Published May 2015

EARLY-SEASON IRRIGATION

INTRODUCTION

BACKGROUND

Potatoes receive 54 % of all water applied as spray irrigation in England & Wales[1] and numerous factors have led to increased irrigation usage in recent seasons. With less predictable weather patterns, the majority of the potato area is now grown on lighter soils to aid cultivations and harvesting, however these sandy and loamy soils require larger amounts of irrigation than heavier soils. The main driver for early-season irrigation in the UK has been tuber quality and levels of tolerance for common scab in both the pre-pack and processing sectors have declined markedly. Common scab is one of the main diseases that can affect quality in potatoes where irrigation is either unavailable or limited. Annual losses from the ware crop have been estimated at £3M for common scab[2].

PATHOGEN AND DISEASE DEVELOPMENT

Published May 2015

Streptomyces scabiei and other pathogenic *Streptomyces* species are the causal organisms for common scab and are widely distributed and thus a threat in almost all soils. *Streptomyces scabiei* infects the tuber by invading undifferentiated lenticels of the developing tuber. Initially the lesions are so small they often go unnoticed. The infected areas of tissue respond by developing a corky layer of suberized tissue. As the tuber grows, the lesions enlarge and as each layer is invaded by the scab organism through cracks or tears, new cork formation takes place until a mature scab lesion is produced. If no scab is visible 4 weeks after a tuber initiates (*c*. 35 mm diameter tuber), it is unlikely that infection will subsequently occur unless the periderm is ruptured e.g. through cracking. Often, growers miss the pin-head-sized lesions at this stage and these lesions can increase significantly in area as the tuber expands . Varietal resistance can effectively limit development of the disease but in the driest years, infection can occur even in highly resistant varieties.

IRRIGATION PRACTICE

The use of irrigation following tuber initiation (TI) has long provided an effective control measure where properly applied[3]. Scab-forming *Streptomyces* can multiply significantly on developing tubers and in the surrounding soil in the 2-4 weeks after TI, a key time for common scab control. With a few exceptions, irrigation should be targeted to begin when the first plants tuberize (around 2-3 weeks after emergence), to ensure that the ridge or bed is close to field capacity by the time TI occurs in the majority of plants.

RISK OF OVER-WATERING

Many growers routinely under- and over-irrigate, owing to the fear of common scab and the poor distribution of water from rainguns. Although precision irrigation systems such as solid-set sprinklers and drip have been around in the UK for over 30 years, they are still in the minority and around 76 per cent of the industry still use a hosereel and rain gun[1]. This often results in more water than is needed being applied during scab control to ensure water reaches the majority of the crop in a particular field and even the best growers frequently apply more water than is needed. There has been a shift towards booms over the last 15 years as a means of addressing poor uniformity from rainguns. It is important that the right balance is struck, as while striving for adequate soil wetness during scab control, over-irrigating can occur leading to detrimental effects such as growth cracking, lenticel eruption, internal rust spot, processing quality and tuber disease (e.g. blackleg and powdery scab).

ALTERNATIVE CONTROL

With increased restrictions on water abstraction, climate change and pressure for sustainable production, alternative approaches to the control of common scab would be beneficial but have not yet proven successful or consistent[4]. By making more effective and efficient use of existing irrigation water, resources will be extended and add value to crops.

NEW FINDINGS

The recently-completed AHDB Potatoes-funded Project R448[5] assessed how irrigation reduces the population build up of pathogenic *Streptomyces* on tubers in a range of varieties. It also evaluated how soil structure within the ridge or bed influences the optimal irrigation regime.

