Irrigation Best Practice

Water Management for Potatoes

A Guide for Growers

defra
Department for Environment Food and Rural Affairs

ADAS

TOP TIPS

Potato growers know that water is an important and valuable resource, which contributes significantly to production of high quality potatoes, to the specification demanded by the market. To get optimum crop performance and ensure efficient use of available water:

- Know the water holding capacity of the soil in each field and understand the water requirements and crop response of the potato crop
- Ensure soil structure at planting is good, so as to maximise the availability of soil moisture to the crop through its roots
- Use an effective soil moisture monitoring system and use it to schedule irrigation accurately
- Choose the right application equipment for your situation and know how to get the best out of it, especially in terms of uniformity of application
- Understand the interactions between water and crop quality, including diseases, pests and disorders
- Manage water application for maximum economic benefit with minimum impact on the environment
- Audit performance afterwards to seek ways of improving the efficiency of water use and application in future years

Contents

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legislation, both in the text and in referenced publications, although accurate at the time of publication, may now be out of date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 potato production. It is essential to maximise both yield and quality. Irrigation early in the growing season minimises common scab, maximises tuber number and encourages crop canopy growth. It allows tubers to grow at an optimum rate, and at the end of the season it can allow harvesting with minimal crop damage.

Water has to be applied in the right amounts at the right time in order to achieve the right crop result. At the same time, the application of water should avoid waste of a valuable resource and be in sympathy with the environment as a whole.

This Best Practice Guide aims to address the key aspects of water and irrigation management appropriate to potato production. Emphasis is given to correct management of water application, both in terms of scheduling and field equipment. This Guide also focuses on the crop quality aspects of irrigation, especially as it affects diseases, pests, disorders and damage.

Environmental considerations are playing an increasing role in the production and marketing of all crops, including potatoes. Careful and effective irrigation management will form part of these considerations, as well as helping the grower to continue producing profitable potato crops.

Horticulture and Potatoes Division
Department for Environment, Food and Rural Affairs
December 2005

2 Seasonal Water Requirements and Storage

Winter storage of water for summer irrigation is becoming more important for growers, in order to guarantee water supplies for crops.

WATER REQUIREMENTS

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, where high value potato crops are consistently produced for packing and/or punnet outlets, 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 both to water availability and source. These can be summarised as:

- Summer surface water directly abstracted for irrigation
- Winter surface water for reservoirs
- Boreholes, for direct supply or reservoir storage

The move to Catchment Abstraction Management Strategies (CAMS), 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 anywhere for summer surface water abstraction. Similarly, there are many areas of the country where new licences for borehole abstraction are unlikely to be granted. For winter abstraction of surface water, a reservoir is required to store the predicted annual requirement.

RESERVOIRS

Most storage reservoirs are clay lined and constructed off stream, avoiding the need to make costly provision for peak flood flows, requiring large overflow and bypass arrangements. On lighter soils where there is no suitable clay available, an artificial liner is needed with a geotextile underlay to help to protect the liner from stone damage.

Larger reservoirs with more than 25,000 cu. metres of water (5.5 million gallons), stored above the lowest surrounding ground level, come under the Reservoirs Act 1975 and need to be designed and later inspected at regular intervals by a specialist Panel of Engineers. Effectively, unless a disproportionate quantity of subsoil is to be moved, a 45,000 cu. metre reservoir can be efficiently built on level ground outside of the Reservoirs Act. Some larger reservoirs are cut into the ground without banks by first abstracting minerals; with careful and sympathetic design they can look very unobtrusive.

Increasingly reservoirs are designed to blend in with the countryside, taking into account a natural shape and the bank slopes and heights. An associated tree or hedge planting scheme is now usually commonplace.

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 £750 - £2,500 per 1,000 cu. metre.

3 System Installation and Equipment

There is no single 'best system' that can be applied to all farms; each must be designed on an individual basis. Scale dictates the system to be used, as well as the level of investment in underground mains and water storage. While hosereels still predominate, centre pivot and linear systems are used on some larger farms. Trickle irrigation schemes are used by a few potato growers.

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 - both mains and pump
- Application equipment

PLANNING

Water sources and quality

Most water sources are suitable for potatoes, but the absence of sand and other particles is crucially important for trickle irrigation in order to avoid blockages. However, given sufficient investment, virtually all water can be adequately filtered. Trickle irrigation may be advantageous in saline water areas, as it delivers the water below the level of the crop canopy, avoiding foliage scorch.

Volume of water required

The frequency of water application at peak summer demand must be decided at the design stage. The volume required at each application depends largely on the soil moisture deficit (SMD) at the time of application, the water-holding capacity of the soil, and the evapo-transpiration rate of the crop. Most hosereel-based systems are planned to irrigate on 5-10 day cycles at peak demand. The water volumes 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 very expensive to alter later. Allowing for later expansion, e.g. by using larger mains near the pump, is advantageous if finances will allow.

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 motor 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 hosereel irrigation, standard 150 mm Class D (12 bar) UPVC British Standard “Kite-marked” marked piping or an equivalent underground mains piping is commonly used. If the main is solely 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 hosereel equipment, the mains and hydrants are usually laid to suit the length of pipe on the hosereel as far as practically possible. Large fields may need hydrants in the middle of them, but usually they are at the side or corners of fields, alongside a farm track etc., preferably 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 within a rotation, it is normally practicable to use portable above-ground pipe.

Allowance must be made for how the farm sprayer will reach the crop without damaging pipes on the headland. Trickle mains, 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.

Irrigation layout - pumps

Many reservoir schemes now use either a single high pressure pump on a floating raft, or have a floating pump to deliver water at a low pressure to a second pump on the bank which then boosts to final mains pressure. These floating 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. Single high pressure floating pumps, with a simple connection to the mains on the bank, 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, whereas conventional fixed speed pumps may exceed the required pressure at hydrants near the pump. The additional capital cost (say £10-12,000) of the former more sophisticated controls can be set against reduced future 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

Few farms are now completely new to irrigation. However, most have the potential to improve some aspect of performance with existing equipment and can make further improvements when additional purchases are being considered.

Potentially, the most water-efficient method of application is trickle irrigation, but apart from use on high value potato crops, or where water supplies are very limited, the investment is currently difficult to justify. Added to this, some recent reports and experience suggest that potential water savings expected do not always materialise in practice.

When comparing different application systems, the factors that should influence choice 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; use on other crops, such as field vegetables
- Tied ridge machines to retain water within the rooting zone

OVERHEAD IRRIGATION

Hosereels

Hosereels operating guns and booms 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 hosereel 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.

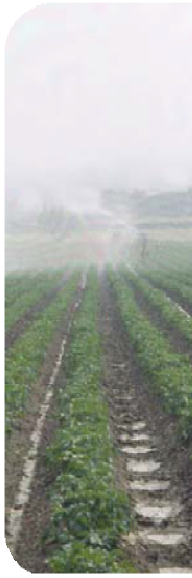
The drive for high outputs can however be overdone. In attempting to apply the maximum volume of water in a given time and so become "more efficient", many machines are fitted with large nozzles (26 mm plus), aiming for shorter wind-in times and wider lane spacings. This often proves “too much” for the mains layout; as a result the correct gun pressure cannot be achieved, resulting in very poor water distribution. An additional machine, although more costly, will give much more even irrigation. To make more efficient and more accurate use of the water, growers are increasingly looking to use booms (see below).

Raingun uniformity can be very poor due to wind, incorrect pressures or gun angles and wrong lane spacings. A Coefficient of Uniformity (C of U) - the variation in water deposition rates measured using catch cans - can be calculated. With poorly set up operations this may be as low as 45-50%, affecting crop yield and quality. However, a 75-80% C of U is feasible.

Minimise common operational problems to improve application uniformity by:

- Ensuring the irrigator is operating exactly at the recommended pressure and gun angle. Lower gun pressures mean larger droplets, which have more energy on impact, resulting in soil erosion of the potato ridges or beds.
- Using the correct lane spacing for the machine (typically 72 metres for larger hosereels) to allow, as far as possible, for cross-winds. There are practical difficulties in varying this spacing during the season to allow for cross winds.
- Using a 'sector angle' of 210° instead of the more normal 180°. This allows the gun to linger on the edges of its throw and gives improved uniformity.

- Some improvements can be made by replacing a fixed angle with a variable angle gun, which allows the trajectory of the water to be lowered, so reducing the effect of a crosswind.
- Using tied-ridge machines, forming mini reservoirs or dams down the wheeling rows or between beds soon after planting to combat soil erosion problems, where applicable. These hold the water, giving time for it to soak into the adjacent soil and by doing so, can significantly reduce run-off. Even on relatively flat ground, tied ridges can be invaluable in preventing irrigation water collecting in low areas, causing problems with blight spray application and tuber diseases.
- Maximising night-time working. The lower average wind speeds experienced at night significantly improve the overall application uniformity.
- Monitoring the in-field performance using simple measuring cylinders or catch cans, making sure the top edges are positioned above the crop canopy across the spread width. These can be used to set or confirm the working width of the machine.
- Using remote signalling systems such as mobile phonelinks to optimise application efficiency.



Booms

In recent years there has been a significant shift towards the use of booms on hosereel irrigators for potatoes. Booms offer several distinct advantages compared with a raingun:

- Smaller droplet sizes, reducing the impact effect on the soil and crop.
- Lower connection pressures leading to an improved performance from the existing pump 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 relatively modest investment overall (an annual charge of around £50-60 per hectare), a hosereel system can be significantly upgraded. It offers a worthwhile improvement in many situations for farms already committed and suited to hosereels.

