mulching or ‘pot toppers’ with weed control as their main objective. Capillary irrigation systems such as sand beds do have the advantage of maintaining a drier surface to the pot, which, for coarser substrates, does conserve some moisture as well as inhibiting weeds.

4.4 Soil water storage

The application of drier (deficit irrigation) regimes has been discussed above. Although the use of strict RDI may be limited to certain HNS subjects, better control of crop water status through more precise scheduling is generally desirable, and has potential for significant water savings and improved crop quality. Achieving more uniform and controlled water status through improvements in the delivery systems is essential first; only then is it possible to improving scheduling and apply drier regimes.

5. Processing

5.1 Washing

Crop washing does not apply to the HNS sector.

5.2 Cooling

A very small amount of water is used in damping down and cold storing bare-root nursery stock held after field lifting, before either transplanting or containerisation.

6. Other

Water use for crop spraying is estimated at a tiny proportion of that used for irrigation. Likewise other nursery uses include some washing of containers for re-use, cleaning / sterilising protected cropping structures, pack houses and machinery.

7. Climate control

7.1 Frost protection

Unlike frost protection irrigation in top fruit orchards, this is rarely used for HNS cropping. Frost sensitive subjects are typically grown in containers under protection, or temporary crop covers used to protect stock in freezing weather.

7.2 Misting

Misting and fog is widely used for the propagation of HNS crops, but the areas involved and volumes of water used are insignificant. There is little scope or need for water savings in this area.

8. References

Briercliffe, T., Hewson, A., and Brough, W. (2000). Independent water audits for container grown nursery stock producers. ADAS Horticulture. Summary report for MAFF Water audits.

Brough, W. and Drakes, D. (2008). Independent Water Audits for Growers of Ornamentals in South East England. ADAS UK Ltd, Boxworth, Cambridge. Summary report for South East England Development Agency.

Burgess, C.M., and Long, B.J. (2003). Container HNS Irrigation: Use of capillary matting under protection. *Final report on HDC Project HNS 107.* Horticultural Development Company, AHDB, Stoneleigh, Warwickshire

Burgess, C.M., Foster, S.A. and Long, B.J. (2004). Container HNS: Improving water management within growing media. *Final report on HDC Project HNS 107a*. Horticultural Development Company, AHDB, Stoneleigh, Warwickshire

Burgess, C.M. (2005). Measuring and improving performance of overhead irrigation for container-grown crops. *HDC Factsheet* 16/05. Horticultural Development Company, AHDB, Stoneleigh, Warwickshire

Burgess, C.M. (2006). Methods and equipment for matching irrigation supply to demand in container grown crops. HDC Factsheet 19/05. Horticultural Development Company, AHDB, Stoneleigh, Warwickshire

Davies, W.J. (2010). Enhancing the quality of hardy nursery stock and sustainability of the industry through novel water-saving techniques. *Final report of HDC / Defra LINK project HNS 97b* . Horticultural Development Company, AHDB, Stoneleigh, Warwickshire

Defra (2006). Basic Horticultural Statistics 2005 (calendar years 1994-2005). Publ. Defra Farming Statistics, York.

Grant, O. M., and Burgess, C. M. (2007). Container Nursery Stock Irrigation: Demonstration and promotion of best practice. *Final report on HDC Project HNS 122 2004-7.* Horticultural Development Company, AHDB, Stoneleigh, Warwickshire

Harrison-Murray, R.S. (1991a). A leaf-model evaporimeter for estimating potential transpiration in propagation environments. *Journal of Horticultural Science* **66**, 131-139

Harrison-Murray R.S. (1991b). An electrical sensor for potential transpiration: principle and prototype. *Journal of Horticultural Science* **66**,141-149

Harrison-Murray, R.S. (2003). Improving the control and efficiency of water use in container-grown hardy ornamental nursery stock. *Final report of HDC / Defra LINK project HNS 97.* Horticultural Development Company, AHDB, Stoneleigh, Warwickshire

Hewson, A, Hutchinson, D and Burgess, C (2006). Capillary irrigation of container grown nursery stock. *HDC Factsheet 01/06*. Horticultural Development Company, AHDB, Stoneleigh, Warwickshire

King, J., Tiffin, D., Drakes, D. and Smith, K. (2006). Water use in agriculture: establishing a baseline. Report for Defra Project WU0102. (http://randd.defra.gov.uk/Document.aspx?Document=WU0102_4274_FRP.doc)

Knox, J. W., Kay, M. G., Weatherhead, E. K., Burgess, C. M., Rodriguez-Diaz, J. A., (2009). Development of a water strategy for horticulture. *Final report HDC Project CP64*. Horticultural Development Company, AHDB, Stoneleigh, Warwickshire

Knox, J. W., Weatherhead, E. W., and Rodriguez-Diaz, J. A. (2007). Assessing optimum irrigation water use: additional agricultural and non-agricultural sectors. Technical Report SC040008 / SR Part 1. Cranfield University, Cranfield, Bedfordshire.

Weatherhead, E. K. (2006). Survey of irrigation of outdoor crops in 2005: England and Wales. Cranfield University, Cranfield, Bedfordshire.