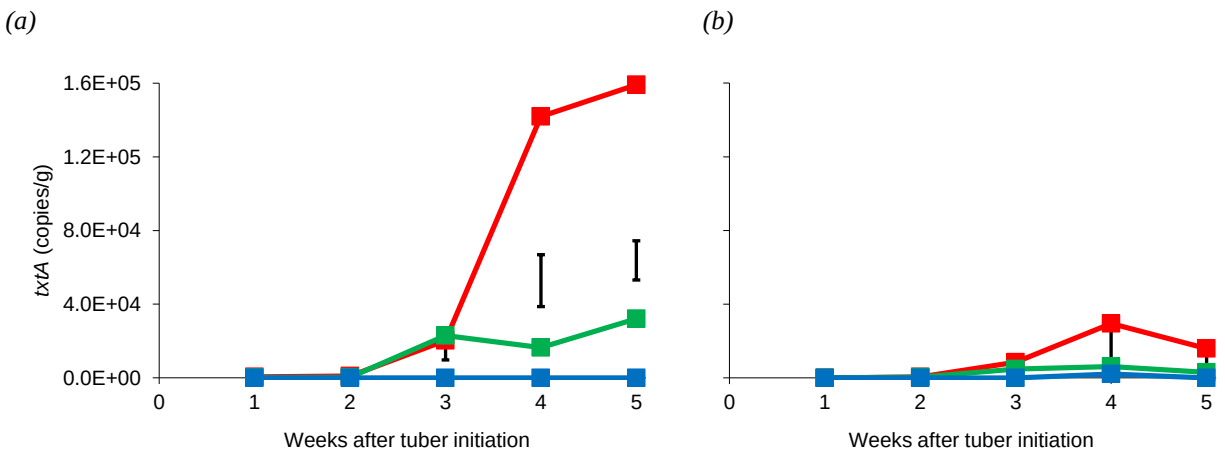
PATHOGEN DEVELOPMENT

There is a balance in maintaining the soil at the correct moisture content. In very wet soils, *Streptomyces* populations can often be undetectable on the tuber surface and measureable pathogens often cannot be detected until 2 weeks after TI. Peak pathogen populations are often found around 4 weeks after TI and generally decline thereafter[6]. In Project R448, there was a large range in pathogen populations on tubers between susceptible and resistant varieties, which supports the theory that one mechanism of varietal resistance could be the suppression or inhibition of pathogen growth.

VARIETAL SUSCEPTIBILITY

Project R448 has provided a better understanding of the optimal water requirements for a wide range of commonly-grown varieties, with the aim of providing growers with information to reduce losses of water and nitrogen and improve profitability. Maris Piper, which currently accounts for 16 per cent of the GB potato area[7] is the most suspectible variety to common scab and is the only variety with a '1' rating (very susceptible) for common scab in the Potato Council's Variety Database[8]. The industry has traditionally taken a blanket approach to irrigation for each variety as if it were the most suspectible. The project has positioned the most susceptible varieties (and those which develop the highest pathogenic *Streptomyces* populations), such as Maris Piper, into Group 1, with Group 3 containing varieties with low susceptibility which develop low pathogen populations (e.g. Vales Sovereign; Figure 1). Group 3 varieties such as Electra, Lanorma, Orchestra and Vales Sovereign) have high resistance rankings of '7' and '8' in the Potato Council Variety Database[8]. However, there are varieties placed in Group 2 with rankings of '7' e.g. King Edward, Melody and Sylvana where the irrigation schedule is more critical, so the Potato Council rankings may act as guide to the scheduling Group but may not correlate perfectly. With Group 3 varieties, it is possible on sandy soils to irrigate at a higher soil moisture deficit (SMD) and extend irrigation intervals to 7 to 10 days for scab control and beyond 10 days in heavier silt or clay soils (Table 1). The target market is also critical, as although a variety such as Maris Peer could intrinsically be placed in Group 2, in practice it needs to be managed as a Group 1 variety, due to very low tolerance for blemishes in the salad sector.

Figure 1. Pathogenic, thaxtomin-eliciting (*txtA*) *Streptomyces* populations in *(a)* Maris Piper; *(b)* Vales Sovereign. Unirrigated, ■; 25 mm SMD, ■; 0 mm SMD for 3 weeks from TI, ■. S.E. based on 10 D.F.



Published May 2015

Table 1. Maximum soil moisture deficit (SMD, mm) for common scab control in different groups of varieties

	Group	1. Susceptible	2. Intermediate	3. Resistant
Soil texture	Varieties	Maris Piper(1) Maris Peer (5)	Charlotte (4) Desiree (4) Estima (6) Exquisa Flair King Edward (7) Marabel† Melody (7) Nectar (6) Rooster (6) Sylvana (7) Safari† (4) Venezia Vivaldi (5)	Bute (4) Electra (8) Elfe Jelly (6) Lanorma (7) Orchestra (8) Perline Regina Vales Sovereign (7) Volare (5)
Sand		9.8	14.6	18.8
Loamy Sand		12.0	17.9	23.1
Sandy Loam		13.4	20.0	25.8
Sandy Silt Loam		14.4	21.5	27.7
Silt Loam		16.3	24.3	31.4
Clay Loam/Clay‡		14.4	21.5	27.7

Notes:
SMD for top 25 cm of ridge and stone-free ridge profile. This can be calculated by water balance ('model'), directly measured or converted from soil water tension.
†Marabel and Safari: tentative.
‡Excessively cloddy soils may need to be maintained at a smaller SMD.
Values in () are Groups for common scab resistance in Potato Council Variety Database. 1 = most susceptible, 9 =fully resistant.

DURATION OF IRRIGATION FOR SALAD VARIETIES

The recent work also resolved one of the issues of irrigating salad potatoes where, owing to the small size of tubers, the crop remains at risk from common scab infection much longer than in maincrops. It appears that 6 weeks' control rather than 8 weeks is sufficient, even in Group 1 varieties and the period can be as short as 4-5 weeks in more resistant (Group 3) varieties. Shortening the control period will improve the rate of skinset and reduce disease (e.g. blackleg and black dot) as soils can be allowed to dry out more prior to desiccation.

