



Irrigation Best Practice

Water Management for Field Vegetable Crops A Guide for Vegetable Growers

TOP TIPS

Vegetable growers recognise that water is an important and valuable resource, which contributes significantly to production of high quality vegetables to specification and on schedule. Both crop performance and efficient use of the available water can be optimised by:

- Knowing the water holding capacity of the soil in each field and the water requirements and response of each crop grown
- Using an effective soil moisture monitoring system and using it to schedule irrigation accurately
- Choosing the right application equipment for your situation and knowing how to get the best out of it in terms of uniform and timely delivery
- Managing water application for maximum economic benefit with minimum impact on the environment
- Auditing performance afterwards to seek ways of improving the efficiency of water use and application

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ADDENDUM – February 2012

Please note that information regarding relevant legislation, both in the text and in referenced publications, although accurate at the time of publication, may now be out of date.

1 Introduction

Water is a vital component of vegetable crop production. An adequate water supply is essential to maximise both quality and crop yield for a given date. It is also an important management tool, enhancing crop establishment, chemical weed control and harvesting of root vegetables. However, water has to be applied at the correct time, in sufficient quantities, but without waste and with sympathy for the environment as a whole.

This Best Practice Guide aims to address the key aspects of water and irrigation management appropriate to field vegetable production (excluding potatoes). It follows a short telephone survey, which established growers current practices and concerns. Particular emphasis is given to crop response periods and the use of effective scheduling systems. The Guide draws attention to the principles of irrigating vegetable crops, identifies the critical factors for measuring crop requirements and controlling irrigation, both to optimise cropping and minimise waste.

We know that water supplies are frequently stretched and action has to be taken to safeguard this essential resource. Legislation expected to come into force this year will change the basis of licensing water abstraction. It will for the first time include water used for trickle irrigation. It is probable that the demand for, as well as the cost, of water will increase. This will mean that all users will need to increase water and irrigation management efficiency to make the most of this basic resource.

Environmental considerations are increasingly playing a part in the growing and marketing of crops. Careful and effective crop monitoring and irrigation control will be critical to profitable cropping in the future.

Horticulture and Potatoes Division
Department for Environment, Food and Rural Affairs
July 2003

2 Water Quality

The quality of water to be used for irrigation is important. All water is not the same. Mains and borehole water sources offer more consistency than surface water. They are unlikely to have the potential problems that can be caused by biological or herbicide contamination, by soil particles or organic matter.

The two main aspects of water quality are its chemical and microbiological properties. Other factors can occasionally affect quality, especially from river or reservoir sources, such as the presence of suspended peat or silt particles or other specific pollutants (e.g. herbicides). The chemical parameters important for irrigation water include:

- pH
- Alkalinity or bicarbonate content
- Electrical conductivity (measure of the total salts content)
- Chloride level
- Sulphate level
- Iron and other trace element levels

(Note that some trace elements such as iron and manganese, although often present in water, are not in a form that can be readily taken up by plants.)

pH and Alkalinity

pH is the measure of how acid or alkaline water is. However, it is the level of bicarbonates (principally calcium, but also magnesium and sodium) in the water that determines whether it is termed either 'hard' or 'soft'. Water may, for example, have a high pH but a low calcium bicarbonate content.

Whilst it is not practical or economic to consider acidification for field grown crops, it may be worth considering the use of acidifying fertiliser mixes when fertigrating with hard water in trickle systems used on high value vegetable crops.

Electrical Conductivity and Trace Elements

The electrical conductivity (E.C. or sometimes referred to as cF) is a measure of the total salts content of the water, reported in micro-siemens per cm. ($\mu\text{S}/\text{cm}$). The main contributors to high conductivity levels are nitrate, chloride and sulphate ions. Water with a naturally high E.C. does not usually give rise to a build up of salts in soils used for field vegetable production due to the diluting effect of winter rainfall.

Rainwater is generally uncontaminated, it has a low conductivity and pH and a very low calcium level. However, borehole water in coastal and fenland areas may have a high conductivity due to salt water contamination. A high conductivity due to high chloride levels makes the water unsuitable for irrigation unless treated or mixed with water from a more suitable source. Crops do vary in their susceptibility to chloride levels and the Table overleaf provides some guidelines on crop sensitivity.

Sensitivity of various field vegetable crops to chloride levels in irrigation water

Tolerance Group	Crops	Safe levels mg/litre Chloride	For limited use mg/litre Chloride	Risk of foliar damage mg/litre Chloride
Very sensitive	Peas French Beans	Up to 100	100 - 200	Over 200
Moderately sensitive	Broad Beans Celery Lettuce Onion Radish	Up to 200	200 - 300	Over 300
Slightly sensitive	Carrots Cauliflower Cabbage	Up to 400	400 - 500	Over 500
Least sensitive	Kale Asparagus Spinach Beetroot	Up to 500	500 - 600	Over 600

Suggested Maximum Trace Element Concentrations

Trace Element	Concentration mg/litre
Arsenic	0.04
Cadmium	0.02
Chromium	2.00
Copper	0.50
Molybdenum	0.03
Nickel	0.15
Selenium	0.02
Zinc	1.00
Lead	2.00
Boron	2.00

Some plants are also known to be sensitive to high fluoride levels; therefore irrigation water with less than 0.25 ppm fluoride is desirable. Boron toxicity is occasionally found where water (e.g. river water) contains high boron levels originating from detergents.

Microbiological Contamination

The main microbiological contaminants of water are fungal spores (e.g. white rot, *Sclerotinia* of Alliums). Irrigation can also provide an entry point for bacteria, such as *E. coli*, into the food chain. This is of particular significance where water is applied to crops eaten raw, such as salads. A risk assessment of water source and period when contamination is most likely to occur should be undertaken. Irrigation water should be checked to ensure it has an acceptably low level of microbial contaminants before use, though sampling where abstraction is direct from river and stream water is less representative because of fluctuating bacterial loading over time. Water obtained from deep boreholes is likely to contain fewer pathogens; water extracted from rivers and stored in reservoirs prior to application will show a decline in pathogen levels over time.

Drip irrigation, because it avoids wetting the aerial parts of the plant, may result in reduced bacterial loadings. However, there is little, if any, information to date on pathogen incidence in irrigation waters at point of use.

Water Analysis

Hand-held equipment is available for monitoring E.C. and pH during the production season, but a full laboratory water analysis is recommended at least every 12 months for each water source used and for surface water abstraction at times of high risk (e.g. dry periods).

