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POTATO LINK
AUSTRALIAN POTATO INDUSTRY EXTENSION PROJECT

MATCHING IRRIGATION TO CROP GROWTH

By Dr Jenny Ekman

Water is not free, and neither is distributing it across a paddock or pivot. There are huge potential gains in yield and dry matter from managing water correctly, so control and accurate management of irrigation should be a top priority for all growers.

SUMMARY

- Too little moisture affects yield more than too much moisture
- The affects of water stress vary at different crop growth stages
- Tuber initiation and tuber bulking are critical times for irrigation to be just right
- Water stress during tuber initiation can seriously affect quality
- Water stress during tuber bulking has the greatest impact on yield
- Too much soil moisture can increase disease and may reduce specific gravity
- Potato plants prefer smaller amounts of water often to avoid water stress, compared to large, less frequent irrigation events
- There are many devices available to monitor irrigation and soil moisture

Potatoes have a relatively shallow root zone and are highly sensitive to water stress. They are often grown on soils with low water-holding capacity, which makes irrigation management difficult. Too much water increases disease and reduces quality, while too little water reduces productivity, yield and nutrient uptake.

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Figure 1. Effect of water stress at different growth stages of potatoes. Derived from Obidiegwu et. al. 2015[1]

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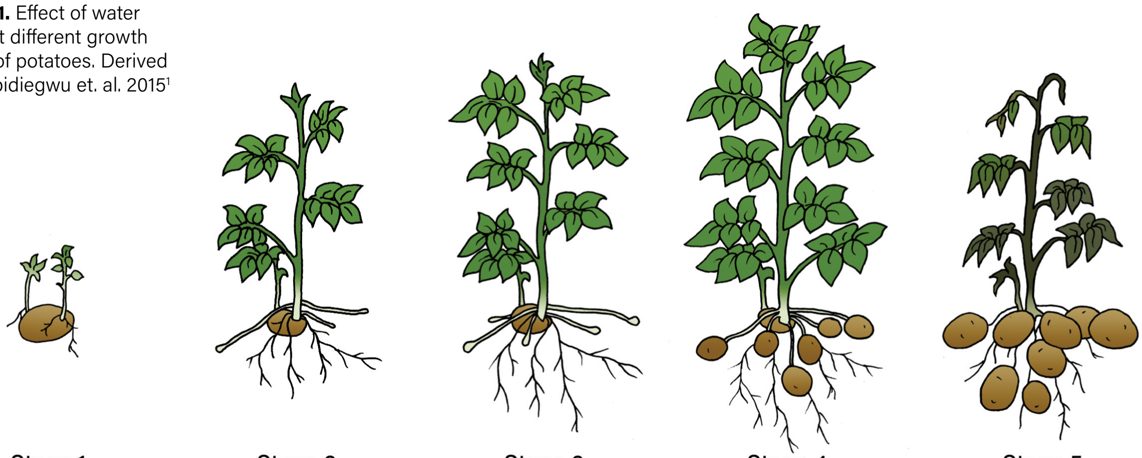


Stage 1 Establishment	Stage 2 Stolon initiation	Stage 3 Tuber initiation	Stage 4 Tuber bulking	Stage 5 Maturation
• Delayed emergence • Root growth reduced • Reduced plant development	• Reduced plant development • Fewer stolons initiated • Reduced root growth • Reduced nutrient uptake	• Reduced plant growth • Reduced number of tubers • Tubers deformed • Risk of sugar end • Tuber dry matter reduced	• Reduced leaf canopy • Reduced root growth • Smaller tubers • Tubers deformed • Early senescence	• Lower dry matter tubers • Blackspot bruise during harvest • Clods at harvest

POTATO DEVELOPMENT

Irrigation requirements change as the potato plant grows and matures (Figure 1). Understanding growth stages is essential to understanding the water needs of the crop. Physiological development of potato plants is commonly divided into five stages (Figure 2).