USE OF DIAGNOSTICS

Knowledge of which fields would be likely to give rise to a high or low incidence of common scab could assist in making decisions on site selection or which variety to grow in a particular field. It is unlikely that a test based solely on the levels of scab-forming species in the soil before planting will usefully predict the likelihood of disease since it is common for undetectable levels of pathogenic *Streptomyces* to be found in soil samples taken pre-planting.

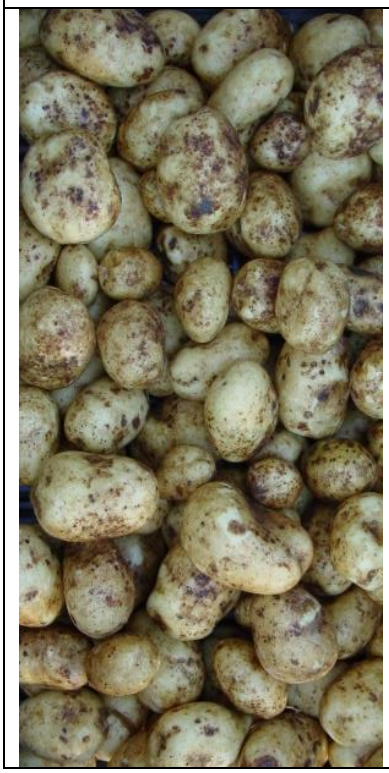
Although still in the experimental stages, new DNA-based tests, developed by FERA, can quantify the populations of common scab pathogens and interacting beneficial soil microflora and also help distinguish between the various species of scab-forming organisms. Work by Thwaites & Stalham[9] showed that populations of the bacterial orders *Flavobacteriales* and *Acidobacteriales*, that may be responsible for inhibiting *Streptomyces*, were higher in frequently-irrigated plots than in unirrigated ones. In a subsequent study in 2009, the two main orders of potential bacterial antagonists that were found to increase dramatically in irrigated soils were *Flavobacteriales* and *Bacillales*. In a smaller- scale study reported by Thwaites & Stalham (2010)[9], *Pseudomonadales* was up to ten times more abundant in irrigated than unirrigated plots. Unfortunately, whilst Project R448 demonstrated differences in populations of the major bacterial phyla *Actinobacteria*, *Bacteroidetes*, *Proteobacteria* and *Acidobacteria* in soils used for experiments, no clear correlation with common scab severity was found. There was also no apparent link between bacterial community structure and levels of pathogenic *Streptomyces*, so clearly our understanding of the control agents is, at present, weak but is worthy of further research.

PRACTICAL RECOMMENDATIONS

MANAGING SOIL MOISTURE

It is essential that soils are wet at TI for adequate control of common scab in susceptible varieties. Populations of pathogenic *Streptomyces* on the surface of the tuber increase rapidly after TI, with the increase being faster in dry soils than in wet. They can be suppressed very significantly with good irrigation management. Changes in soil water content during the first 2-3 weeks after initiation are critical in changing the populations of *Streptomyces* and there appears little difference or change in the populations between unirrigated and irrigated treatments after 4-6 weeks. Previous work by Lapwood *et al*. (1971)[3] and Stalham & Firman (1996)[10] has shown that only irrigating for 2 weeks after TI results in worse common scab than maintaining wet soil for 3 or 4 weeks. Ceasing irrigation at this critical stage allows pathogens adequate moisture to multiply but the suppressing populations of antagonists are not provided with sufficient moisture to inhibit *Streptomyces* in the later phase of infection. In most varieties, daily irrigation has proven no better than well-timed and distributed water applied at 3-6 day intervals (Figure 2), which offers potential savings in water application and drainage losses.

Figure 2. Effect of irrigation regime on common scab severity in Maris Piper

Unirrigated	Irrigated every 4-6 days for 4 weeks post-TI	Irrigated daily for 4 weeks post-TI
		

SCHEDULING FOR DIFFERENT VARIETIES

Irrigation regimes for common scab should be adapted according to varietal susceptibility (Table 1). The most susceptible varieties should not be planted in fields where high severity of scab has been previously recorded and irrigation has proven to be ineffective in controlling the disease. Often, poor scab control in irrigated fields is a result of incorrect timing (start date and frequency of irrigation), variable emergence which delays the end of scab control, poor infiltration into the ridges as a consequence of poor structure or capping or uneven irrigation distribution.

TIMING

If the soil is dry, start irrigation when the first plants begin to initiate tubers to allow time to complete watering the field before the majority of plants have tubers. Dig up the largest (earliest-emerging) plants to judge when to start irrigation. This will be 16-19 days after emergence in most varieties.