3 Seasonal Water Requirements and Storage

In a telephone survey carried out in connection with this booklet, 75% of vegetable growers said that they had been short of irrigation water at some time in the last 10 years and 40% said they had insufficient in at least one season during the last 5 years. As a result of these experiences, many had been active in installing water storage facilities. Indeed, the need for businesses to store reasonable quantities of water is likely to become even more important as water costs rise and competition for supplies increases.

The April - September water requirement will vary with soil type, climate, the crops to be irrigated and the growing system. Where annual storage is required, it has been normal to design a scheme around the demand in the 15th driest year in 20. The Environment Agency and local planners have accepted this as the normal basis for water allocation. However, for high value crops there may be a case to move towards designs based on, say, the 18th driest year in 20.

The feasibility of water storage will relate to water availability and source. These can be summarised as:

- Summer surface water directly abstracted for irrigation
- Winter surface water for reservoirs
- Boreholes, including wells and well points – direct supply or for reservoir storage
- Public mains supply

The move to a Catchment Abstraction Management Strategy, designed to balance the needs of water users and the environment, will enable the Environment Agency to operate a transparent system where availability of further water supplies is evident. Currently, it is unlikely that new or increased abstraction licences will be granted for summer surface water abstraction. Similarly, there are many areas where new licences for borehole abstraction are unlikely to be granted. Other sources require storage facilities. For winter abstraction of surface water, a reservoir is required on farm to store the predicted annual requirement. Mains water systems are more appropriate for smaller scale production areas and plant raising nurseries. Here sufficient water should be stored to meet one or two day's use at maximum demand.

In the future it is possible that in some areas, water from the mains will be available at "Off Peak Rates". It is also possible that availability from the mains will be restricted at times of peak demand. To cater for such eventualities, additional storage may be necessary and cost-effective.

For planning purposes it is possible to accurately predict a crop's annual water requirement for a given geographical area using past meteorological data with the aid of a planning tool, such as the ADAS meteorological unit programme "Irriplan". As a simple 'rule of thumb':

- For many field vegetable crops a working figure of up to 150mm per season can be used
- For more intensively irrigated crops, such as celery, 200mm should be adopted
- For trickle or drip systems, it is more important to consider the maximum daily water requirement per plant or row. This should be based on area evapo-transpiration rates, which can be as high as 6 or 7mm per day but more usually 3mm/day

Reservoirs

Storage reservoirs are most commonly formed using an off-stream, earth embankment construction, filled by gravity or pumping. This avoids the need to make provisions for flood flows, with any surplus water being returned via an overflow pipe. Occasionally, reservoirs are made by damming an existing watercourse. This option can be expensive, requiring overflow and bypass arrangements.

Depending on scale, site considerations and the need for lining (which can itself account for 60% of the total cost), installation costs are in the range of £1000 - £3000 per 1,000m³.

Storage Tanks

Water for immediate use on glasshouse plant-raising units should be stored in a covered tank to prevent contamination. The storage tank can be an elevated sectional metal tank, a ground level reinforced concrete tank, or a ground level corrugated metal tank. The latter is the most cost-effective.

4 System Installation and Equipment

The scale and cropping type dictates the system to be used, as well as the level of investment in underground mains and water storage. While hose reel systems still predominate, centre pivot and linear systems are also of significance on some large-scale farms. Trickle irrigation schemes, at least at present, are usually tailored for small areas or specialist applications.

There are several stages to work through in designing and installing an irrigation scheme.

- Water source and quality
- Volume of water required
- Planning the irrigation layout
- Application equipment

Water Source and Quality

Water quality considerations and water source options have been referred to in Sections 2 and 3. Most water sources are suitable for the whole range of crops and systems, but physical water quality is crucially important for trickle irrigation, to avoid blockages. Given sufficient investment, virtually all water can be adequately filtered. The use of trickle irrigation may be advantageous in saline water areas, as it delivers the water at ground level, avoiding foliage scorch.

Volume of Water Required

The frequency of water application at peak summer demand should be decided at the design stage. The volume required at each application depends on the water-holding capacity of the soil, evapotranspiration rate and the cropping. Most hose reel-based systems are planned to irrigate on 5-10 day cycles at peak demand. The water volume needed, combined with the area being irrigated, the pressure required by the system and the land levels dictate the size and type of irrigation mains and the pump specification. It is crucial to get these design points right from the outset because it is difficult and expensive to alter later. Allowing for expansion, e.g. by using larger mains near the pump is advantageous, if finances will allow.

Planning the Irrigation Layout - Mains

Irrigation mains are sized on the flow required, allowing for acceptable pressure drops. For larger schemes, a ring main is a great advantage, enabling the water to flow from each direction to a hydrant. This limits the pipe size needed and reduces pump size, but is more suited to farms that are broadly rectangular in shape rather than long and narrow. Sufficient hydrants should be incorporated in the design to permit flexible use – very few farms have more than they need! Mains piping should be specified for the task involved; for hose reel irrigation standard 150mm Class D (12 bar) UPVC British Standard “Kite” marked piping or an equivalent underground mains piping is commonly used. If the main is only required for trickle irrigation, lower pressure piping is more than adequate.

To plan the most efficient systems, fields need to be individually considered for the soil type, slope and especially row length. For hose reel equipment, the mains and hydrants are usually laid to suit the length of pipe on the hose reel as far as practically possible. Large fields may need hydrants in the middle of fields but usually they are at the side or corners of fields, alongside a farm track etc. hopefully serving land on both sides.

Where a field is on the perimeter of the farm and only to be irrigated say once in 5 years in a rotation, it is normally practicable to use portable above-ground pipe. Trickle mains and especially the header pipes are often fabricated in black polyethylene and are either buried or laid on the soil surface; layflat

hose (firemen's type) is laid on the surface, although this is not recommended if there are any sharp stones.

Planning the Irrigation Layout - Pumps

Many reservoir schemes now use a floating pump either to deliver water at a low pressure to a second pump on the bank to boost the final mains pressure or have a single high horsepower pump on the floating raft itself. These pumps move up and down with the reservoir water level, so ensuring the mains system is always "primed" and the water can be successfully lifted over the bank. A pump sited on a bank cannot "lift water" vertically more than about 6 metres. Floating pumps, with a simple connection to the mains on the bank, also avoid the cost of building a pump house and are less prone to vandalism.