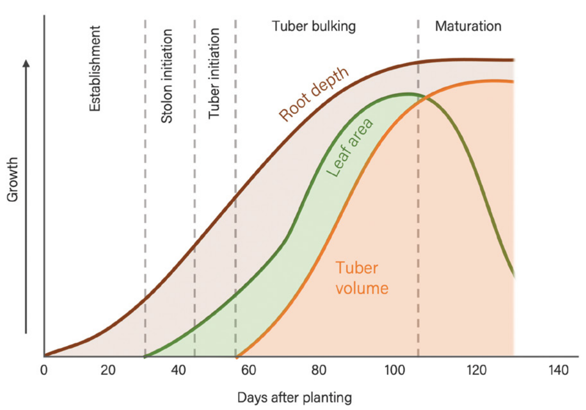
WHAT IF PLANTS HAVE TOO LITTLE WATER?

The first physiological response to water stress is closure of the stomata (breathing holes) on leaves. Moisture inside the leaves evaporates through open stomata (Figure 3). This cools the leaf canopy to keep temperatures below ambient air, but also results in moisture loss[2].

If the plant closes stomata to reduce moisture loss, then carbon dioxide movement into the leaf is also reduced. This inhibits photosynthesis, limiting accumulation of starch and sugars. Potato yield and quality (e.g. specific gravity) depend on photosynthesis exceeding the everyday energy needs of the plant to allow storage of excess carbohydrate in the developing tubers.

Water deficits also reduce the plant's internal pressure. Sufficient pressure is necessary for cell expansion and growth. Leaf canopy and root growth can be significantly

Figure 2. Potato Plant development stages



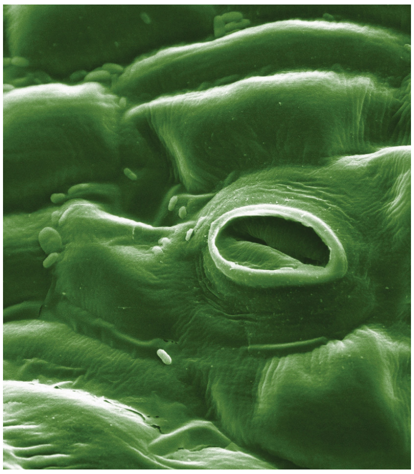


Figure 3. Stomata control gas exchange between cells inside the leaves and the outside environment.

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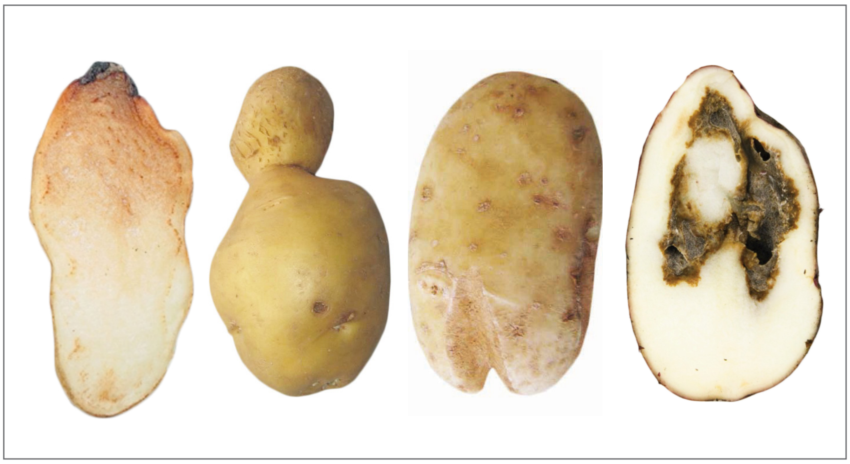

Figure 4. Disorders associated with dry conditions during tuber initiation and bulking include (from left) sugar end (M. Thornton, Uni Idaho); dumbbell (JM Gravouille, INRA); growth cracks (K Bouchek-Mechich, INRA) and internal heat necrosis (A Robinson NDSU).

Figure 6. Puffed lenticels on potatoes harvested from a wet area.

reduced if pressure drops. Although tuber development resumes when water becomes available, the disruption can result in deformed tubers with bottlenecks or pointed ends. It also increases the likelihood of tuber cracking (Figure 4).

It is well established that insufficient water at any stage will reduce yield. Overall, the penalties for under-irrigating are greater than those for over-irrigating (Figure 5). Importantly, avoiding moisture stress is more critical in some parts of the cropping cycle than others.