Booms, however, apply water to a unit area of land over a much shorter time than a raingun. Higher instantaneous application rates therefore result, which can be a problem on silty soils, which slump ("run together"), or on sloping land. Booms are ideally suited to rectangular fields without obstructions caused by trees, electricity pylons etc. Where field shape is especially irregular and there are many obstructions, rainguns may still be the only practical option available.

Centre Pivot and Linear Machines

Some farms growing potatoes 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 potato crops around the rotation. A number of similar rectangular fields are almost obligatory to make efficient use of the gantry sections. 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 number of machines which can potentially be installed is limited.

Sprinkler Irrigation

Although most 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, unless they are fixed for the season, which is costly in terms of the amount of equipment required.

TRICKLE IRRIGATION

The main advantages of trickle irrigation are:

- Theoretically more efficient use of water than overhead systems. Actual savings are likely to depend on row spacing and other factors, including management input.
- Less energy used compared with hosereel 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 crop canopy, so eliminating potential leaf scorch.

The main disadvantages can be summarised as:

- The higher costs and the practicalities of handling re-usable trickle pipes. In practice, most growers use lower quality and less costly tape, replacing it every year.
- Separate mains and pumps or pressure regulating valves may be required when trickle systems are being run alongside an existing overhead irrigation system.
- Unless the tape is adequately buried, rabbits, hares and vermin can be a problem, causing leaks under the crop canopy which are not always immediately apparent.
- Unless care is taken, attachments of tape to mains can be ripped out by crop sprayers turning, leading to wet areas on headlands and the ends of wheelings.
- The expenditure and effort laying the tape is fully committed at the start of the season, whether it is a season which proves to need high volumes of irrigation water or not.
- For crops where common scab control is important, and this includes the vast majority of crops under trickle irrigation, it is essential to keep the soil fully moist following tuber initiation. If not, the zone of soil wetting becomes too narrow and the whole surface of developing potatoes is not kept moist. This is especially the case on lighter soil types. In a dry spring, to overcome this effect it may be necessary to fully moisten soil with overhead irrigation before beginning trickle irrigation.
- The range of tools available for accurate irrigation scheduling is much reduced.

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 been well satisfied with the results obtained and have expanded the area of crop covered. Much depends on the dedication of the irrigation manager in making the system work.

Types of tape or pipe

The lighter weight irrigation tapes are thin-walled with a welded joint, and readily collapse 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. Further variables are the spacing of emitters along the pipe, which commonly range from 0.3m to 1m, combined with a range of discharge rates, typically 2-4 litres/hour per emitter. Costs vary from say 6p to 13 p/metre. The cheaper tape for standard 90 cm potato rows amounts to around £650/ha, plus the cost of pumps, mains, header pipes, filtration, valves and possibly a mechanism to add fertiliser to the water flow.

Lightweight tapes are readily disturbed by high winds and so need to be buried to a minimum depth of 50mm, except under polythene or woven polypropylene covers, when they can be laid on the soil surface.

More durable and rigid long-life piping has pressure-regulated emitters moulded into the pipe as it is formed. Each emitter consists of a labyrinth of narrow waterways to reduce the energy of the water, allowing it to trickle out. All modern piping of this type is UV-proof and non-degradable.

Trickle layouts

Field design needs to be tailored to soil and 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 tape can work reasonably well with a slope up or downhill of 3% for lengths up to 230m. Wherever possible, it pays to run the tape down the slope to give longer runs. Pressure-regulated piping can cope with virtually any slope and 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 periodically “pulsing” the system with chlorine-based solutions. Similarly carbonate deposits should be removed with hydrogen chloride and iron deposits with hydrogen sulphide. All lines can usually be flushed by opening up the ends of the laterals.

4 Water and the Potato Crop

A typical crop of maincrop potatoes grown in England will use approximately 350 mm of water in an average growing season. Although some of this can be provided by the soil, most must come in the form of rainfall and irrigation. This 350 mm of water on a per hectare basis represents some 3,500 tonnes. A crop yielding 58 t/ha will therefore use approximately 60 tonnes of water to produce each tonne of potatoes. This section examines some of the principles underlying effective use of water in the potato crop.

The soil as a reservoir for water

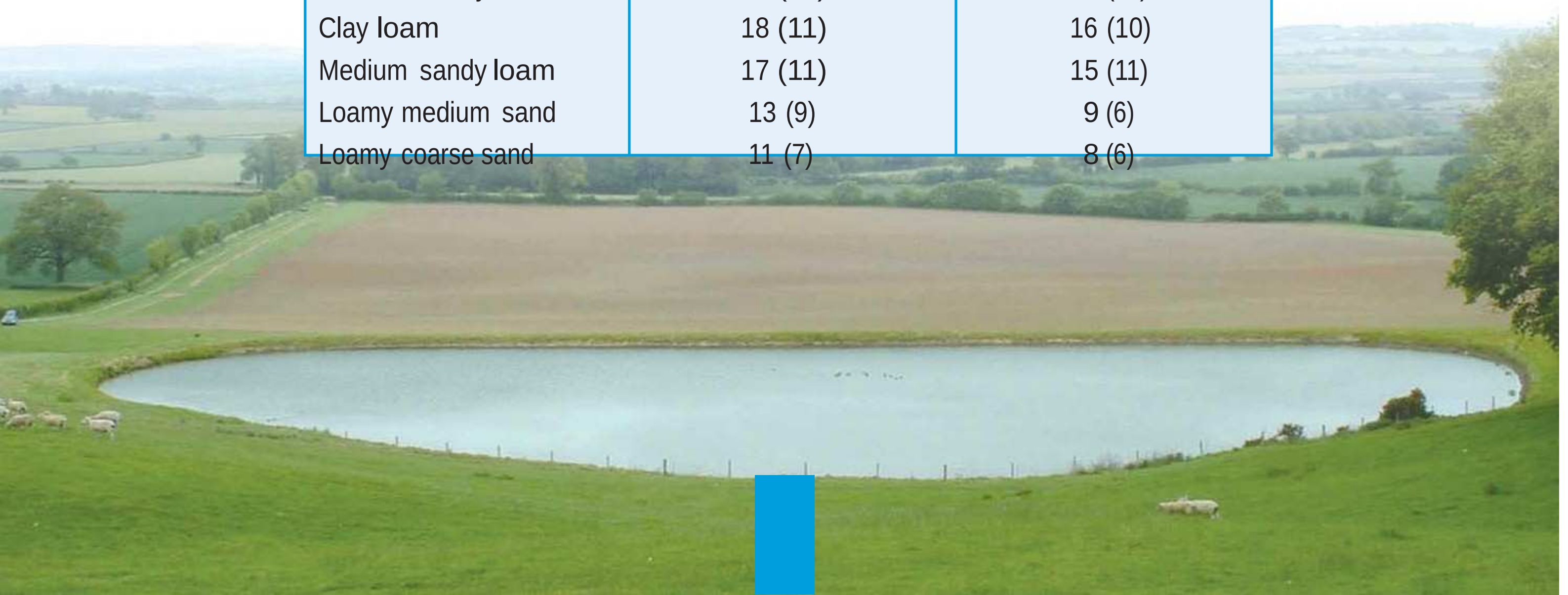
It is useful to think of the soil as a holding reservoir for water. The amount of water capable of being held in a soil depends on its texture (sand, silt, clay etc) and structure (loose, compacted etc). In a saturated soil, all spaces are filled with water. Drainage due to gravity progressively removes water from the pores of the soil. As more water is lost, so the forces holding it around the soil particles increase until equilibrium is reached. This stage is known as 'field capacity'. 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 (or SMD). Another way to look at SMD is to regard it as the amount of water required to bring the soil back to field capacity.

Soil texture and available water

Soil texture and structure affect how much water the soil can hold at field capacity. Sandy soils hold relatively little water, as their porous nature allows it to drain freely down the soil profile. Heavier soils are less porous and are able to retain more water. However, the quantity of water held by a given soil is not necessarily the same as the amount available for extraction by plants. The drier a soil becomes, the greater the difficulty a crop has in extracting water from it. The table below presents the total 'available water capacity' (AWC up to 15 bars of tension) and the easily available water capacity (up to 2 bars) for a number of typical soils in which potatoes are commonly grown.

Typical Soil Available Water Capacity

Soil Texture	Topsoil AWC % (easily available %) %)	Subsoil AWC % (easily available
Silt Loam	23 (15)	22 (14)
Medium sandy silt loam	19 (11)	17 (11)
Clay loam	18 (11)	16 (10)
Medium sandy loam	17 (11)	15 (11)
Loamy medium sand	13 (9)	9 (6)
Loamy coarse sand	11 (7)	8 (6)



4 Water and the Potato Crop

Rooting depth and soil structure

The amount of water available to a crop also depends upon the depth of rooting. A crop with deep roots is able to draw upon a larger soil water reserve than one with shallow roots. This should be considered when estimating how much water is available in the soil for crop use, as the rooting pattern of crops changes with time, increasing as the season progresses.

For the potato crop, rooting depths can vary. However, the effective maximum rooting depth of potatoes, in terms of water uptake by the crop, is commonly 700 mm.