Most existing and some new systems rely on fixed speed pumps designed to supply a wide range of volumes at a relatively uniform pressure. Variable speed pumps offer the advantage of matching delivery pressure at the irrigation hydrant to need. Conventional pumps may exceed the required pressure at hydrants nearer the pump. Thus the additional capital cost (say £10-12,000) of these more sophisticated controls can be set against reduced energy costs.

Where trickle irrigation is used in conjunction with other application systems, a separate lower pressure main with dedicated pumps may be the right solution. This will depend on the relative scale of the operations, when and how the trickle operates and at what distance. The alternative is to use pressure-reducing valves to lower the mains pressure before it enters the trickle system. These valves and associated hydrants can be controlled using solenoid switches to automate the system.

Application Equipment

The chief consideration should be the needs and value of the cropping set against the annual cost of the equipment. Few farms are now completely new to irrigation; however, most have the potential to improve some aspect of performance with existing equipment and can consider further improvements when additional purchases are being considered.

Potentially, the most water-efficient method of application is trickle irrigation, but apart from use on very high value vegetable crops, or where water supplies are very limited, the investment is currently difficult to justify on field vegetable crops. When comparing different application systems, the factors that should be considered are:

- Relative energy requirements
- The uniformity of distribution and therefore potential water saving
- Labour requirement
- Types of hosereel: raingun versus booms
- Irrigation management e.g. lane spacings, maximising night-time irrigation
- Capital cost versus the crop value
- Tied ridge machines to retain water within the rooting zone

Hosereel Irrigation

Hosereels are used for 95% or more of the water applied to UK arable crops. Their advantages are



great flexibility and adaptability, with a wide range of sizes and outputs available. Most of the larger hoses reel irrigators are described by the outer pipe diameter and the pipe length, e.g. 110mm/450m. Costs are around £12-18,000, equivalent to a capital investment of about £550 per ha. irrigated per season. Typically, these larger machines have an output of 55-65 cu. metres per hour through a rain gun fitted with an 18mm to 26mm nozzle, covering 2-3 hectares in one setting.

The drive for high outputs can however be overdone. In attempting to apply the maximum volume of water in a given time and so become "more efficient" many machines are fitted with large nozzles (26 mm plus), aiming for shorter wind-in times and wider lane spacings. This often proves "too much" for the mains layout; as a result the correct gun pressure cannot be achieved, resulting in poor water distribution. An additional machine, although more costly, will give more even watering. To make more efficient and more accurate use of the water, growers are increasingly looking to use booms (see below) and are reducing quantities applied per pass to about 18mm or less e.g. for establishment prior to full crop cover, rather than the normal maximum of 25mm.

Raingun uniformity can be very poor in the wrong conditions – averaging perhaps a 75 % Coefficient of Uniformity (C of U) over a season. Many machines operate much less uniformly than this. Both application performance and water use efficiency can be optimised by:

- Ensuring the irrigator is operating exactly at the recommended pressure, gun angle and lane spacing. Lower gun pressures mean larger droplets, which have more energy on impact resulting in soil erosion, leaching of fertilisers and plant and crop contamination.
- Using tied ridge machines, forming mini-reservoirs or dams within the rows or between beds at planting time to combat soil erosion problems, where applicable. These hold the water, giving time for it to soak into the adjacent soil.
- Using the correct lane spacing for the machine - typically 72 metres for larger hoses reels - to allow, as far as possible, for cross-winds. There are practical difficulties in varying this spacing during the season to allow for wind.
- Using a 'sector angle' of 210° instead of the more normal 180°. This allows the gun to linger on the edges and gives improved uniformity. Some improvements can be made by replacing the gun with a variable angle gun, which lowers the trajectory of the water so reducing the effect of a crosswind.
- Maximising night-time working. Lower wind speeds (at night) improves the overall efficiency.
- Measuring actual performance against expected and making adjustments.
- Using remote signalling systems such as phonerlinks to optimise application efficiency.

Booms

There has been a significant shift towards the use of boom irrigators for field vegetables. They offer several distinct advantages compared with a hoses reel raingun:

- Smaller "sprinkler" droplet sizes, reducing the impact effect on the soil and crop, with very low leaf contamination.
- Lower connection pressures leading to an improved performance from the existing pumping and distribution systems e.g. where the connection pressure may be a problem on parts of the farm.
- Much improved accuracy. A typical 90% C of U, offering a distinct contribution to improved efficiency.

- For a modest investment overall (an annual charge of around £50-60 per hectare), a hose reel system can be significantly upgraded. It offers a worthwhile improvement in many situations for farms already committed to hose reels.

Booms, however, apply water to a unit area of land over a much shorter time than a raingun. Higher instantaneous application rates therefore occur which can be a problem for a few silty soils which “run together” or on sloping land.

Centre Pivot and Linear Machines

Some farms growing vegetables on a significant scale have installed centre pivots and more recently linear machines, which give an extremely accurate application, typically above a 90% C of U. The droplets are very fine, delivered close to the ground and so are relatively wind-proof. Linear machines can be moved around the farm to follow irrigation-responsive and high value crops. A number of similar rectangular fields are almost obligatory to make efficient use of the gantry sections. Because of the undoubted accuracy, fertiliser could potentially be added to the water. However, a significant disadvantage is the difficulty of moving the equipment on public roads and a requirement for low or no hedges to facilitate operation. Because of the above site-specific points the numbers being installed are limited.

Sprinkler Irrigation

Although uncommon nowadays, some holdings may still have access to traditional sprinkler systems. These offer advantages of low energy use, small droplets and a relatively even application pattern. However, even with a variety of methods employed to reduce the labour inputs required for these systems, the sprinklers still need to be moved every 3-4 hours.

Recent developments now allow plastic sprinklers spaced on a 18m x 18m or 12m x 12m grid to be used. These can be operated on a fixed setting for the whole irrigation season, but even so crop spraying operations may mean temporarily dismantling sections of the header pipe on the headlands or using small “ramps” to enable the sprayer to drive over pipes. Such sprinklers, even with a cost around £2000/ha, can provide for small area applications or where rainguns/booms are difficult to use. They offer an 85% C of U and are simple to maintain as well as offering a low energy input.

Trickle Irrigation

The main advantages of trickle irrigation are:

- Potentially more efficient use of water than overhead systems, though estimates vary and actual savings are likely to depend on row spacing and other factors.
- Less energy used compared with hose reel systems - of the order of 50%.
- The design and layout is very flexible, fitting almost any shape of field.
- Less labour required during the growing season.
- In extreme cases more saline water can be used because the water is applied below the leaf canopy.