WHAT IF PLANTS HAVE TOO MUCH WATER?

Over-irrigation leaches nitrogen from the root zone. This reduces fertiliser use efficiency, potentially restricting plant growth, as well as contaminating ground water. It also increases disease, often obvious in damper patches of the paddock, and can have long term effects on tuber quality and storability. Initial symptoms of anaerobic, waterlogged conditions are puffed lenticels on the tubers (Figure 6).

If the soil profile remains fully saturated for more than 8-12 hours, anaerobic conditions can damage roots and tubers. This can cause "black heart" of the tubers, where the inner tissues collapse due to oxygen starvation (Figure 7). More than 36 hours of waterlogged conditions will also result in denitrification, or loss of soil nitrogen to the atmosphere.

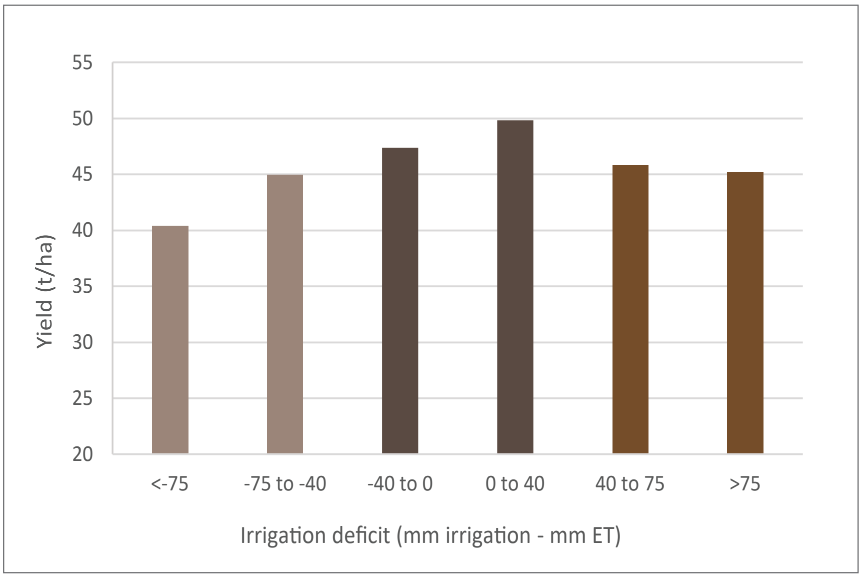

Figure 5. Total tuber yield as influenced by the difference between total irrigation and evapotranspiration (ET). Data from 45 commercial potato farms in Idaho (Stark, 1996[3]).
N.B. divide by 2.47 to convert to t/acre.

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Figure 7. Disorders associated with too much water include (from left) brown centre (JM Gravouille, INRA); hollow heart (JM Gravouille, INRA) and black heart (A Robinson NDSU).

GROWTH STAGES AND IRRIGATION

Stage 1. Establishment

Relatively high soil moisture before planting is ideal. If this happens, irrigation after planting may not be needed. Some light watering to replace surface evaporation can be useful if soil moisture is marginal. In damp soil, the seed itself has enough internal water to support the developing sprout.

If soil moisture is too high, the soil will restrict the rapid respiration rate of the sprouts. It can also allow potential infection by soil-borne pathogens. For example, early dying has been linked to high moisture during emergence[4]. It can result in increased seed piece decay and delayed emergence due to cooler soils.

Stage 2. Stolon initiation

Although tubers have not yet started to develop in stage 2, water use increases as the leaf canopy expands. The leaf area index generally reaches about 50-80% row closure in this phase resulting in increased transpiration.

Water deficits at this time can reduce the number of stolons that form, as well as negatively affecting plant growth and maturation.

The most critical periods for accurate management of irrigation are stage 3 – tuber initiation, and stage 4 – tuber bulking.

Stage 3. Tuber initiation

Water stress (and/or high nitrogen status) leading into this stage can delay tuber initiation by several weeks. The effects are often greatest for indeterminate varieties, increasing the length of the cropping cycle and potentially creating other issues. In contrast, some determinate varieties are relatively insensitive to water stress during this period and will mature normally.