Soil compaction will reduce the ability of roots to find water in the soil. It may also influence irrigation scheduling recommendations, as assumptions of rooting depth, and hence available water, will be false. Test digging to check for compacted layers and then planning cultivations accordingly is a wise precaution before growing crops which will be irrigated.

Yield loss and SMD

When water is lost from the soil by evapo-transpiration, the water content is reduced and an SMD develops. Water tends to be extracted from the larger pores first, because it is held less tightly by the soil. As evapo-transpiration continues, only the tightly retained water remains in the soil, and eventually the plant responds by closing stomata (leaf pores), thereby reducing water loss. As a consequence, the plant's development slows and yield and crop quality suffer. A judgement has to be taken as to when the yield/quality penalty associated with a lack of water in the soil becomes sufficiently great to warrant the application of irrigation.

Estimating available water capacity

As an example of estimating AWC, for a crop rooting to 700 mm, with 330 mm of topsoil and 370 mm subsoil, the AWC of a medium sandy silt loam would be calculated as follows:

Horizon	Depth		AWC%		Available water
Topsoil	330 mm	X	19%	=	63 mm
Subsoil	370 mm	X	17%	=	63 mm
Total					**126 mm**

It is certain that depletion of the AWC beyond 50% (63 mm in this case) would result in a significant yield penalty. Under hot, drying conditions when evapo-transpiration rates are high, a significant yield penalty would occur at a much lower SMD. This needs to be taken into account when scheduling irrigation for individual crops.

The effect of rooting depth on AWC is easy to calculate. If, for example, rooting is restricted to 500 mm, then the subsoil AWC drops to 29 mm and the total AWC to 92 mm. A shallow-rooted crop can therefore access less moisture from the soil reservoir and will drought that much easier.

Effects of drought early in the growing season

- Drought early in the growing season restricts canopy expansion and therefore light interception and yield.
- During canopy expansion the crop will not have reached its maximum rooting depth, and so the SMD at which a yield penalty occurs will be lower. Therefore, irrigation should take place at lower SMDs earlier in the season.
- In popular farming mythology is the idea that dry soils encourage root activity in their search for water. However, the experimental evidence points to the opposite effect; that is, moist soils encourage root growth (as long as soil structure is good). Therefore in dry springs, early irrigation is desirable to encourage root growth.
- There are many factors that can affect tuber number including nutrition, plant-to-plant competition and light levels at this time. Also, drought around the time of tuber initiation can reduce the number of tubers formed and the longer the period of drought, the greater the reduction in tuber number. Early irrigation therefore maximises tuber number, other things being equal.
- For the control of the blemish disease common scab, irrigation needs to be applied well in advance of 50% depletion. The aim of irrigation scheduling and application for maximum common scab control is to maintain soil water reserves close to field capacity.

Avoiding waste and pollution

The amount of irrigation that can be applied at any one time is limited by both the SMD and the infiltration rate of the soil. Growers should not apply more water than can be absorbed by the soil without drainage. For example, if irrigation is to be applied at an SMD of 15 mm there is no benefit from applying more than 15 mm of water. It is usually sensible to apply less than this, so there is spare capacity in the soil should significant rainfall occur soon after irrigation has been applied.

Well-structured porous soils such as loamy sands may be able absorb up to 100 mm of water per hour. Compacted heavier soils such as clays and silty clays are restricted to approximately 5 mm per hour, although the rate is higher when loose and well structured, which is normally the case in the potato ridge itself. The rate of application should not exceed the infiltration rate of the soil, otherwise run-off will occur.

Excess nutrient levels and leaching can increase pollution of both surface and groundwater. Accurate scheduling of irrigation water linked to sound fertiliser planning will optimise nutrient uptake and minimise possible leaching of nitrate. Growers are recommended to use RB209 (Fertiliser Recommendations for Agricultural and Horticultural Crops, 7th Edition), or PLANET software (the interactive version) as their basis for fertiliser planning.

Irrigation management when water is in short supply

At some stage in the growing season, particularly in dry years, growers may find there is a shortage of irrigation water and/or equipment to apply irrigation. If the water supply is restricted, the question arises as to whether full irrigation should continue on part of the crop, or limited amounts of water be applied to the whole crop.

The answer depends on the crop and the market for which it is intended. Irrigation increases crop yield, but crop quality is often of greater importance, because a crop that does not meet the necessary quality criteria may be unsaleable, or only saleable at a much-reduced price.

If the aim is yield, then applying relatively small amounts of water to the whole crop will give the highest overall yield. Also it might rain; if it does, the whole crop will be capable of responding.

Where the achievement of quality is just as, or more, important than yield, such as with pre-packed potatoes, it is vital that the crop is not subject to moisture stress. If limited irrigation does cause moisture stress, a reasonable yield may still be obtained, but of a quality so poor that it is much less acceptable to the market. In such cases, it may be necessary to sacrifice some of the crop in order to fully irrigate the remainder. This will ensure that both an adequate yield and quality is achieved, albeit on smaller areas, to meet market requirements.

When to start irrigating

In the last 20 years, start dates for irrigation have become earlier in the life of the crop. The main reason for this has been the increasing pursuit of minimising common scab. This applies both in the pre-pack sector, where market tolerance levels have declined markedly and also for processing outlets, where buyers are now less tolerant of severe common scab, which may be difficult to completely remove with mechanical or steam peeling.

Irrigation should normally be targeted to begin shortly after full emergence, and certainly no later than 15% crop cover, so that topsoils are close to field capacity by the time tuber initiation begins. It may not be necessary to begin this early, but it is better to have the equipment out, tested and ready for normal operation in good time.

In following this policy there is a risk of nitrogen leaching from the soil if the weather breaks down. With little ground cover, evapo-transpiration rates will be relatively low, so the risk of leaching is relatively high with soils already close to field capacity. Therefore, it would be wise to consider splitting the nitrogen application, with at most two thirds in the seedbed and the rest top-dressed around the time of tuber initiation.

When to stop irrigating

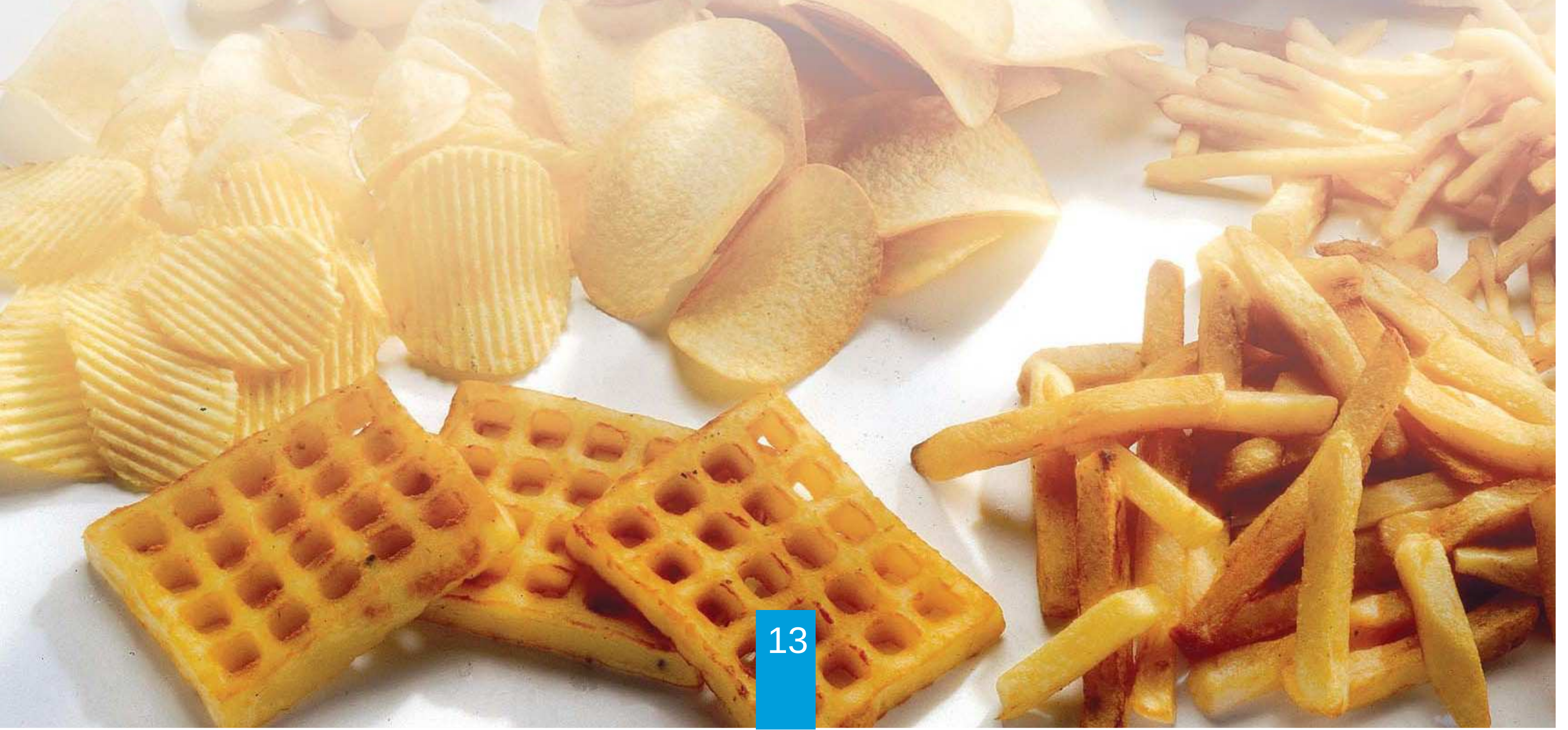
Crops lifted green-top during the summer months. It is normal for quality characteristics to be regularly monitored as the season and irrigation progresses. When the quality criteria for the intended market are met, the crop is harvested. Therefore, irrigation should continue up to within, say, a week of harvest.