The disadvantages can be summarised as:

- The higher costs and the practicalities of handling re-usable trickle pipes.



- Separate mains and pumps or pressure regulating valves may be required when trickle systems are being run alongside an existing irrigation system.
- Unless the pipe is adequately buried, rabbits and vermin can be a problem.
- The expenditure and effort laying the pipe needs to be committed, whether it is a season which proves to need high volumes of irrigation water or not.

Experience with field-scale trickle systems has so far been varied. Some growers have experimented with the equipment, but found the cost and practicalities did not suit their current farming system. Others have found trickle well suited to their requirements (e.g. runner beans, salads) and are expanding the area covered.

Types of Pipe

The lighter weight type of pipe is thin-walled, with a welded joint, and readily collapses flat when not under pressure. There are several grades, ranging from those which are only likely to be suitable for a season's use, to a quite durable thickness which can be laid out and taken up again for re-use. A further variable is the outlet spacing, which commonly ranges from 0.3m to 1m. Typical discharge rates are 2-4 litres/hour per outlet. Costs vary from, say, 6p to 13p/metre. Overall in-field costs can vary widely, according to pipe emitter specifications and row spacings, from £600 to £1,500/ha or more. The cost of the pumps, mains, header pipes, filtration, valves and possibly a mechanism to add fertiliser to the water flow are additional. These types of lightweight pipe are disturbed by wind and so need burying for field crops at a minimum depth of 50mm up to 150mm. Under polythene covers, pipes can be laid on the soil surface.

More durable and rigid piping has pressure-regulated emitters moulded into the pipe as it is formed. The spacing therefore must be specified at the time of manufacture. Each dripper consists of a labyrinth of narrow waterways to reduce the energy of the water, allowing it to trickle out. All modern piping is UV-proof and non-degradable.

Trickle Layouts

Field design needs to be tailored to crop requirements and row spacings. It is normal to divide up a trickle-irrigated area into blocks, which are watered sequentially. Water flows are surprisingly high, so there may well be 4 settings a day, each taking 3-4 hours to apply sufficient water. With the fixed layout and valve controls, water can be applied more frequently in smaller amounts, with little added labour.

Few fields are really flat, but unregulated pipe can work reasonably well with a slope up or downhill of 3% for lengths up to 230m. Wherever possible it pays to run the pipe down the slope to give longer runs. Pressure-regulated piping can cope with virtually any slope. With correct design single runs of 400-500 metres can be accommodated.

Filtration

This is crucial for the success of trickle irrigation. Simple mesh filters can be used for smaller schemes, but sand filters and particularly disc filters are now increasingly common, as they offer a self-cleaning option. Algae and slime build-up can be a problem on 'long-life' pipes, especially with fertigation. This can be cured by periodic chlorination. Similarly, bicarbonate or iron deposits can be removed with the use of appropriate acid treatments. All lines can usually be flushed by opening up the ends of the laterals.

5 Irrigation Scheduling and Crop Response Periods

It is useful to think of the soil as a holding reservoir for water. In late winter the soil is generally at field capacity, i.e. when the soil is fully saturated and any surplus has drained off. As the crop grows, water is extracted from the soil and lost by transpiration from the leaves and evaporation from the soil and leaf surfaces (the combined effect is known as evapo-transpiration). The accumulated amount of water lost from the soil is referred to as the soil moisture deficit (SMD). Any water added either by rain or irrigation is subtracted from the SMD to determine the current soil moisture status.

The type and depth of soil in which the crops are growing influences the amount of water which is available to the plant, with heavier soils normally holding more water. In contrast, light sandy soils, such as those of Norfolk, Nottinghamshire and Suffolk, where vegetable production has increased in recent years, have more limited water-holding capacity. On these soils, which hold as little as 18mm water per 150mm soil depth, irrigation has to be more precise and frequent to grow high quality vegetables to a guaranteed harvest schedule. This practice has the advantage of reducing the risk of water loss through run-off and drainage.

In all soils a proportion of the total water present is not available to the plant. Soils with a high clay content usually have a high water-holding capacity, but a relatively high proportion is not readily available. As the water reserve in a soil is depleted, so the plant has increasing difficulty in obtaining the remaining water; the plant's development slows and yields and quality suffer. The point at which this happens is known as the Critical SMD, which is usually between 35 and 55% of the soil's available water capacity in the crop rooting zone. The aim of irrigation scheduling and application is to maintain soil water reserves above the Critical SMD at important phases – the response periods - of the crop's life and to avoid over-watering.

Rooting depth and soil type are both important factors that affect water availability for the crop. Trigger deficits for irrigation range from 15mm to 75mm and are dependent on rooting depth, soil type, crop and accuracy of the equipment used. To assess suitable irrigation regimes, soils can be divided into 3 classes, each having different levels of water availability for a given depth:

Class A Low soil water availability:
Not more than 60mm of water per 500mm of depth
e.g. Coarse Sand; Loamy Coarse Sand; Coarse Loamy Sand.

Class B Medium soil water availability:
Between 60mm - 100mm of water per 500mm of depth.
e.g. Loamy Sand; Loam; Silty clay loam; Clay etc.

Class C High soil water availability:
Above 100mm per 500mm of depth.
e.g. Very Fine Sand; Peat; Peaty Loam.

To enable crops to access the maximum moisture reserves, rooting depth is important. Good soil preparation is essential prior to planting or drilling to allow the plant roots to penetrate to depth, enabling the crop to have full access to available moisture reserves. Compacted soil limits a crop's access to water.

Water uptake is affected by the root's proximity to the soil particles. Young plants when first planted need sufficient water during the establishment stage to grow away rapidly. Careful planting is essential to ensure that the soil is settled closely around the roots, without being over-firmed, thus causing root damage. Irrigation after planting settles the soil around the roots and fosters rapid plant establishment.

Similarly with drilled crops, moisture must be available at seed depth to encourage germination and most critically moisture must continue to be present to allow the seedling root to keep growing and eventually exploit a larger volume of soil. Drilling depth can be manipulated for most vegetable crops with deeper drilling in warmer and drier months of the year.

The irrigation plans in the following Table are based on experimental data from trials over a number of years and industry experience. Changing cultural practices may mean that individual crop irrigation plans will vary from those set out here.



