Sector: Protected Edibles

1. Introduction

This sector covers protected vegetables (e.g. lettuces, tomatoes, cucumbers, herbs, peppers) and protected fruit (mainly soft fruit under glass). Field grown soft fruit (e.g. strawberries) covered by temporary Spanish or French polythene tunnels is excluded. All protected crops are dependent on irrigation to meet crop water requirements for growth, yield and quality, with a high proportion of the marketable edible product composed of water. Any restriction in water supply, even for very short periods, can have catastrophic consequences for the crop and business sustainability.

Given the high crop value and levels of technology employed, for a significant majority of protected edible cropping businesses, water is already used very economically. There is thus little incentive for further reducing water consumption *per se* within the sector provided a reliable water supply is available. However, there is always potential for improving irrigation management (scheduling) driven by the financial benefits associated with improvements in crop quality combined with legislative demands for greater environmental protection. This section reviews water use in the protected edibles sector and the opportunities for water saving attainable within specific areas (hydrological pathways) of water use. However, many of the water management issues highlighted for the hardy nursery stock (HNS) sector are equally applicable to protected edible cropping –the potential options for water saving are thus similar to those in the HNS sector.

2. Hydrological pathways

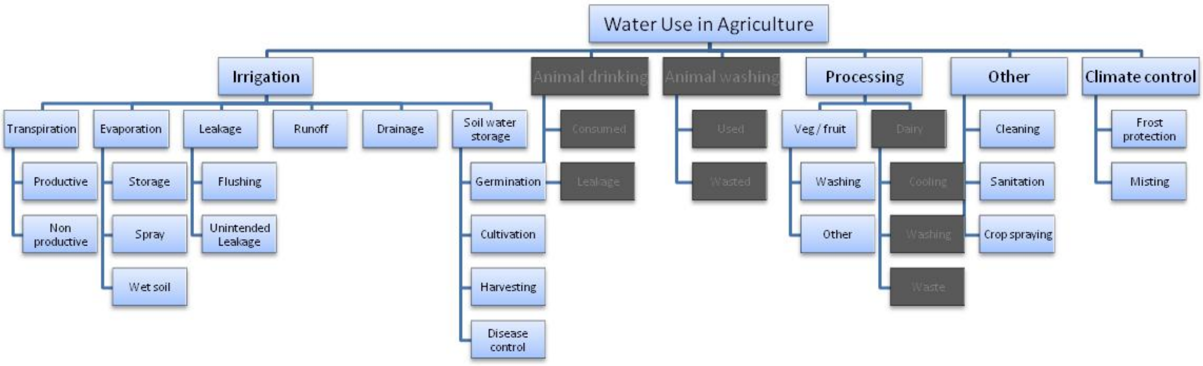
Water use in protected edibles (PE) is mainly required to meet crop demand (irrigation) with relatively small amounts used for crop spraying, cleaning of cropping structures (glass, floors and equipment), and crop washing. For example, field data collected from a series of on-farm water audits on selected nurseries confirms that crop water demand generally accounts for around 80-90% of total water use in the business (Table 1). Other areas including spraying, equipment washing and drainage collectively account for a small proportion (<10%). The logical area for identifying opportunities for water saving should thus focus on crop water demand.

Table 1 Measured water consumption on two lettuce nurseries (Source: EA, 2003).

Water use	Lettuce nursery		Lettuce nursery (NFT production)	
	Average water use) m^3/ha/annum	%	Average water use (m^3/ha/annum)	%
Crop demand	4176	92.2	6317	91.6
Drainage	222	4.9	0	0.0
Crop spraying	30	0.7	25	0.4
Glass washing	6	0.1	10	0.1
Equipment washing	6	0.1	5	0.1
Crop washing	0	0.0	0	0.0
Staff facilities	90	2.0	60	0.9
Other	0	0.0	483	7.0
Total	**4530**	**100.0**	**6900**	**100.0**

The main hydrological pathways for water use in PE cropping are summarised in Figure 1. A small amount of water is used for misting in propagation environments and sometimes to humidify specialist crop areas, but air cooling (by misting or aspirated wet pads) is not used in the UK as simple ventilation is usually adequate. A brief overview of water use in the PE sector generally and then within each specific area is given below.