While irrigation deficits during tuber initiation can affect yield, it is the impacton tuber quality that is more crucial. Even short periods of dryness can greatly affect tuber quality, without reducing the yield. Dumbbell shapes, cracks and other deformities result from uneven soil moisture during tuber initiation and early development (Figure 4).

Development of "translucent end" or "sugar end" can occur if there is water stress at this stage, especially when combined with high temperatures. Dry conditions mean that sugars produced by photosynthesis are not fully converted into starch in the tuber. The result is a colour gradient from the light tip to the dark stem end following processing (Figure 4). Maintaining high soil moisture during tuber initiation and early bulking is essential for good dry matter. However, over-moist conditions during tuber initiation combined with cool conditions increase the risk of susceptible varieties developing brown centre or hollow heart (Figure 7).

Stage 4. Tuber bulking

Water stress during tuber bulking usually affects yield more than quality. These effects cannot be recovered; total yield will be reduced.

Maintaining a large, actively photosynthesising leaf canopy is essential for tuber expansion. The leaf canopy continues to grow in this period, reaching row closure near the end of stage 4.

Dry conditions interrupt shoot growth and hasten the decline of older leaves. Reduced photosynthesis slows tuber development.

The root system also expands in stage 4. Mature roots can access water down to about 50 cm deep within the soil profile. However, most roots remain within the top 30 cm of soil, so plants are still susceptible to moisture stress.

Tillage pans or restrictive layers within the soil can limit the penetration depth of potato plant roots. Understanding the depth of root penetration is critical to managing irrigation volume and frequency in this growth stage. Varieties that have greater root branching, better root architecture and

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increased root depth are likely to be less sensitive to water deficits than those with less efficient root systems.

Tubers enlarge fairly linearly over time as long as environmental conditions are maintained. A key point is that the plants' maximum water requirement is also the same time when it is most critical to avoid water deficits[5].

It is also important to avoid excess irrigation at this stage as wet conditions increase disease, leach nutrients and may reduce dry matter.

Figure 8. Potatoes that are dehydrated at harvest are more susceptible to blackspot bruising (M Thornton, Uni Idaho).

Stage 5. Maturity

Irrigation needs drop as plants begin to die off in stage 5. Tuber growth rates decline, and skins start to mature and harden.

Translocation of nutrients from the leaves, stems and roots into the tubers leads to a small amount of further expansion, even as the tops die.

However, the soil should not be allowed to dry fully, as this can increase number and hardness of clods at harvest, as well as dehydrate tubers.

Dehydrated tubers are more likely to suffer bruising during harvest (Figure 8), while wet conditions during harvest can lead to cracks and shatter bruise damage. For more information read the PotatoLink factsheet on bruising and management.

Excessive irrigation after the vines have died off increases risk from pythium leak (*Pythium* spp.) and pink rot (*Phytophthora* erythroseptica), as well as secondary infection by soft rots. It can also reduce tuber dry matter.

IRRIGATION METHOD AND FREQUENCY

The sensitivity of potatoes to soil moisture levels, combined with their shallow root system, means that irrigation needs to be applied before the crop is affected by water stress. Frequent irrigations have been found to result in higher yield and tuber dry matter compared to intermittent irrigation (Figure 9)[6].

Drip irrigation is frequently cited as the gold standard in irrigation for potatoes. Drip allows soil to be kept continually moist and avoids wetting leaves, thereby reducing foliar diseases. However, it is expensive and not compatible with Australian growing practices.

Linear move and centre pivot are the next best options, followed by side-roll systems.

Furrow irrigation allows large and undesirable fluctuations in soil moisture content.

It is recommended to avoid irrigation by sprinkler system in the late afternoon or evening because leaves are likely to remain wet overnight. Leaf wetness increases risk from diseases such as black scurf, common scab and early blight[7].

Large volume and infrequent irrigation events not only fail to maintain even soil moisture, they contribute to runoff, can pollute ground water with nitrates and are more likely to oversaturate soil than frequent irrigation. According to King and Stark[5], this is most likely with side roll and handmove sprinkler systems, where soil water holding capacity and root depth may be overestimated.