Irrigation should be scheduled using an accurate, validated measurement system and may be required every 3-6 days, depending on rainfall, evaporative demand and application amount. Soil moisture deficits for triggering irrigation in susceptible varieties (Group 1) range from 9 mm (sand) to 17 mm (silt loam), with a proportionate increase in allowable SMD for less susceptible varieties (Table 1). This low SMD should be maintained for 3-4 weeks after TI in maincrop varieties. Protracted emergence (i.e. greater than 10 days

from first plants emerging to 90 % of plants emerged) will lengthen the control period required. Since the target is to control moisture within the tuber zone, SMDs should be measured or modelled in the uppermost 25 cm, effectively ignoring the water content of soil deeper in the profile as there will be adequate water for growth with a well-maintained scab regime.

DELAYED START IRRIGATION

For all varieties other than Maris Piper, delaying start of irrigation until 1 week after initial TI will produce equally good control of common scab to commencing irrigation at TI. Delayed-start irrigation timing should be based on initial TI as using the date of 50 % TI in variably-emerging fields could allow significantly more scab infection and there needs to be sufficient irrigation capacity to water all fields at their critical phase.

PRE-IRRIGATION

Infiltration of water into hydrophobic or capped soils is often poor when irrigation commences and in these situations, watering should begin 1-2 days before the initial irrigation is due but no further ahead than this as the soil surface will dry out again, reducing infiltration rate into the ridge. Inspection may reveal that ridges may be dry following this initial irrigation and a repeat application may need to be made within 2-4 days to wet the ridge adequately.

DURATION OF IRRIGATION FOR SALAD VARIETIES

A 6-week period for scab control is sufficient in susceptible varieties such as Maris Peer and Charlotte and a 4-5 week period in less susceptible varieties such as Perline, Regina or Venezia.

DRIP VS OVERHEAD

Hosereel-raingun irrigation often leads to over-watering in an attempt to avoid dry areas. Boom irrigation improves uniformity of scab control but is restricted in some fields owing to topography, layout, 'field furniture' and soil type. Drip irrigation can place water in the target area very effectively providing emitter spacing and soil conditions are suitable. There has been a move towards a single drip line per bed for processing crops but in packing crops adequate scab control is only achieved when each row has a drip line. In sandy or cloddy soils, or where the emitters are widely-spaced (e.g. 40 cm), it is difficult to create lateral flow of water to reach the edges of ridges where tubers are at risk from common scab[10]. 'Pulse' irrigation (i.e. 3-5 small doses per day) and narrower emitter spacing (e.g. 15-20 cm) can help if the system pressurizes quickly but potential savings in water are often undone by watering for too long at each application.

SOIL STRUCTURAL CONDITIONS

Fine soil structure ensures good soil contact with the surface of developing tubers and maintains films of water which encourage growth of antagonist to suppress *Streptomyces* populations. Fine-textured (e.g. silty) soils are conducive to keeping the surface of the tuber moist and reducing scab infection unlike sandy soils or soils where the clay content leads to clods. Large aggregates leave large air voids which drain rapidly, providing a dry environment for the scab organism to thrive.

However, care should be taken to ensure soils are not over-cultivated at planting, particularly during destoning, declodding or bed-tilling. Excessively fine seedbeds, or those where fine soil particles are deposited at the base of the ridge during destoning or declodding, can impede drainage and lead to

increased risk of waterlogging and powdery scab and do not result in better control of scab. This has been substantially supported by work conducted in Project R459[11].

SCHEDULE AFTER SCAB CONTROL PERIOD

The allowable SMD during the scab control period can be increased to a value suitable for preventing yield loss (e.g. 30 mm in sands to 50+ mm in silty or clayey soils) immediately the control period is over. Unless the soil is kept above field capacity for substantial periods during the control phase, there is little evidence that frequent watering impedes root growth thereby leaving the crop more susceptible to drought later in the season.

EFFECTS ON CANOPY GROWTH

Commencing irrigation in the week before TI and maintaining soil close to field capacity (zero SMD) has often been found to increase the initial rate of canopy expansion compared to starting at TI and maintaining more moderate SMDs (e.g. 12-15 mm). However, the differences in overall canopy duration between very frequent irrigation and moderate SMD regimes are often small at the end of the season, with little or no consequential effect on yield and there is great potential to over-water by commencing so early in the crop's life.

RISK OF OVER-WATERING

Over-watering and maintaining the soil above field capacity during TI and the scab control phase should be avoided as this increases the incidence of tuber cracking and lenticel eruption, increases the spread of powdery scab, blackleg and other rotting diseases, reduces nitrogen uptake and promotes early senescence and yield loss in some varieties. Careful monitoring of soil water status is therefore recommended to avoid over-watering.

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