Early set skin crops (bakers, punnets etc). These are normally intended for harvest as soon as possible. Irrigation helps meet the necessary quality and yield criteria, so again they should be irrigated close to the time of desiccation.

Maincrop potatoes on heavier soils. There are no hard and fast rules that should be followed and growers need to make individual judgements on a field-by-field basis. It can be considered desirable to allow an SMD to build up prior to desiccation. This provides a buffer against a certain amount of wet weather occurring in the period up to harvest. In other words, the soil can absorb a level of rainfall without becoming too wet to harvest under reasonable conditions. Set against this are the risks of increased levels of bruising and mechanical damage at harvest if soils remain dry. Also, thumbnail cracking is a greater risk when soils are allowed to dry out prior to desiccation. All in all, agronomic factors favour irrigation up to desiccation, but the desirability of harvesting the crop under reasonable conditions may be considered as the overriding priority.

Irrigation and processing quality

Many effects of irrigation on potato quality apply to all crops and are dealt with elsewhere in this Guide. In most instances, the effect of irrigation on yield is normally overriding. The effects on processing quality are regarded as of secondary importance, unless a particular aspect of quality is likely to be marginal. However, if crop dry matters are marginal and the time of desiccation is approaching, then stopping irrigation may cause them to rise if the weather stays dry. Unfortunately, this effect can be insignificant if senescence is well underway. Recent BPC-funded research has shown that if the crop is defoliated when the canopy is still very green, then fry colours are often poor out of store. In order to prevent this happening, it may be considered desirable to curtail irrigation early in order to try and induce senescence. But this can have undesirable consequences as far as bruising and mechanical damage are concerned.



5 Soil Moisture Monitoring Techniques

It is entirely possible to have the best irrigation system available but still apply the wrong amount of water at the wrong time! Optimising the use of water for both crops and the environment still depends on someone recording rainfall, checking equipment and scheduling irrigation application. It is important that responsibilities concerning irrigation management on the farm are clearly defined. A range of sophisticated techniques and tools is available to measure soil water content and schedule irrigation, to assist in optimising water use, crop yield and quality, and environmental care.

Several soil moisture monitoring methods can be used, based on different technologies. There are two broad categories: direct methods, which use various techniques for measuring the soil water content or tension and indirect methods, which rely on environmental measurements to estimate crop water loss. There are advantages and disadvantages to each method.

DIRECT METHODS

Equipment that measures soil moisture directly depends crucially on siting of equipment 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.

Neutron probes

The technique is based on the principle that when fast moving neutrons collide with hydrogen (which in the soil is largely associated with water molecules), they slow down. The neutron probe has both an emitter and a detector, the latter being used to count the neutrons slowed following collision with water molecules. By a series of calculations, an estimate of the amount of water in the soil is made.

Because a licence is required for the storage of the radioactive source, neutron probe measurements are normally undertaken by a contractor. After the potato crop has been planted, holes are drilled in the ground, commonly 3 per field, and aluminium tubes are inserted. At regular intervals during the growing season, normally weekly, the neutron probe is lowered down the tubes and readings are taken at various depths to produce a profile of soil moisture.

The technique can be accurate and is widely used by research workers to determine soil water status. Recent results from United Nations funded research suggest that when correctly used, this technique remains the best method for directly measuring soil water content.

However, the technique does present certain problems when used for scheduling irrigation. Firstly, the probe should be calibrated when the soil is at field capacity and, all too often, potato fields do not naturally return to field capacity following planting. Therefore, estimates of field capacity sometimes have to be made. Secondly, any measurement of soil moisture by neutron probes only relates to the area immediately adjacent to the access tube. Where irrigation is applied relatively unevenly, as is so often the case with rainguns, a single point reading is of limited use when trying to accurately measure the SMD. This problem can be overcome, to some extent, by taking readings from a number of areas in the field to provide a more representative picture of the soil moisture status. Thirdly, the technique does not operate well close to the soil surface, especially if the soil is dry in that region of the profile.

But when installed, calibrated and used correctly, neutron probes can provide a good measure of the quantity and distribution of water in the soil profile.

Tensiometers

Tensiometers are relatively cheap instruments that measure the tension with which water is held by the soil. The greater the tension the drier the soil. This measurement is particularly useful, as it directly relates to the crop's ability to extract water from the soil at the time the reading is taken. The tensiometer itself simply consists of a porous ceramic cup filled with water, which is placed in the soil and attached to an upright tube of water with a vacuum gauge. As the soil dries, water is drawn out of the porous cup causing a vacuum to develop in the tube. Recently, an electronic version of this system has been marketed which provides a greater range of tension readings and requires no in-field servicing.

Tensiometers are normally used in pairs, one being sited in the upper third of the root zone and the other in the lower third. As each crop has a critical tension, which is not affected by soil type, irrigation timing can be determined simply by reference to the soil tensions measured on the vacuum gauge. The aim of the system is to apply water before the critical tension is detected in the upper third of the root zone. The tensiometer sited lower in the soil profile helps to determine how much water is needed to re wet the whole soil profile.

There are three main difficulties with the use of tensiometers for irrigation scheduling. Firstly, as with neutron probes, tensiometers provide only point measurements of soil water status. Secondly, water-based manual tensiometers require a fair degree of in-field servicing during the growing season. Thirdly, tensiometers provide little advance warning of when irrigation will be required. This can affect the grower's ability to plan ahead so that irrigation equipment is available at the right time. However, if tensiometers are available, it is useful to run them alongside another system of scheduling as a check.

Capacitance probes

Capacitance probes consist of electrodes connected to an oscillator circuit. The probes are normally inserted vertically into the soil in a PVC access tube at a range of locations down the soil profile. When a signal is sent to the probe, the returning signal is altered by the water content of the surrounding soil. After calibration, the output from the probe can be converted to measurements of soil moisture. These systems have the ability to continuously monitor soil moisture changes at a range of soil horizons using a data logger and a power unit. Additionally, spot measurements can be taken with portable systems where a single probe is used to take measurements from a number of points in the field.

The information generated can describe soil moisture conditions throughout the rooting profile and thereby assist with irrigation scheduling. As with neutron probes, where irrigation is applied relatively unevenly, a single point reading is of limited use when planning irrigation. Therefore, multiple installations are required. Further, the actual volume of soil measured by these systems is even less than for neutron probes. This may lead to inconsistencies in soil of high stone content and/or variable texture. Again this problem can be addressed by increasing the number of installations in any one field.

Time domain reflectrometry (TDR) and frequency domain reflectrometry (FDR)

These techniques estimate the volumetric water content of the soil by sending high frequency pulses to parallel electrodes, which are placed in the soil. In TDR systems, microprocessors are used to measure the time taken for these pulses to travel to the end of the probes and be reflected back to their origin, which is affected by soil moisture. In FDR, changes in frequency are measured, again affected by soil moisture. This information is used to calculate the average soil water content over the length of the probes.

The accuracy of the system relies on the maintenance of a constant distance between the two probes, and a good continuous contact between the probes and the soil. Therefore, great care should be taken to ensure probes are installed correctly. If not, the readings taken tend to be a measure of the probe's contact with the soil, rather than the moisture status of that soil. As with other point measurement systems, a number of readings will be necessary to gain a representative picture of the whole field. At the present time, neither TDR nor FDR are commonly used to measure soil moisture for commercial irrigation scheduling of potatoes.

INDIRECT METHODS

Manual water balance sheet

This approach is based on the simple concept of a water balance. Water, which enters the soil as rainfall or irrigation, is treated as credit, and the water which exits as evapo-transpiration, drainage or run off is recorded as debit. The difference between the two is used to calculate the SMD. Amounts of rainfall and irrigation are recorded daily on the farm. Potential evapo-transpiration figures can be purchased in some parts of the country; otherwise they are estimated from charts.

There is a need for adjustment where crops have not attained full leaf cover, and there are several simple methods of estimating this. Unfortunately, the price for simplicity is loss of accuracy, and manual balance sheets often contain significant errors which increase as the season progresses. In practice, the biggest errors are associated with the estimation of potential evapo-transpiration. Also, most balance sheets assume the crop is able to extract water from the soil at a constant rate no matter what the SMD, whereas in fact crops have increasing difficulty abstracting water from the soil as it dries out. So if irrigation gets behind as it often does, an accumulation of errors can lead to significant inaccuracies in the estimation of SMD later in the season.

Computerised water balance methods

These are effectively very sophisticated manual balance sheets that are fully capable of dealing with the complexities which manual balance sheets can not.

There are a number of computerised systems available that use crop, meteorological, rainfall and irrigation data to calculate rates of evapo-transpiration and soil moisture deficits. They are based on a modified Penman-Monteith equation, which has been repeatedly shown to accurately predict rates of evapo-transpiration across a range of conditions.