Irrigation Schedule for Outdoor Vegetables

Response Periods and Critical Application Times

Crop	Months when pre-sowing or planting irrigation may be needed	Response periods Growth stage	Response periods Time of year	Irrigation plan for 3 soil types mm of water at mm SMD			Notes
				A Low AWC	B Medium AWC	C High AWC	
Asparagus harvest	Irrigation may be required for plant establishment particularly if plants are raised in modules			Nil	Nil	Nil	Avoid irrigation during harvest as this has adverse effects on spear quality. In other countries with a similar climate there is some evidence that irrigation encourages fern growth, producing a higher yield the following year.
Beans, Broad (Vicia spp.)		At early flowering and again at pod swelling	Mid May to Early July	20 at 25 +	20 at 25 +	20 at 25 +	Irrigation can be associated with increased risk of chocolate spot.
Beans, Dwarf (Phaseolus spp.)	April/May	Early flowering green bud stage and pod swelling	June to August	20 at 25 +	20 at 25 +	20 at 25 +	Shallow rooting crop, do not irrigate at petal fall.
Beans, Climbing (Phaseolus spp.)	April/May	Early flowering onwards	June to August	20 at 25 +	25 at 30 +	40 at 50 +	
Beetroot	April to June	Throughout life	May to August	20 at 25 +	25 at 50 +	25 at 50 +	Irrigation to maintain less than 18mm SMD will reduce scab infection on light soils.
Brussels sprouts	May to June for plant establishment	When lower buttons are 15 to 18 mm diameter	August to October	40 at 40	40 at 40	40 at 40	
Cabbage, Spring hearted	July to August when following another crop	20 days before cutting	April to May	20 at 20	25 at 25	25 at 25	One application only at pre-harvest stage.
Cabbage, greens	July to August	Pre-drilling and to establish transplants	May to September	20 at 20	25 at 25	40 at 50	Irrigating after fertiliser top dressing may be beneficial in dry conditions. Excessive application should be avoided to prevent leaching.
Cabbage, Summer and Autumn	April to July	Pre-drilling and to establish transplants	May to September	20 at 20	25 at 25	40 at 50	Where water is limited satisfy the SMD up to 50mm 20 days before cutting.
Cabbage, Winter and Savoy	April to July	Pre-drilling and to establish transplants	April to July	20 at 20	25 at 25		

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Carrots	April to June	Throughout life on high density crops	June to September	20 at 25	40 at 50		Irrigation to maintain less than 18mm SMD will reduce scab infection. Irrigation following a large SMD may increase splitting. Irrigation of low-density crops during 7 weeks post-drilling may depress yield.
Cauliflower, Early Summer		Throughout life or 25mm when 50% of plants have 30mm curd diameter	April to June	20 at 20	25 at 25		Crops under polythene may need irrigation on removal or prior to removal to aid lifting of the polythene. Do not exceed 50% depletion of water in the rooting zone.
Cauliflower, Summer and Autumn		Throughout life or 25mm when 50% of plants have 30mm curd diameter	May to September	20 at 20	25 at 25	50mm 20 days before cutting starts	Do not exceed 50% depletion of water in the rooting zone.
Cauliflower, Winter	May to June	After planting for establishment	July	25 at 40	25 at 40	25 at 40	
Celery	June	Throughout life	June to August	18 at 20	20 at 25	20 at 25	Absolutely essential to maintain soil moisture for quality and succulence.
Courgettes	April to May	Throughout life	May to August	20 at 25	20 at 25	20 at 25	
Leeks	April to July	Throughout life	May to August	20 at 25	25 at 50	50 at 75	
Lettuce, Summer	April to July	Throughout life	April to August	20 at 20	25 at 25	25 at 50	Irrigation of block raised and transplanted lettuce immediately after planting is important, 12mm at 2 or 3 day intervals may be required in dry weather. Minimising the duration of leaf wetness will reduce disease risk.
Onions, bulb, spring sown/planted		Throughout life	May to July	20 at 25	20 at 40		Avoid irrigating after end July or bulb ripening may be delayed.
Onions, salad	April to August	Throughout life	April to August	20 at 25	20 at 25	20 at 25	It is important to minimise the duration of moisture on the crop canopy to reduce disease risk.

Irrigation Schedule for Outdoor Vegetables				Response Periods and Critical Application Times			Notes
Crop	Months when pre-sowing or planting irrigation may be needed	Response periods Growth stage	Response periods Time of year	Irrigation plan for 3 soil types mm of water at mm SMD			
				A Low AWC	B Medium AWC	C High AWC	
Parsnips	April to May	High plant populations will respond to irrigation in dry					Irrigation not advised except for plant establishment of late crops and possibly before / after polythene removal on early crops
Peas, green, vining and harvesting dry	April to May	At early flowering, then at pod swelling	June	25 at 30 +	25 at 30 +	25 at 40 +	Maximum response is at start of flowering, irrigation at petal fall increases the risk of Botrytis on the pods.
Radish	April to August	Throughout life	April to August	20 at 25	20 at 25	20 at 25	
Rhubarb		Post-harvest	May to September	40 at 50	40 at 50	50 at 75 +	
Spinach	April to July	Throughout life to August	May to August	20 at 25	20 at 25	20 at 25	
Swedes	May to June	Start of root swelling onwards	June to July	20 at 25	20 at 25	50 at 75	
Sweetcorn	June	Throughout life	June to August	25 at 50	25 at 50	50 at 75	
Turnips	April to May	Start of root swelling onwards	June to July	20 at 25	20 at 25	50 at 75	Irrigation 10 to 18 days after drilling can depress yield.

Trickle Irrigated Vegetable Crops

Crop	Response Period	Plan for 3 Soil Types (Maximum SMD mm)		
		A Low AWC	B Medium AWC	C High AWC
Runner Beans	May to late August	10mm	20mm	35mm
Courgettes/ cucurbits	May to late August	10mm	25mm	40mm
Lettuce	April to late August	10mm	25mm	40mm

Notes: The soil moisture tension between plant roots and trickle source must be maintained and management is normally on the basis of replacing the amount of water lost during the previous day. The soil should not be allowed to dry, otherwise the spread from drippers will be seriously affected. Overhead irrigation may be required for plant establishment in dry conditions to establish the moisture tension between trickle and plant roots in all the above crops. Overhead irrigation to aid pollination and flower set in runner beans may be required in addition to trickle irrigation.

6 Water Monitoring Techniques

It is possible to have the best irrigation system but still get it wrong. Optimising the use of water for both crops and the environment still depends on someone recording rainfall, checking equipment and scheduling application. It is important that responsibility concerning irrigation decisions is clearly defined. A range of increasingly sophisticated techniques and tools is available to measure soil water content and to help prioritise irrigation choices. In our survey of vegetable crop irrigators, about a quarter used balance sheet methods to plan their irrigation, with half employing direct measurement methods. The remaining 25% were still largely basing their irrigation decisions on experience.