Figure 1 Water use in protected edible production.



3. Protected edibles – cropped areas, water use

The estimated area and value of UK protected edible crop production is summarised in Table 2. The total cropped area (680 ha) of protected vegetables is very small compared to the reported area for field vegetables (116315 ha). However, its value (output per unit cropped area) far exceeds field vegetable production by a factor of 37. Similarly, the cropped area of protected fruit has an average output factor about 6.5 times greater than field-scale (outdoor) soft fruit production.

Table 2 Estimated cropped areas and farm gate values for UK protected edible production (excluding mushrooms) based on data from 2008 (Source: Defra, 2009).

Crop	**Area (ha)**	**Value (£ million)**
Protected vegetables:		
Lettuce	226*	13.6
Tomatoes (heated)	212	95.0
Cucumbers	103	38.1
Sweet peppers	65	14.0
Self-blanching celery	26*	2.3
Others***	48*	12.6
Total protected vegetables	680	175.6
Protected fruit**	180	39.5
Total protected edibles	**860**	**215.1**
Field vegetable production (outdoor)	116315	814.4
Soft fruit production (outdoor)	9280	331.2

* Where more than one crop grown per year = area x no. crops grown/year.
** Protected fruit grown under permanent glass or plastic and excludes temporary Spanish or French polythene tunnels used in much field production. Over three quarters of the protected fruit area is strawberries, with the remainder raspberries and other mainly soft fruit.
*** Other crops include herbs, aubergines, unheated tomatoes, courgettes, and chilli peppers.

Based on an estimated water use for protected edibles of 9600 m^3 ha^{-1} yr^{-1} (960 mm yr^{-1}) (King *et al.*, 2006), the overall water use for this sector in the UK is about 8.3 Mm^3 yr^{-1}. The greatest consumption is in South East England, where 25% of the total production area is concentrated, where solar radiation levels are greatest but where summer droughts are most likely to affect water resource availability (Thompson *et al.*, 2007).

Water use varies with crop type and cropping system. Tomatoes are a large consumer of water as they produce a very high yield over the longest cropping season. They consume between 750 mm yr^{-1} in closed or re-circulating systems such as nutrient film technique (NFT) and 1200 mm yr^{-1} in open irrigation systems where waste flows to run-off (King *et al.*, 2006; Hayman, 2010). Cucumbers and sweet peppers consume about 60 – 70% as much water as tomatoes under comparable conditions (Hayman, 2010), whereas lettuce averages about 550 mm yr^{-1} for the AYR crop (Knox *et al.*, 2007).

Protected edible crops have high water use efficiency (WUE) due to the intensive nature of production. In a protected environment with less air movement and higher relative humidity, evapotranspiration (ET) rates will be slightly lower than outside. For example, in field potato cropping, the WUE expressed as yield per 10 mm of irrigation is about 2.4 tonnes fresh weight ha^{-1} cm^{-1}. In contrast, a tomato crop under glass with a yield of 60 kg m^{-2} yr^{-1} and water requirement of 750 mm yr^{-1} has a WUE of 8.0 tonnes fresh weight ha^{-1} cm^{-1}. Coupled with the much higher output per unit area of protected edibles compared to field vegetables, the return per volume of water consumed is considerably greater (Thompson *et al.*, 2007).

Although approximately 50% of nurseries rely on public mains water as their primary water source, many larger nurseries use direct abstraction and/or harvest roof water. These make up a high proportion of total water used for irrigation in this sector (ADAS, 2004). There is an increasing trend towards nurseries collecting their own rainwater from glasshouse roofs, and planning regulations for new construction now insist on storm water collection to minimise flood risks, so it makes sense for nurseries to build irrigation storage reservoirs where space permits (Hayman, 2010). If sufficient storage capacity exists, rainwater harvesting from glasshouse roofs could potentially supply much of the irrigation needs for protected crops, and a few nurseries are moving towards self-sufficiency in water. Space for water storage and capital investment for the necessary infrastructure is currently limiting more widespread uptake by nurseries.