These systems offer not only a good level of accuracy, but also release the grower from time consuming record keeping and calculations associated with the manual balance sheet. A potential problem with the technique is that they calculate estimates of soil moisture status, which are not normally verified by actual measurements. Therefore care must be taken to ensure that all the data fed into the programme are accurate (especially soil type, rainfall, irrigation applied and crop canopy development), otherwise discrepancies will arise. Often however, the least accurate figure fed in to these programmes is the amount of irrigation applied by the grower.

MONITORING SOIL MOISTURE UNDER TRICKLE IRRIGATION SYSTEMS

Trickle irrigation systems are different in that water is applied to localised areas, so the soil profile is not uniformly wetted. Also water is applied directly to the soil surface and does not wet the foliage of the crop. Both these issues can present problems when choosing an appropriate scheduling system.

As water applications are localised, the spatial variability of soil moisture is much greater than with overhead irrigation. This should be considered when using direct soil measurements for scheduling, to ensure that the assessment of soil moisture relates to the volume of soil from which the crop would normally extract water.

Problems exist for computerised systems also, as the Penman-Monteith model assumes water enters the system from above, wetting the foliage and soil surface. This influences the soil moisture calculation, as the model includes significant evaporative loss from the leaf and soil surface, which largely does not occur with trickle irrigation.

Although both approaches present problems, correctly taken and sufficiently replicated **direct** measurements of soil moisture are likely to provide the best chance of success.

It is important that irrigation from trickle systems is applied in frequent small doses. Infrequent large applications, or applications made after the soil has dried significantly, will produce pockets of saturated soil in an otherwise dry field.

6 Irrigation Scheduling

Without proper scheduling, irrigation at best becomes hit and miss, and at worst, both wasteful and crop damaging.

Scheduling has as its core a method of measuring SMD. Systems can be based on manual balance sheets, computerised balance sheets or manual plans using direct soil moisture measurement as a baseline. Scheduling requires an estimate of likely evapo-transpiration in the period ahead (normally weekly), which may range from 1mm per day or less at around the time of emergence to 4.5 mm per day or more during hot dry weather in mid-summer. Schedules will vary according to the type of crop being grown and the quality criteria required, equipment and labour available, irrigation water available and soil type. As a consequence, there is no one magic schedule suitable for all crops. Schedules need to be drawn up around the need to get tractors into the field for other purposes, especially blight fungicide application, and for overhead irrigation it is increasingly common for both irrigation and fungicide applications to be planned on a weekly cycle.

Weather forecasts

Schedules need to be tied to weather forecasts and an increasingly sophisticated range of these is available on TV and radio, over the telephone and on the internet. Forecasting future rainfall accurately remains difficult, but is an important element of scheduling.

Idealised schedules

A few idealised schedules are given overleaf, along with comments which might cause growers to modify them on a field-by-field basis. These should in no way be regarded as definitive for the crop or soil type represented, but simply examples of the types of schedule which may be adopted.

Estima for pre-packing, grown on a silt loam, with a history of common scab

	10% crop cover to 6 weeks after TI*	6 weeks after TI to mid August	Mid August to desiccation
Typical schedule	10mm @ 12 mm SMD	25 mm @ 40 mm SMD	20 mm @ 50 mm SMD
Comment	Crop free of common scab essential. Therefore, soil must be kept close to field capacity.	Main bulking period. High water holding capacity soil allows some latitude in terms of SMD at which irrigation occurs.	Significant SMD maintained as a buffer against heavy autumn rainfall turning fields uncomfortably wet.
Effect of excessive irrigation	Risk of nitrate leaching at low ground covers if heavy rain falls. Blackleg.	Disease (blackleg and bacterial soft rots, fungal rots, powdery scab).	Expanded lenticels. Disease.
Effect of insufficient irrigation	Common scab.	Reduced yield and tuber size. Coarse skin finish from uneven growth. Growth cracking.	Reduced yield and tuber size. Coarse skin finish and growth cracks. Bruising, mechanical damage and thumbnail cracking.

* TI = tuber initiation. Tuber initiation can occur at a range of crop covers (defined as the percentage of the soil surface obscured by vegetation when viewed from above). In practice, there is no substitute for digging in the field with a spade to assess when TI has actually begun.

In the above example, where the soil has a relatively high water holding capacity, it is unlikely that insufficient irrigation would have a large effect on tuber number. Where irrigation has stopped early and the autumn remains dry, irrigation prior to harvest may well be considered.

Lady Rosetta grown on a loamy sand, for crisping, off-the-field in late August

	20% crop cover to 4-5 weeks after TI	4-5 weeks after TI to late harvest
Typical schedule	20 mm @ 25 mm SMD	25 mm @ 35 mm SMD
Comment	Low level of common scab acceptable.	Low AWC soil and drought susceptible variety means that irrigation should not get behind.
Effect of excessive irrigation	Some risk of nitrate leaching at low ground covers if heavy rain falls. Blackleg.	Some risk of nitrate leaching if heavy rain falls. Disease (blackleg and bacterial soft rots, fungal rots, powdery scab).
Effect of insufficient irrigation	Excessive common scab. Low tuber number causing excessive tuber size for the intended market.	Early crop death and much reduced yield in this drought-susceptible variety.

In this example, irrigation needs to be managed cheaply and efficiently for a crop normally sold at a fixed price on contract to a crisper. Keeping this light soil, with low AWC, close to field capacity throughout means there is always the risk of some leaching during the summer months, although in practice experience suggests this is rare once full ground cover has been achieved.

Maris Piper for chipping outlets, grown on sandy loam, destined for storage

	15% crop cover to 4-5 weeks after TI	**4-5 weeks after TI to late August**	**late August to desiccation**
Typical schedule	15 mm @ 15-18 mm SMD	25-30mm @ 35-40 mm SMD	18 mm @ 35 mm SMD
Comment	Low level of common scab acceptable.	Main bulking period. Important not to stress the crop.	Moderate SMD maintained as a buffer against heavy autumn rainfall.
Effect of excessive irrigation	Some risk of nitrate leaching at low ground covers if heavy rain falls. Blackleg.	Disease (blackleg and bacterial soft rots, fungal rots, powdery scab).	Expanded lenticels. Disease.
Effect of insufficient irrigation	Excessive common scab. Low tuber number causing excessive tuber size and hollow heart at harvest.	Reduced yield and tuber size. Internal Rust Spot (IRS).	Reduced yield and tuber size. Growth cracks, bruising and mechanical damage.

Grown on a lighter soil type than the Estima, insufficient irrigation early in the growing season may well cause tuber number to be reduced. Despite the susceptibility of the variety and the lightness of the soil, common scab incidence is not as important for a processing crop as it is with Estima for pre-pack, so scab reduction irrigation can occur at slightly higher SMDs.

Irrigation can either encourage or suppress many diseases, pests and disorders of potato. The occurrence and severity of these is also affected by factors other than irrigation, including variety, seed quality, location, nutrition, soil type, field history and prevailing weather conditions. All these factors should be carefully considered when deciding on the irrigation management of each crop.

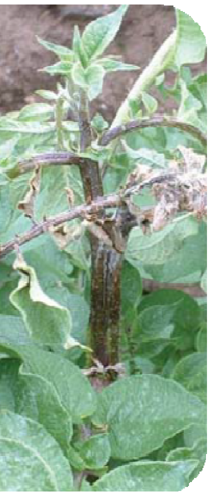
DISEASES

Common scab

Recommendation:

- **Maintain a soil moisture status close to field capacity during the 4 to 6 weeks following tuber initiation, to inhibit infection**

Common scab leads to major financial loss within the potato industry, due to the reduction in tuber quality that it causes. Symptoms range from lightly scabbed lenticels to extensively raised, angular pitted scabs. Varieties differ in their susceptibility to the disease. The disease is caused by many Streptomyces species world-wide. However, it is likely that the most common species in the UK is S. scabies, which causes the typical often superficial, but sometimes deep, corky lesions on tuber surfaces. The pathogens are Actinomycetes, bacterium-like organisms that are extremely common in soils. Seed-borne transmission is possible, but in the UK is only thought to be important in the distribution of new strains or species. Soil moisture during and shortly after tuber initiation has a dramatic influence on common scab infection. Maintaining low SMDs during this period remains the principal means of disease control. The disease is more common on light, sandy soils that have been recently limed. Reducing or preferably eliminating the risk of common scab infection is a major aim of most growers when they irrigate potatoes. A well-managed trickle irrigation system should potentially give the best control of common scab, because water is being applied directly to developing tubers on a very regular basis.



Blight

Recommendations:

- **Controlling foliage re-growth on waste potato dumps should have the highest priority**
- **Fungicide programmes should begin well before blight becomes established in the area**
- **Plan irrigation and blight control programmes to operate in harmony during the growing season**

Late blight is the most economically important disease of potatoes in the UK. It is caused by the fungus Phytophthora infestans. All parts of the potato plant can become infected. The disease cycle usually starts when an airborne spore, the sporangia, lands on potato foliage. These spores germinate, penetrate the host plant and can cause visible symptoms in as little as 3 days (under suitable conditions). One or two days after symptoms become visible, the pathogen produces new spores provided that moderate temperatures (10-25^{o}C) and wet conditions (prolonged surface wetness or 100% RH) are present. The cycle is completed when spores from those infections themselves land and infect other hosts. Spores can be washed from leaves and stems into the soil by rain and overhead irrigation. Once in the soil, these spores can cause tuber infection.