Several water monitoring methods can be used, based on different technologies. There are three broad categories: indirect methods, which rely on environmental measurements to estimate crop water loss; direct methods, using various techniques for measuring the soil water content or tension; and plant based methods, which are still largely at the experimental stage and rely on measurements of the crop plant water status or water stress. There are advantages and disadvantages to each method.

Indirect Methods

Balance Sheets

By using known models of evapo-transpiration, together with weather station data on rainfall, temperature, relative humidity, wind speed and solar energy it is possible to estimate the rate of water loss from a crop, given the crop cover. A balance sheet can then be constructed to schedule irrigation applications to match water that has been lost via evapo-transpiration. In the simplest form these can be manual sheets filled in with details of farm rainfall and irrigation, with evapo-transpiration from weekly published Meteorological Office data.

Example of average daily evapo-transpiration rates for an agroclimatic area in Eastern England

Month	mm/day
April	1.9
May	2.7
June	3.1
July	3.1
August	2.3
September	1.5

The above example relates to a full grass crop cover. In practice, allowance needs to be made for the percentage ground cover, as during crop growth water loss will be reduced compared with the full grass evapo-transpiration value. Evapo-transpiration also varies between the various vegetable crops. At full ground cover, water loss may well exceed that for grass.

The figures shown are averages. Actual daily evapo-transpiration during the summer can vary from 1.5mm/day on a cool damp day to 7mm/day on a hot windy day. As well as determining the current soil moisture deficit by calculation or measurement, it is highly desirable to take some account of weather conditions and potential water loss, as well as the weather forecast, when deciding how much water to apply over the coming week.

On-farm estimates of evapo-transpiration are possible using specifically designed equipment such as the etGauge. There are also computerised 'balance sheet' models available such as ADAS Irriguide, which takes away the need for calculations, though rainfall and crop cover data need to be inputted periodically. These systems also overcome the inaccuracies associated with manual balance sheets as they model ground cover development and root extension. They also calculate actual evapo-transpiration of the crop.

The information provided by balance sheets is only as good as the information fed in. Inaccuracy in measuring rainfall or irrigation or in estimating crop cover or rooting depth (e.g. if affected by compaction) can lead to accumulated errors.

However, the advantages of balance sheet methods are that relatively little equipment is required, forward predictions are possible and an average result is given which is not dependent on a direct soil water measurement at a point that might not be representative of the whole field. Assessments of the sophisticated versions show that they compare favourably for accuracy with other measurement methods.

Direct Methods

Equipment that measures soil moisture directly depends crucially on siting of probes at points that are typical both of the soil type and the irrigation applied. Variations in soil texture or the amount of water applied across a field can lead to difficulties in interpreting data, though it is normal to have a number of measuring points per field to help overcome this.

Measuring Soil Water Tension - Tensiometers and Resistance Blocks

The physical characteristics of a soil and its water content determine the tension or pressure at which water is held. The availability of water to the crop and the ease with which this can be extracted from the soil or soil-less substrate is known as moisture tension and can be measured by Tensiometers. Of all the methods used for irrigation scheduling, measurement of soil moisture tension most closely relates to the availability of water to the crop at that point.

Tensiometers contain water in a porous cup mounted on a column that is inserted into the soil. As the soil becomes dry, water moves out of the cup and this creates a vacuum elsewhere in the instrument which is read from a dial gauge or, in the more recent devices, transduced via a sensor to give a digital readout. Tensiometers are normally sited in pairs, one being placed at about one third of the total rooting depth, and the other within the lower third of the rooting zone. Irrigation is applied when a certain critical tension is reached in the upper zone. The reading in the lower zone indicates when the whole rooting zone has been restored to a moist state, thus avoiding over-watering.

As mentioned above, optimum siting of the instruments is critical to minimise (or characterise) the effects of in-field variation. Tensiometers are well suited for use in trickle-irrigated crops.

The main problems are breakage in the field and unexpected loss of tension in the water columns if the soil becomes exceptionally dry. Once purchased, the running costs are low as readings can be taken by the grower.



Porous Blocks

Soil water tension may also be measured with the use of porous blocks. These are buried in the soil at the desired depth where the water content of the block equilibrates with the surrounding soil water. Various types are available, but the most common are gypsum resistance blocks where the electrical resistance of the block is measured by a meter, which is calibrated to the soil water tension. Gypsum blocks are short-lived, but relatively inexpensive. The Watermark block, of synthetic manufacture, is available in the UK and is longer lasting.

In comparative trials, the Watermark block was slower to respond to changes in soil water tension than tensiometers or 'TDR' probes (see below).

Measuring Dielectric Constant - Time Domain Reflectometry (TDR) and Capacitance Probes

It has been shown experimentally that the measurement of the dielectric constant (the ease with which electromagnetic waves can be transmitted) of the soil can be directly related to the volumetric water content.

There are two approaches to measuring the dielectric constant of the soil and hence the water content: Time Domain Reflectometry and radio frequency capacitance.

Time Domain Reflectometry (TDR) has become an accepted technique for soil moisture measurements. In the last few years the cost of the equipment has reduced and a number of portable and data logging devices have become available in the UK offering the advantages of easy probe installation, independence of soil type and the option of instantaneous readout or data logging. Frequency Domain Reflectometry (FDR) equipment operates in a similar manner.

The standard TDR technique uses 2 or 3 parallel steel rods attached to a handle connected to the unit via a coaxial cable. Pulsed transverse electromagnetic waves are transmitted along the probes and the return lines of the pulses reflected by the end of the probes are measured. This signal is determined by the dielectric constant of the surrounding soil, which can be related to the volumetric water content.

When installed vertically, the probes give an average reading over the length of the probe. To obtain readings at different depth zones, probes would need to be inserted at each depth. This is much less convenient than with the neutron or capacitance probes where point readings can be taken down the profile through one access tube.

With the TDR equipment it is relatively easy to take readings of soil moisture in the 0 - 15cm zone; shallow soil depth readings are more difficult with a neutron probe.

Due to the importance of correct installation – their performance is very sensitive to the effects of air gaps or stone, TDR equipment is probably best used permanently sited, with a data logger, so that variations in water content at one point can be continuously monitored, eliminating site to site variation. Relatively short probe lengths (<10cm) allow the probe to be inserted tightly in the soil with greater ease but reduces the volume of soil being measured.