4. Irrigation

The vast majority of protected edibles are grown hydroponically in artificial substrates, using rockwool or the nutrient film technique (NFT). Exceptions are lettuce, self-blanching celery and small areas of tomatoes and some other vegetables which are mainly grown in soil. Most protected soft fruit is grown in peat-based or coir bags or modules, with raspberries often grown in large containers.

For soil grown edibles, permanent overhead sprinkler irrigation is widely used. Similar considerations to those discussed for nursery stock under protection, concerning optimum design of sprinkler layouts to achieve good uniformity and appropriate application rates also apply to PE cropping. However, the need to vary irrigation schedules for different crops in adjacent bays is likely to be less relevant to edible crops, where monocropping in glasshouses is more typical. In these cases, irrigation layouts which rely on overlapped sprinkler patterns from adjacent bays will not be a problem in contrast to HNS production.

A significant area of soil grown lettuce and some other salad crops, however, are irrigated using low-level trickle lines along the crop rows. As with all trickle irrigation, slow application rates and frequent, smaller quantities (or pulsed irrigation) are usually more efficient than large doses applied too quickly, which can lead to a high proportion of drainage loss. The correct spacing and location of trickle irrigation laterals relative to crop rows and the lateral spread of water from emitter points is also important to ensure that applied irrigation reaches and remains within the active root zone.

Crops grown hydroponically in rockwool slabs, or in peat, coir or other media in bags and pots, rely on micro-irrigation using individual drippers. Pressure compensated drippers are capable of providing very high levels of irrigation uniformity when correctly designed and installed. Rockwool grown crops will typically receive 10 or more small applications per day during summer to match crop demand. Economy of water use in these systems can be very high in relation to crop yield (see below). Maximum water economy will be achieved in closed systems. These include the nutrient film technique (NFT) but also where run-off from rockwool slabs or modules can be harvested and re-circulated.

4.1 Transpiration and evaporation

The management of nutrition and irrigation for a significant area of hydroponic or non-soil grown edibles is largely undertaken using computer controlled systems, often linked to a glasshouse environmental control computer. These monitor electrical conductivity levels of applied and run-off solution levels, and control the injection of stock feed solutions (often from two or more stock feed tanks) as well as acid injection to control solution pH. Typically, evapotranspiration (ET) from the crop is estimated by the sum of solar radiation as measured by a solarimeter on the glasshouse roof. This is then used in the calculation of the amount and frequency of feed solution needed to be applied to the crop. The overall level of feed measured as electrical conductivity in the growing medium (e.g. rockwool slab) and/or the run-off solution will also influence how much feed is applied. This makes the irrigation scheduling more complicated than simply trying to match irrigation applications to crop demand. In very hot weather, for example, water loss through transpiration may exceed the rate at which nutrients are taken up and used by the crop. Feed builds up in the substrate and needs to be ‘flushed’ or leached out by the application of extra solution. Conversely, during periods of rapid growth, nutrient use may exceed the rate at which it is being applied, resulting in lower conductivities and the need to change the strength or balance of feed solution applied.

With hydroponic edibles, there is a strong link between irrigation regimes and product quality. Excessive water, and/or too low a concentration of salts or fertiliser in solution during fruit formation (e.g. tomato and strawberry) will result in poor flavour (Hobson, 1995). Conversely, excessive solution conductivity or over-restricted water supply will reduce yield. Optimum irrigation scheduling is therefore a balance between achieving good yield consistent with high quality. The main scheduling techniques are summarised below.

Evaposensor for ET based scheduling. The Evaposensor (Harrison-Murray, 1991a & 1991b; Davies, 2010), takes into account all the main drivers influencing evapotranspiration, not just solar radiation, and is thus a better basis for controlling irrigation scheduling than using the radiation sum alone. The Evaposensor is placed within the glasshouse, and thus reflects more closely the actual crop environment than a light sensor placed externally on a glasshouse roof. There should be potential, therefore, for techniques such as the Evaposensor to be investigated and adopted in this sector for irrigation scheduling in preference to existing radiation based scheduling. Further details on this are provided in the HNS section.