Crops with significant levels of tuber blight tend not to store well because infected tubers are often predisposed to bacterial soft rot. Crops with even trace levels of tuber blight may be difficult or impossible to sell.

Controlling foliage re-growth on dumps of waste potatoes is an extremely important part of reducing sources of primary infection at the start of the growing season. It is also important to avoid planting blight-infected seed tubers.

In the growing season, control is centred on fungicides that need to be applied prior to the arrival of pathogen on the plant. Spray programmes should be underway well before blight becomes established in the area.

Overhead irrigation can:

- Accelerate the erosion of protectant fungicides from the crop canopy, so increasing the risk of foliage infection
- Encourage canopy growth, which can dilute fungicide deposits on leaves already formed and encourage the formation of new foliage, which is unprotected until the next blight spray is applied
- Prolong periods of leaf wetness, thereby encouraging infection. In practice, this is likely to have a relatively small effect, because if irrigation is applied during high humidity conditions then the weather is already suitable for blight infection. But if applied under low humidity conditions (hot and sunny), the canopy will quickly dry out in a situation where the overall environment is already unsuitable for infection
- Wash spores already on leaves and stems down into the soil and provide suitable conditions for tuber infection. This is a very important aspect of risk. Before irrigating crops with even trace levels of foliage blight, expert opinion should be sought. Soils close to field capacity are at much higher risk of tuber infection than those which are relatively dry

Powdery scab

Recommendations:

- **Avoid planting seed infected with powdery scab in fields which will be irrigated**
- **Avoid growing irrigated crops of susceptible varieties in soils with a history of the disease**

Powdery scab is a disease caused by the fungus Spongospora subterranea. It develops best under cool, damp conditions. All underground parts of the plant can be infected. The pathogen produces pimple-like swellings that enlarge and eventually erupt, releasing spore balls into the soil. These 'scabs' if present on the tuber surface can, like common scab, severely reduce the value of the crop. Powdery scab can also cause cankers with gross deformations of tubers leading to severe losses in saleable yield. The powdery scab organism survives for many years in soil, certainly more than 15 years. It can also be transmitted via infected seed tubers, although the relationship between seed and progeny infection is often unclear. It is best to avoid the disease by planting seed free from powdery scab in uninfested soil. However, finding soil that is entirely free from the pathogen may be unrealistic in many potato growing areas. Therefore, for practical purposes, control is focused on avoiding poorly drained soils with a known history of the disease. Irrigation should be carefully managed to avoid 'pushing' soils above field capacity, taking care to weigh up the risks of common scab developing early on in the irrigation season. Varieties differ in their susceptibility to the disease.

Fungal rots (pink rot, watery wound rot, rubbery rot etc.)

Recommendation:

- **Where there is a history of one or more of these diseases in the field, irrigate to leave a significant SMD in the mid-late summer period**

Pink rot (caused by Phytophthora erythroseptica), watery wound rot (caused by Pythium species) and rubbery rot (caused by Geotrichum candidum) are all produced by soil-borne fungi. Pink rot in particular is a problem in the West Midlands where it can cause severe yield losses. The rots develop in soils approaching field capacity, especially when temperatures are high. Poor drainage or soil compaction can worsen the severity of these diseases.

Blackleg and bacterial soft rots

Recommendation:

- **If blackleg becomes a problem in a crop, consider reducing or even stopping irrigation**

Blackleg and tuber soft rots are caused by Erwinia species. These bacteria are carried in or on tubers, primarily inside the lenticels. Contaminated tubers remain symptomless until they become stressed or damaged, either in the field or during storage. Rotting is encouraged under conditions where a film of water is present around the tuber, reducing the oxygen availability, and temperatures are greater than 20°C. In the field, rotting seed tubers release bacteria into the surrounding soil. Irrigation can compound the situation by allowing the movement of Erwinia across the field. Blackleg develops when the pathogen is moved up the xylem into the stem. Bacteria can be brought from nearby potato crops or dumps via contaminated irrigation water. Overhead irrigation (and rain) can spread the disease by splash and aerosol effect. Varieties differ in their susceptibility to blackleg.

Silver scurf and black dot

Recommendation

- **Timely harvest rather than irrigation management offers a better means of disease minimisation**

Silver scurf (caused by Helminthosporium solani) and black dot (caused by Colletotrichum coccodes) are blemish diseases. They are especially important in pre-pack and punnet markets where appearance plays an important role in saleability. Infections of the tuber skin occur prior to lifting, so control centres on harvesting the crops in a timely manner. Research into the influence of irrigation on both these diseases is at best incomplete and at worst contradictory. Some reports mention an increase in disease following irrigation (possibly due to the washing of spores from infected tubers and roots to uninfected plants). However, other research shows that irrigation reduces disease because stress levels in the crops are minimised. So until definitive information becomes available through further research, it is best to focus on methods other than irrigation management to minimise these diseases, especially timely harvest.

Spraing

Recommendation:

- **Irrigation, especially for common scab control, can increase the risk of spraing, so where this disease is a threat, take necessary precautionary measures to control it**

Spraing manifests itself as brown arcs in the flesh of the tuber which, when severe, may also be visible on the tuber surface after washing. Even low levels of spraing can render the crop unsaleable. It can be caused either by Potato Mop Top Virus (PMTV), transmitted by the motile spores of the powdery scab fungus, or by Tobacco Rattle Virus (TRV), transmitted by infected 'free-living' nematodes Trichodorus and Paratrichodorus spp. In this country. it is largely TRV transmitted by free-living nematodes that we are concerned with, in relation to irrigation practice.

The brown arcs in the flesh are the tubers' reaction to virus infection. This usually occurs through feeding by infected nematodes on tubers soon after initiation. The free-living nematodes exist in light sandy soils and depend on soil moisture for movement. Wet soils, especially soon after tuber initiation, can increase the risk of spraing where TRV-carrying nematodes are present. In other words, irrigation for common scab control will increase the risk of spraing. There are large differences in varietal susceptibility to spraing, with Pentland Dell being notoriously susceptible. Nematicides are available to reduce its incidence.

Field history is a good guide to assessing risk. Although laboratory analyses are now becoming available to test for the presence of the virus in the nematodes extracted from soil, the patchy nature of the disorder in the field can mean that unless sampling is intensive, false negatives could result.

PESTS Cutworms

Recommendation:

- **Correctly timed overhead irrigation can largely eliminate the risk of cutworm damage**

Cutworms are the caterpillars of several moth species, the most common being the turnip moth (Agrotis segetum). Eggs are laid on suitable host plants, including potatoes, in the late spring/early summer. Newly hatched caterpillars initially feed on leaves but then move down to the soil where they then feed on tubers, producing relatively large holes which, viewed externally, are normally much larger than those caused by slugs. Young cutworms die in wet soil and therefore irrigation or rainfall when caterpillars are still small can and does provide effective control. Crops which receive water in the form of 10 mm or more of rain, or 20 mm of overhead irrigation when the risk is highest (often early-mid July and in a dry season) are unlikely to be at risk. It should be noted that potatoes are not as susceptible as many other crops, such as lettuce, leek and red beet. Based on our current understanding of the biology of cutworms, young larvae are washed off the foliage by rain or irrigation and are not able to resume feeding. Therefore, unless or until information to the contrary becomes available, trickle irrigation should not be regarded as providing any significant control of this pest.

Slugs

Recommendation:

- **Irrigation increases the risk of slug damage, therefore take other measures to achieve control**

Slugs cause damage by penetrating the skin of tubers and excavating cavities within the flesh. The risk of damage is increased if soil is kept moist by irrigation, and this should be considered at the crop planning stage. Varieties differ in their susceptibility to damage and, of commonly grown varieties, Marfona, Maris Piper and Estima are especially susceptible. Heavier soils are generally, though not always, at greater risk of damage. Early harvest reduces the period of feeding available to slugs.

DISORDERS

Internal rust spot

Recommendation:

- **Use well scheduled irrigation to reduce the risk of IRS**

The name Internal Rust Spot (IRS) describes the disorder well. Brown or rust coloured spots or blotches appear at random in the tuber flesh. IRS appears to be a stress-related disorder associated with restricted calcium uptake into the tubers, despite most arable soils having ample available calcium in them. BPC-funded research has shown that periods of drought can reduce calcium uptake into tubers, and therefore a well-scheduled and executed irrigation regime can reduce the risk or level of IRS. Defra-funded potato disease surveys have also shown reduced levels of IRS in irrigated crops. So whereas irrigation may increase the risk of spraing, it is likely to reduce the risk of IRS. There are varietal differences in susceptibility to IRS; for example, the crisping varieties Lady Rosetta and Hermes are apparently much less susceptible than Maris Piper and Estima. It appears that any factor which reduces calcium uptake into the plant can induce IRS, and this not only includes drought, but also nematodes, both free-living and cyst (PCN). It is therefore not surprising that IRS and spraing can occur in the same tuber together, and anecdotally, nematicide treatment aimed at controlling spraing or PCN also reduces the incidence of IRS.