Radio frequency capacitance devices (commonly known as Capacitance probes) have also become

more widely available in recent years. These devices use high frequency radio waves to measure soil capacitance, which is related to the dielectric constant of the soil, and hence the volumetric water content. They employ a permanently sited access tube similar to that used with a neutron probe. The probe is lowered into the access tube and readings are taken at each required depth.

Some care is needed to ensure the access tube is installed tightly into the soil with no air gaps, which would result in inaccurate, low readings. When correctly installed and calibrated, capacitance probes will give accurate readings with many of the advantages of the neutron probe system, repeatable measurements at the same location and depth profiles. Unlike the neutron probe, near surface measurements are possible, and there are no radiological hazards. However, the volume of soil measured is small and prone to error in soils with a high stone content.

Neutron Probes

The neutron probe offers another way of determining the volumetric water content of the soil. The soil moisture is measured by lowering a source of 'fast' neutrons and a detector tube down an aluminium access tube set into the soil for the life of the crop. The detector tube detects 'slow' neutrons which are created when 'fast' neutrons from the source in the probe collide with the hydrogen atoms of water. The quantity of 'slow' neutrons is proportional to the amount of water present.

Because of the radiological hazards, only licensed operators can use this equipment so specialist contractors are normally employed. Commercial operators generally offer a service whereby 2 or 3 x 1.2m tubes are inserted in a field and readings are taken by the contractor weekly or as the grower requires. The results are converted into mm water at 100 - 200mm zones down to 1.2m and a deficit calculated. Daily crop water use is estimated by deducting any rainfall or irrigation from the water loss.

Correction factors or calibration curves are required for each soil type to convert the readings into volumetric water content. In practice, commercial operators generally select a standard curve for the soil type on the site.

As with TDR and capacitance probes, the neutron probe gives a reading of volumetric water content. To convert volumetric water content into a soil moisture deficit (which is essential to interpret the results) it is necessary to know what the water content was at field capacity ("full point"). This requires readings to be taken at an appropriate time during the winter or at any time when the soil is thought to be at field capacity.

Normally the access tubes are sited in pairs in one location in the field, near the headland for convenience of reading. However, there is a risk that they may not be representative of the field as a whole. Another important consideration for shallow-rooted crops is that the neutron probe is less accurate for readings within 15cm of the soil surface, due to the escape of 'slow' neutrons from the soil surface.

Notwithstanding these limitations, neutron probe readings have proved accurate in estimating the amount of water lost from a soil profile at a site between one reading and the next. This is still a very useful facility when trying to maintain soil moisture at a set level.

The ability to measure water content at different depths through the profile is also useful in interpreting the results and can lead to a better understanding of rooting depth and soil compaction within a profile.

The need to employ contractors to take readings at each site on a regular basis is unfortunately becoming increasingly expensive. Although there are advantages of subcontracting this work to knowledgeable specialists, some growers prefer the flexibility of taking readings using their own equipment such as TDR or capacitance probes.

Plant Based Methods

Remote Sensing of Plant Water Status

A number of techniques have been used experimentally to measure directly plant water status. Of these, the use of infra-red sensors is now the closest to commercial exploitation. The technique involves taking measurements of leaf temperature using an infra-red thermometer or camera and comparing it with a reference reading of a standard wet and dry surface. The degree to which the leaf is able to maintain a temperature below that of the ambient air temperature is used to generate a measure of plant water stress.

At present the potential application of infra-red thermography is being assessed in a limited number of field crops within the UK.

Soil Moisture Deficits to Irrigation Schedule

The list of fields and crops with their associated soil moisture deficits needs to be transformed into an irrigation plan for the next 5–10 days, taking into account:

- Difference between the current SMD and the critical SMD; the response periods
- Rate of moisture loss and weather forecast
- Crop priority ranking
- Nearness of equipment and time taken to apply necessary irrigation

Some scheduling systems incorporate a forecasting element which assists forward planning; often it is the subject of discussion between farm management and consultant. Careful matching of crop requirements and equipment is necessary to ensure that irrigation keeps pace with demand. As peak demand periods approach it may be necessary to anticipate increases in soil moisture deficit by irrigating above a crop's immediate needs, as long as this does not bring the soil above field capacity.

A qualitative summary of the advantages and disadvantages to the grower of currently available methods of soil moisture monitoring
 A score of low, medium or high is given to each assessment category

Type	Typical products	Initial cost	Ease of use	Running costs	Accuracy		Continuous data logging possible	Water content by depth profiling
					Representative	Point accuracy		
Manual balance sheet		Low	Low	Low	High	-	No	No
Computerised balance sheet service	Irriguide	Low	High	Medium	High	-	No	No
Tensiometer	Irrimeter	Medium	Low	High	Low	High	No	No
Digital electronic tensiometer	Skye electronic tensiometer	Medium	Low	Low	Low	High	Yes	No
Synthetic block	Watermark	Medium	Low	Low	Low	Medium	No	No
TDR FDR	Theta probe Grodan meter ISUF (Netafim)	High	Low	Low	Low	High	Yes	No
Capacitance probe with data logging service	Enviroscan Delta T profile probe	Low	High	Medium	Low	High	Yes	Yes
Capacitance probe service	Diviner	Low	High	Medium	Low	High	No	Yes
Neutron probe service	Various	Medium	High	High	Low	High	No	Yes

7 Irrigation Auditing

Growers understand the value of irrigation and the benefits that it can bring. Many have been improving the efficiency with which it is applied to crops. However, in our preliminary survey only half - 53% - of growers conducted a water audit at the end of each season. Within this figure some audited more formally than others. A review each season is recommended and may be required in future to ensure that all water is used in an effective and responsible manner. With future legislation it is likely that efficiency of water use will be assessed when licences are reviewed.

Where extra land is taken on, or when major changes to the system are envisaged, careful consideration of all managerial points within this manual will show benefits in improved operation. A water audit should be undertaken annually, covering the following:

- Assess water use records for recent years - identify existing and future needs
- Compare water availability with anticipated cropping demand and quantity of licensed abstraction
- Measure accuracy and uniformity of application
- Review scheduling system – were data inputs accurate? Is the system delivering the required information and is it cost-effective?
- Ensure compliance with legislation and customer crop production protocols
- Ensure application equipment is capable of meeting the anticipated demand
- Ensure planting systems and application method minimises water loss, soil erosion and leaching whilst maximising crop response
- Check for leaks and ensure equipment is maintained
- Ensure that staff involved are adequately trained



8 Legislation

The European Union has identified water as a key natural resource, which must be managed in a sound and environmentally responsible manner. EU Directives are implemented in the UK under various Acts of Parliament and Regulations relating to both water pollution and management of water resources. The new European Water Framework Directive and the draft Water Bill will impact on growers during the coming years.