Soil moisture based scheduling. Recent developments using soil moisture probes (Delta-T Devices SM200) and logger/irrigation controllers (GP1) in container HNS crops have previously been described for HNS. Where crops are grown in the soil, in bags or in containers (e.g. lettuce or soft fruit), soil moisture probes potentially offer an accurate method of managing irrigation, although there will still be a need to monitor and control conductivity (nutrient levels) in the growing medium and in applied and drainage solution where fertigation is used. Delta-T’s W.E.T. sensor (Delta-T Devices Ltd, 2005) directly monitors the conductivity of pore water within the growing medium as well as moisture and temperature, and calibrations for using this device with rockwool slabs and other media have been developed in association with research centres in Holland. Careful monitoring of conductivity is critical for the successful cultivation of hydroponically grown crops and where fertigation is used in soilless media. Water is used more effectively with less wastage for flushing out excessive salt accumulation, and reduced environment pollution from run-off.

Scheduling based on sensing leaf or stem thickness. Sensors which can measure changes in stem or leaf thickness – i.e. the turgor pressure of cells, have been used to schedule irrigation in research projects in recent years. For example, an Israeli company (LeafSen, 2006) claims improved water use efficiency and as good or better yields for citrus, avocado, corn, cotton, tomatoes, peppers and grapes using this technique. The system irrigates the crop continuously but with flow rate to drippers regulated according to small changes in leaf turgor during the day that are monitored continuously. Although the system has been researched and developed over two decades, it is not yet widely used in the industry, thus it is likely that practical difficulties remain which limit its commercial uptake.

4.2 Runoff

With closed or part-closed hydroponic systems, there are difficulties in achieving total re-circulation of run-off water. This is because the nutrient solution (i.e. fertigation) and not just irrigation is almost exclusively used in the cropping of protected edibles out of the soil. This contrasts with HNS cropping in containers where most nutrition is provided with controlled release or other fertilisers in the growing medium, and irrigation is also used. Growers try to apply fertigation with individual nutrients balanced to match crop uptake, but this is difficult to achieve in practice as crop uptake varies with stage of growth and other factors, and ion exchange out of root systems also contributes to an imbalance in nutrient levels. Often, therefore, it is simplest to discard a proportion of the run-off and replace it with fresh solution to avoid a nutrient imbalance in the system. Open systems therefore may have as much as 20-50% run off to waste of applied fertigation.

At present, laboratory analysis of nutrient solution samples is required to accurately assess the relative levels of individual nutrients. Solution probes currently measure electrical conductivity, giving a measure of the total amount of nutrients in solution, and pH for acidity. Further development and commercial availability of ion-specific probes are required to allow individual nutrients to be monitored automatically and allow automatic selective replenishment of nutrients. This would be a major advance in minimising the amount of feed solutions flushed to waste, thus saving on fertiliser and minimising potential point-source pollution risks to the environment.

Overall, the scale of potential pollution caused by runoff from protected cropping of edibles is small compared to field-scale agriculture, however the intensity of glasshouse production means that the risk of local or point-source pollution remains (Lillywhite *et al*, 2007). It is important that the fate of run-off is traced and monitored. More accurate feeding of crops and maintaining correct balance in solutions will greatly reduce the proportion of nutrient solution disposal. Where nutrient run-off is inevitable, treatments such as reed beds need to be implemented.

5. Conclusions

Overall, water consumption for protected edible cropping constitutes a very small proportion of total agricultural and horticultural consumption, even though local water use may be high from large nurseries in summer. Water use efficiency (amount of ‘crop per drop’) is, however, very high compared to field cropping due to the intensity of production. Additionally, the high relative crop value means that the financial value (benefit) of the water applied is very high compared to most other irrigated crop sectors.

In most nurseries, irrigation scheduling is accurately achieved to meet crop needs consistent with maintaining necessary crop quality. There may be some scope to incorporate newer technological developments, but there is relatively little scope for saving large quantities of water applied.

Hydroponic cropping involving application of nutrients in solution limits the degree of recirculation possible to maintain nutrient balance without the need for some solution replenishment. Further development into e.g. ion-specific probes is needed before completely closed systems are possible.

The trend of substituting mains or abstracted water with harvested rainwater will continue, and is likely to have the greatest impact on reducing pressure on water resources. However, space for building sufficient storage capacity is a real problem for some nurseries. There may be opportunities for building and sharing reservoir storage between nurseries where they are in close proximity.

6. References

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