Growth cracking

Recommendation:

- **Use well scheduled irrigation to reduce the risk of significant growth cracks**

High internal pressure within the tuber during rapid tuber growth, often following a period of slower growth, splits the surface tissues. Uneven water supply is therefore one of the prime causes of growth cracking. Significant rainfall and/or irrigation, which ‘push’ soils above field capacity can induce growth cracking, even in a crop with an otherwise well-managed water supply. This emphasises the need to marry, as far as possible, irrigation management to weather forecasts, although this will never be an exact science! Of commonly grown varieties, Estima is regarded as being especially susceptible to growth cracking. Droughted crops that have the stress suddenly relieved by irrigation or heavy rainfall may also exhibit growth cracking.

This disorder can also be made worse by certain viruses, especially Potato Virus Y (PVY). Where pre-harvest sampling indicates that cracking in individual tubers occurs randomly across a field or part of a field, then irregular water supply should be suspected. When all the main tubers on a plant are cracked, whereas those on its neighbours are not, then virus infection should be considered a possibility. Cracking linked to tuber malformation may be associated with an irregular water supply, but it may also be a symptom of damage caused by free-living nematodes.

Raised lenticels

Recommendation:

- **Avoid 'pushing' soils above field capacity, especially from mid season onwards**

Lenticels are the breathing pores of tubers. They can become white, raised and enlarged in partially waterlogged soil. They are, therefore, a symptom of water management that has broken down. Occasional instances of raised lenticels are inevitable where unexpected rainfall follows irrigation, but if they are a routine occurrence in irrigated fields, then the scheduling and management of the irrigation regime, and perhaps soil structure too, requires examination. Lenticels which are raised for any length of time leave obvious spots on the tuber surface at harvest, detracting from the appearance of the crop. These can then become sunken if the crop is stored in low humidity conditions, which is so often the case in refrigerated stores. It is possible too for raised lenticels to become infected with common scab in the field, further downgrading the sample. They may also become infected with bacteria, which cause soft rots.

Greening

Recommendations:

- **The right irrigation equipment operated at the right pressures can reduce levels of greening**
- **As far as possible, avoid irrigation during canopy senescence**

Greening occurs when tubers are exposed to light and produce chlorophyll. This is extremely undesirable, not only because of the appearance of tubers with partial greening, but especially because it means tubers have also been producing glycoalkaloids, which both taste bitter and are mildly toxic to humans. Greening can occur because of erosion of the ridge by rain guns, especially before full canopy development, and again as the canopy senesces. Action can be taken at the planting stage to minimise greening, in terms of depth of planting (deeper) and also in terms of ridge shape (flatter and wider) so that the erosion effects are less. During the irrigation season, erosion of the ridge is made worse by the gun nozzle being too big and the pressure at the gun too low. Where deep fissures in the ridges of heavier soils cause greening later on in the growing season, irrigation may actually close these up, at least partially, and reduce levels of greening, although a ridge-runner may be considered to be a better option.

Thumb-nail cracks

Recommendation:

- **Irrigate up to desiccation to reduce levels in susceptible varieties**

These are especially common in Estima and Desiree. Their name describes them well, in that they are the shape, size and depth of a mark that could be caused by a thumb-nail. They normally occur during harvesting and grading, when turgid tubers are exposed to drying conditions. Where this is a regular problem on a farm or soil type, it is possible that irrigation is ending too early.

Bruising and mechanical damage

Recommendation:

- **Irrigate up to desiccation and again prior to harvest if necessary, to reduce both bruising and external damage**

The risk of bruising can be made worse by ending irrigation too early in the season and allowing SMDs to rise prior to desiccation. When this happens, turgor pressure in tuber cells declines as crops have increasing difficulty extracting moisture from soils. Then, during harvest and grading, cell deformation more easily occurs, resulting in damage to cell membranes and cell walls. This leads to enzymic reactions which cause black melanin pigments to be formed, accounting for the bruises we see. Clearly, irrigation right up to desiccation will help keep tuber cells turgid and reduce the risk of bruising.

Also, stopping irrigation in order to allow an SMD to build up prior to desiccation can increase dry matters and this in itself can increase the risk of bruising.

Levels of both bruising and/or mechanical damage can be high in the absence of a cushion of soil on the harvester when conditions are dry. Carefully managed irrigation just ahead of harvest can wet-up the ridges sufficiently to alleviate these problems, often dramatically, so this technique is becoming more common in the industry. One of the keys to success is to marry irrigation application to soil type. The higher the water-holding capacity of the soil, the greater the amount of irrigation water that should be applied. This will range from 15mm on very light soils such as loamy sands to 25mm on soils with much higher water-holding capacities, such as silty clay loams. It is important not to irrigate too far ahead of harvesting; just a few hours up to 24 hours ahead is ideal. The need to keep irrigation and harvesting close together occurs because the technique tends to be used for crops already desiccated. Overhead irrigation at this time can therefore lead to erosion of the ridge and so potentially increase levels of greening. Keeping the two activities close together also minimises the risk of an unexpected breakdown in the weather making soils too wet for harvesting.

Hollow heart

Recommendation:

- **Follow a well-scheduled irrigation programme to reduce the incidence of hollow heart**

This disorder tends to be more common in large tubers (especially when they have growth cracks) and some varieties have a greater tendency towards it. Non-uniform growth as a result of irregular irrigation can increase the risk of hollow heart developing, so it follows that a well-scheduled irrigation programme will help reduce its incidence. Too little irrigation early in the growing season may reduce tuber number per plant, leading to excessively large tubers with hollow heart.

8 Water Quality

Many chemical substances can often be found in irrigation water including calcium, iron, and magnesium. Also, water can vary in its pH as a result of dissolved carbonate and bicarbonate content. These contaminants will rarely cause a problem as regards the irrigation of potatoes. The main chemical issue of water quality affecting potato irrigation is salinity. In addition to chemicals, surface abstractions and water from shallow boreholes could be contaminated with bacteria that can have implications as regards disease.

SALINITY

Recommendation: Potentially saline water sources which are used for irrigation purposes should be regularly tested for their chloride levels.

Saline water is contaminated with salt (sodium chloride). Some soils of marine origin, especially those around the Wash, naturally contain high levels of salt. This tends to be more of a problem with summer abstraction where salt becomes concentrated when flow rates in streams and rivers fall. Differences of 4 to 6 fold in the level of salt between summer and winter in irrigation water have been reported.

In addition, water pumped from salt bearing strata in some coal mining areas can temporarily lead to high levels of salt in rivers from which irrigation water is being abstracted. This is clearly somewhat unpredictable in its nature.

Chloride and scorch

The main problem with salt relates to its chloride component. Chloride can both:

- Scorch foliage directly
- Reduce water uptake by roots

Foliage scorch normally occurs where overhead irrigation takes place in bright, sunny conditions when evapo-transpiration rates are high. Here, the concentration of chloride increases as water droplets deposited on the leaf dry out. In such circumstances, night-time irrigation reduces the risk of this happening. Apart from the effects of weather at the time of and soon after irrigation, there also appear to be varietal differences in susceptibility to chloride scorch.

Chloride in the soil

In the soil, the effect of chloride is to reduce uptake of water into the roots of plants. With multiple irrigation applications of saline water, this effect will increase as the season progresses. Chloride levels of 500 mg/l should be safe to potatoes and experiments at ADAS Gleadthorpe in 1970s and 1980s showed that even at 2,000 mg/l of chloride, the yield of potatoes was higher with irrigation than without it. Approximate guidelines on the use of saline water for overhead irrigation have been given by Bailey (1990) and are as follows:

- Up to 1,000 mg/l, irrigation should normally be worthwhile
- At 1,500 mg/l, there is an unpredictable risk of scorch, but on balance it is probably better to irrigate
- At 2,000 mg/l, the risk of scorch is quite high; irrigate only if the situation is considered desperate

Recommendation: These guidelines should be considered for single applications only and not be regarded as suitable for repeat applications throughout the season. From the point of view of water storage planning, an average chloride concentration of no more than 400 mg/l in a reservoir should be considered.

Clearly trickle irrigation does not involve applying water to the foliage and therefore the risk of leaf scorch is removed. In such situations it will be possible to irrigate at higher levels of chloride than with overhead irrigation, although there is the risk of clogging of emitters from salt crystalisation.

Soils with high chloride levels following irrigation with saline water rely on winter rainfall, in excess of that required to bring the soil back to field capacity, in order to leach the chloride below the rooting zone of arable crops. This normally occurs, but may not do so when an exceptionally dry winter is experienced. In such circumstances, it would be wise to seek expert advice, which is likely to include an assessment of soil conductivity.

TRACE ELEMENTS

Suggested maximum trace element concentrations in irrigation water are shown in the table below. At these levels it would be considered safe to irrigate crops for well over 50 years without exhausting the soil's ability to absorb them.

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

Source: Defra (MAFF Leaflet 776 (1981))

Boron toxicity is possible where water (e.g. river water) contains high boron levels originating from detergents. Potatoes are moderately sensitive to boron and the total amount per season applied to a potato crop should not exceed 3 kg/ha.

Recommendation: **Where seasonal irrigation demand is 100 mm of water, the safe boron concentration is 3 mg/l, but where the irrigation demand is 200 mm, the safe boron concentration reduces to 1.5 mg/l.**

MICROBIOLOGICAL CONTAMINATION

The main microbiological water contaminant of significance to potato production is Ralstonia solanacearum, the bacterium that causes brown rot. However, Clavibacter michiganensis, the cause of potato ring rot, whilst not considered to be present in UK watercourses, can be transmitted via contaminated potato washing water. Both brown rot and ring rot pose serious threats to UK potato production and vigilance is required to prevent further introduction and spread.