Enforcement

The enforcement of most water-related legislation is the responsibility of the Environment Agency (England and Wales) and the Scottish Environmental Protection Agency (Scotland). Most concerns over legal compliance should be routed through these agencies in the first instance.

Water Pollution and Contamination

The Water Resources Act (WRA) 1991 allows for individuals responsible for causing pollution to be prosecuted. Under the WRA it is an offence to cause or knowingly permit a discharge of poisonous, noxious or polluting matter or any solid waste to enter ground or surface waters without proper authorisation. Within the WRA the Groundwater Regulations 1998 have been implemented. These Regulations make it an offence to dispose of listed substances (including pesticides and some elements in fertilisers) to land where this may lead to a direct or indirect discharge to groundwater. Growers need to apply to the Environment Agency for authorisation to dispose of listed substances, which include pesticide tank washings.

Water pollution offences can carry a penalty of up to £20,000 in a Magistrates Court and an unlimited fine in the Crown Court. It may also be necessary to pay for any damage caused by pollution and clean-up costs.

The Code of Good Agricultural Practice for the Protection of Water ('Water Code') 1998 contains a section on 'Specialised Horticulture' which is relevant to soil-less substrate grown crops. The Code suggests that irrigation and feed system runoff should be monitored and operated in a way that minimises nutrient run-off.

Businesses using the public mains water supply come under the Water Supply (Water Fittings) Regulations 1999 (Water Byelaws 2000 in Scotland). These Regulations replace the former Water Supply Byelaws. They relate to the design, installation and maintenance of plumbing systems (including irrigation), water fittings and water using appliances. Their purpose is to prevent misuse, waste, undue consumption or erroneous measurement of water and, most importantly, to prevent contamination of drinking water. Businesses are required to carry out a contamination risk assessment for each water fitting or appliance that contains water, or other liquids, and is connected to the plumbing system. Only approved fittings should be used to prevent backflow and water suppliers should be provided with advance notification of any water system (e.g. irrigation) installation. Approved plumbers can provide certificates to demonstrate that systems are compliant.

Regulations under the Water Industry Act 1991 implement drinking water standards set under EC Directives 80/778/EEC and 98/83/EC (the 'Drinking Water Directives'). These set maximum admissible concentrations (MACs) for 57 listed parameters. The MAC for nitrate in drinking water is 50 mg/l NO₃. The MAC for total pesticides is 0.5 µg/l, and 0.1 µg/l for a single pesticide. Restrictions could be imposed on holdings found to be causing contamination of the source waters of public drinking water supplies.

The EU Water Framework Directive (WFD) (2000/60/EC) came into force in December 2000 and should be incorporated into UK law by 22 December 2003. The Directive covers both pollution and water resource management and aims to bring together various EU Directives relating to water. The Directive will require the development of Catchment Area Management Strategies (CAMS) across the country, which will regulate water use. Each area will develop its own strategies, depending on the regional pressures faced. Growers may be affected in terms of the range of pesticides and fertilisers that can be used within certain catchments as well as measures to minimise impacts on local ecology and habitats.

Water Resource Management

Dry summers during the 1990s highlighted regional water shortages in various parts of the country. In February 2003, the Government published a Draft Water Bill, with a view to it being on the statute book in 2004. The draft Bill proposes measures to facilitate the sustainable management of our water resources and will undoubtedly impact on water abstraction licence holders. Under present legislation, all new abstraction licences are time limited. Existing non-time limited licences will become time limited under the proposed Bill. The Environment Agency (England and Wales) will assess licences and will probably tie time limits in with the six yearly cycles developed for CAMS. In the majority of cases, licences will be granted for 12 years. This will be increased for schemes with reservoirs and reduced in areas where demand is high or habitats are threatened.

Where abstractions are causing adverse impact on the environment, then action will have to be taken to reduce the levels of abstraction. This may involve providing compensation to the abstractor involved. This compensation would be financed through increased licence fees. In some areas of 'water stress', licence holders will be required to carry out environmental monitoring which may make water abstraction too costly for some abstractors. The efficiency of water use will also be assessed when licences are reviewed.

9 Sources of Information

Useful References

Legislation guides and codes of practice

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Good Irrigation Practice – making every drop count when there is not enough to go round (PB 2513). Reprinted May 1996.

Irrigation Water Assessment and Management Plan – Efficient use of irrigation water (PB3935). Printed February 1999.

Irrigation Scheduling – Uses and Techniques (PB2511). Printed 1996.

PB booklets all from: Defra Publications, ADMAIL 6000, London SW1A 2XX

Tel: 08459 556000 Fax: 020 8957 5012

Relevant Organisations and Contact Details

Environment Agency, Head Office, Rivers House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS12 4UD.

Tel: 01454 624 400 Tel: 08459 333 111. Emergency Hotline: 0800 80 70 60

Internet: <http://www.environment-agency.gov.uk>

<http://www.environment->

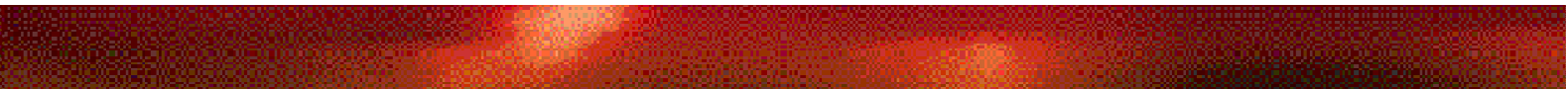
[agency.wales.gov.uk](http://www.environment-agency.wales.gov.uk)

The Met. Office, London Road, Bracknell, Berkshire, RG12 2SZ.

Tel: 0845 300 0300 Internet: <http://www.metoffice.com>

UK Irrigation Association Executive Secretary: Melvyn Kay

Tel: 01427 717624 Internet: <http://www.ukia.org>



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Principal authors John Birkenshaw
 John Bailey

For further copies contact: ADAS Horticulture
 Battlegate Road
 Boxworth
 Cambridge
 CB3 8NN

Tel: 01954 268214
Fax: 01954 267659
Email: horticulture@adas.co.uk
Website: www.adas.co.uk/horticulture