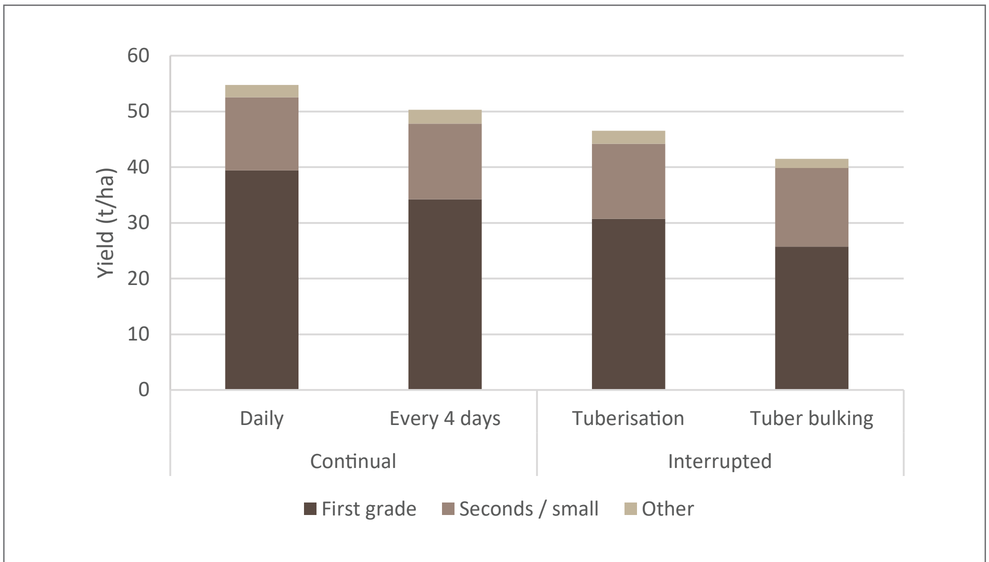

Figure 9. Effect of irrigation frequency (daily or every 4 days) and interruption during either tuber initation or tuber bulking, on average yield divided into grade 1, seconds and smalls (<114 g) and waste. Derived from Miller and Martin, 1990[8].

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MEASURING SOIL MOISTURE

Tensiometers

Tensiometers work like plant roots in that they measure the "suction" required to extract water from the soil. Tensiometers are a sealed, water filled tube with a porous tip at one end and a pressure gauge (kPa) at the other. As the soil dries, moisture moves from the tensiometer into the soil, creating a partial vacuum in the tube. This is equal to the soil water potential (kPa). Fully saturated soil gives a reading of 0 kPa, whereas -40 kPa or less indicates the soil is dry.

For reliable readings, the cylinder must be sealed against air leakage and there must be excellent contact between the soil and the porous tip.

Time domain reflectometry (TDR) sensors

These sensors measure volumetric soil moisture content. TDR sensors have two or three parallel metal rods. The time taken for an electromagnetic wave to travel from one rod to the other indicates soil moisture content.

TDR sensors are a well-established technology and widely used in agriculture to measure soil moisture. Small portable systems have been developed that allow data to be uploaded to a website, where it can be easily accessed.

The TDT (time domain transmissometry) sensor is a variation on the TDR. Instead of parallel rods, the sensor consists of a "U". TDT sensors are less portable than TDR but sample a larger soil volume.

Soil moisture capacitance sensors

Capacitance sensors also measure volumetric moisture content, but by measuring the charge time for a capacitor with electrodes separated by the soil. Fast charge times indicate high moisture contents. There are many brands available commercially, with associated equipment for transmitting and storing data.

	Tensiometer	TDR	TDT	Capacitance
Accuracy	Variable	Very good	Excellent	Good
Cost	$150-500	$300-500 per sensor + comms	$300-500 per sensor + comms	$300-400 per sensor + comms
Life expectancy	5 years	10 years	10 years	5 years
Remote access?	Normally manual	Yes	Yes	Yes
Affected by salinity?	No	Yes but can be compensated	Yes but can be compensated	Yes but can be compensated
Sensing area	Small	Moderate	Moderate-large	Small
Notes	Easy to install and use, needs regular maintenance	Can be portable	Normally permanently installed	Requires good contact with soil

Table 1. Comparison of types of soil moisture sensors

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