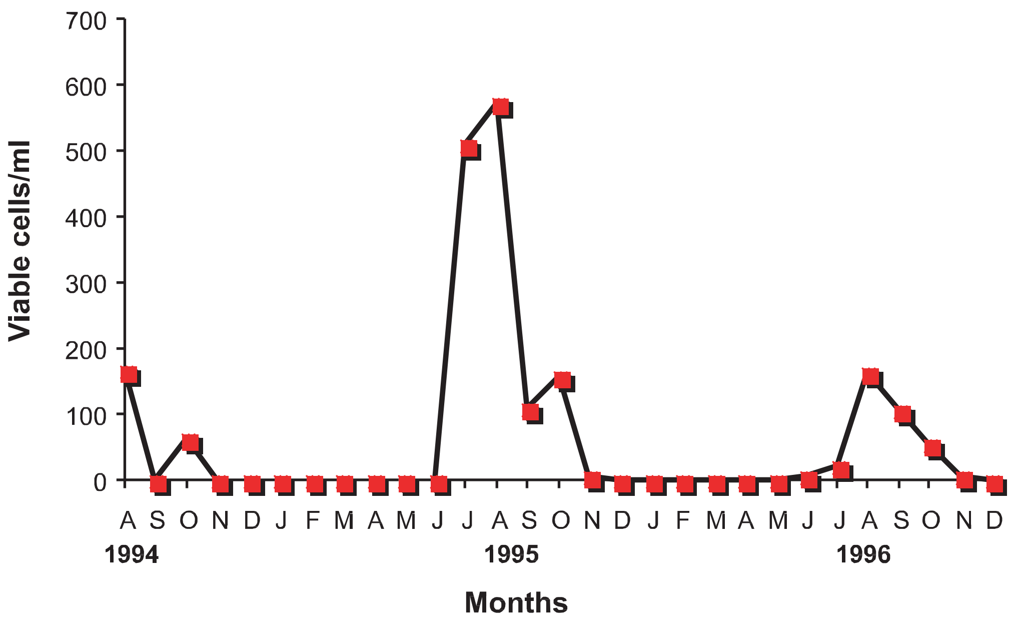
Brown Rot *(Ralstonia solanacearum)*

Brown rot has quarantine status in the EU to restrict its spread. The pathogen has entered GB watercourses, possibly in industrial or municipal effluents containing potato washings, and has become established in the weed host, woody nightshade (Solanum dulcamara), which commonly inhabits river banks. Transmission to potatoes (and tomatoes) can then result from irrigation using contaminated river water. Both irrigation and spraying with water from watercourses 'designated' as contaminated by Defra's Plant Health and Seed Inspectorate (PHSI) has therefore been prohibited. Official measures ensure that regular surveys identify the limits of pathogen distribution within the EU and that potato crops are not irrigated or sprayed with infected surface water. In the UK, collaborative work has been undertaken to attempt to find practical tools to effectively monitor and control the brown rot bacterium. This work has included the eradication of woody nightshade from infected watercourses.

Winter abstraction and storage in relation to brown rot

Water may, with the prior agreement of PHSI, be abstracted from designated watercourses during the winter months (when pathogen populations fall below detectable levels - see Fig 1) and used to fill reservoirs for potato irrigation the following season. The pathogen survives for only a few days in reservoirs provided they are kept free from host plants such as woody nightshade. It is a requirement that reservoirs filled from 'designated' water courses are inspected by PHSI to confirm the absence of the aquatic host plants and the water sampled to confirm the absence of the brown rot bacterium.

Fig 1. Seasonal population dynamics of R. solanacearum
- in river water at a single point downstream from infected Solanum dulcamara.



Source: CSL

Water treatment methods

A number of measures can reduce the risk of transmission of the brown rot bacterium during irrigation. In cases where watercourses have been designated as contaminated with the organism, such water can only be used with the written authority of a PHSI inspector, who must be satisfied with the water treatment process.

Filtration of water through reed bed systems and slow sand filters has been shown to remove contaminating bacteria.

Two chemical treatments have been shown to effectively kill the brown rot bacterium through rapid oxidation. Dosing should ensure a critical residual level of chemical agent is maintained over a minimum reaction time throughout the volume of water being treated. Peroxygen, a hydrogen peroxide-based chemical, can give complete control of the brown rot pathogen provided a residual level of at least 4 mg/litre is maintained for a minimum of 2 minutes. For example, this can be achieved by injecting irrigation water during pumping (at 15-35m^3/hour) with a commercial formulation.

Removal of the brown rot bacterium is also possible by treating water with 0.1 mg/litre of residual chlorine dioxide.

Ring Rot (Clavibacter michiganensis)

The ring rot bacterium, which also has quarantine status in the EU to restrict its spread, is primarily transmitted via infected seed tubers. Plant to plant spread occurs through direct contact with contaminated surfaces. There is some indication that spread of the pathogen is increased through waterlogged soils. However, the bacterium is relatively short-lived in water. Therefore, given that there is no secondary aquatic host, the spread of C. michiganensis through surface irrigation water is unlikely to be as important as for the brown rot bacterium.

Human pathogens

It is possible for irrigation water to provide an entry point for disease-causing bacteria such as E. coli into the food chain. This is of much greater significance where crops are eaten raw, including salads. However, this is less important with potatoes, which are cooked prior to consumption. Nevertheless, a common sense attitude needs to be taken to minimise any possible risk from contamination of irrigation water. Irrigation water abstracted from deep boreholes is likely to contain fewer pathogens. Also, water abstracted from rivers and stored in reservoirs prior to application will show a decline in pathogen levels with time. Some crop production protocols require laboratory testing of irrigation water for human pathogens.

Blackleg

Blackleg, caused by Erwinia bacteria, can be spread in irrigation water sourced from surface abstractions. Probably the biggest area of risk relates to drainage from potato dumps, and therefore the isolation of waste potatoes from possible sources of water abstraction should be an integral part of any crop hygiene plan. When irrigating from rivers or reservoirs, floating pumps should be the norm, to avoid drawing silt, which may be contaminated with Erwinia, into the irrigation water.

9 Irrigation Auditing

Growers recognise the value of irrigation and the benefits that it can bring. Most are improving the efficiency with which it is applied to crops. A review of water use for irrigation each season is recommended and may be required in future to ensure that all water is used in an effective and responsible manner. It is probable that efficiency of water use on the farm will be assessed when licences are reviewed.

Where extra land is taken on, or when major changes to the irrigation 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. Especially identify peaks in demand for water
- Ensure the overall irrigation system is capable of meeting the anticipated demand
- Estimate accuracy and uniformity of application. In particular, check the relationship between what the meter says has been applied and what was planned to be applied. Where these are at variance with each other, then application methodology requires revision
- Review the irrigation scheduling system. Were data inputs accurate? Is the system delivering the required information and is it cost-effective?
- Assess the effects of the irrigation regime achieved on crop quality, pests, diseases and disorders - plan adjustments if necessary
- Ensure compliance with legislation and customer crop production protocols
- Ensure application equipment minimises water loss, soil erosion, run-off and leaching whilst maximising crop response
- Operate a programme of equipment maintenance which includes underground mains, where these have been installed
- Ensure that staff involved are adequately trained and fully understand their respective responsibilities.

10 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 management of water resources and water pollution. The new European Water Framework Directive and the Water Act 2003 will undoubtedly have an increasing influence on water availability and its management by growers.

Enforcement

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

The EU Water Framework Directive (2000/60/EC) came into force in December 2000 and has now been incorporated into UK law. The Directive covers both pollution and water resource management and aims to bring together various EU Directives relating to water. It requires the development of River Basin Management Plans (RBMPs) which will involve strategies for regulating water use.

Water Resource Management

Dry summers during the 1990s highlighted regional water shortages in various parts of the country. The Water Act 2003 aims to improve protection of the environment and provide a more flexible process of regulation. It will change the licensing system (under the Water Resources Act 1991) in several key areas including:

- Trickle irrigation, which in the past has been exempt from licences will now need a licence.
- Similarly, dewatering of mines, quarries etc which has also been exempt from licences, will now need a licence.
- Barriers to trading water licences will be reduced.
- Abstractors will have a responsibility not to let their abstraction cause damage to others.
- If an existing ‘permanent’ licence is causing serious damage to the environment it may be varied or revoked without compensation after 15 July 2012.
- Existing licences can be revoked without compensation if they have not been used for 4 years (previously 7 years) unless non-use is an agreed part of the licence, for example if a crop rotation is itself long.
- New licences will not have to specify the land on which abstracted water can be used but will have to specify the purpose for which the abstraction is made.

Some changes have already been introduced and the rest are expected to occur in 2005/06.

The efficiency of water use will also be assessed when time-limited licences are reviewed, so it is important that growers do implement documented irrigation audits as a matter of farm policy.

11 Sources of Information

Useful References

Legislation, guides and codes of practice

Defra Publications:

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Websites of Relevant Organisations

Defra	www.defra.gov.uk
ADAS	www.adas.co.uk
BPC	www.potato.org.uk
Environment Agency	www.environment-agency.gov.uk
NIAB	www.niab.com
PLANET	planet4farmers.co.uk
The Stationary Office	www.tso.co.uk
UK Irrigation Association	www.ukia.org
TAG	www.thearablegroup.com

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