Dr Jenny Ekman reports

MATCHING IRRIGATION TO CROP GROWTH

"Potatoes don't eat, they drink. Potatoes drink, but they don't swim."

F. Mulcahy

Potatoes are mostly water, packaged with starch plus various minerals, vitamins and other nutrients. While they are often regarded as being a high water use crop, they are more productive per megalitre of water than many other horticultural crops.

Potatoes have a relatively shallow root zone and are very 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.

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

POTATO DEVELOPMENT

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

Stage 1 – Establishment: Planting and emergence (20 to 35 days)

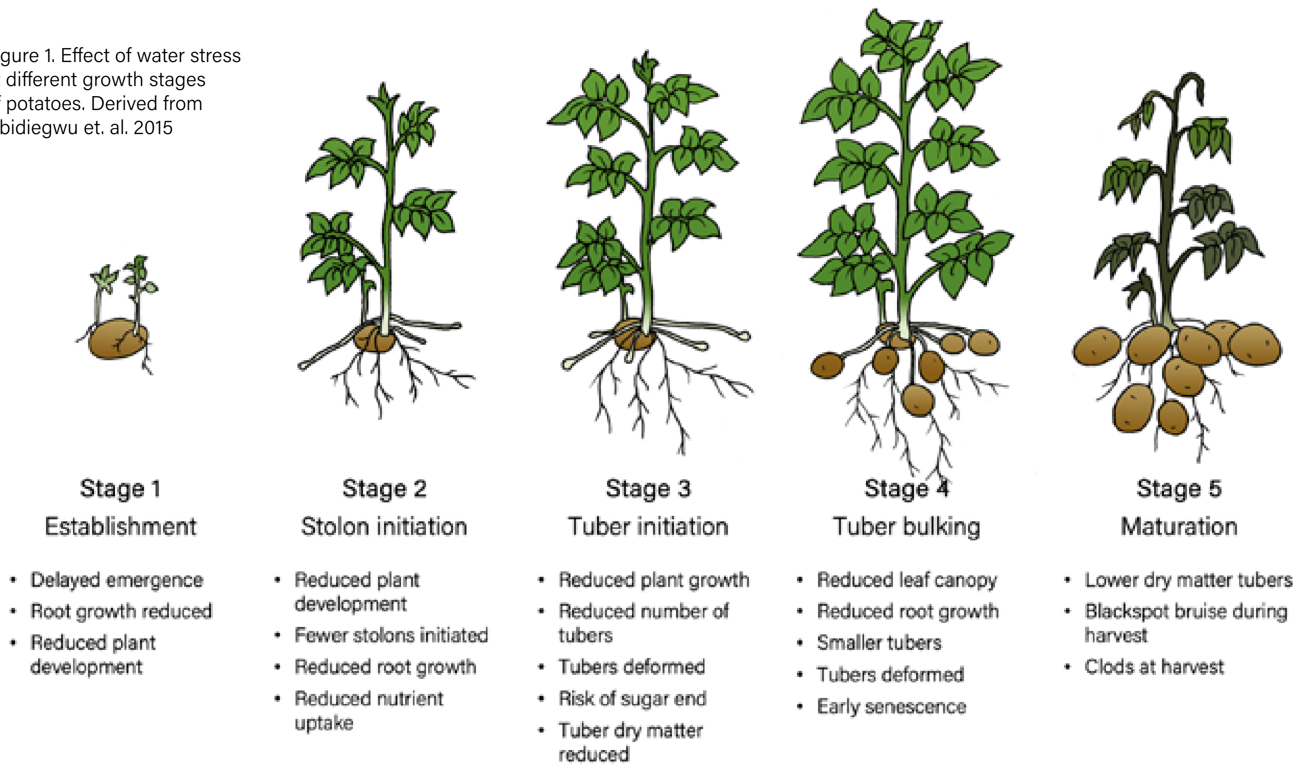
Stage 2 – Stolon initiation: Early vegetative growth and stolon development (15 to 25 days)

Stage 3 – Tuberisation: Tuber initiation at the end of the stolons (10 to 15 days)

Stage 4 – Tuber bulking: tubers fill and expand (30 to 60 days)

Stage 5 – Maturity: Tuber maturation and vine death (15 days or more)

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



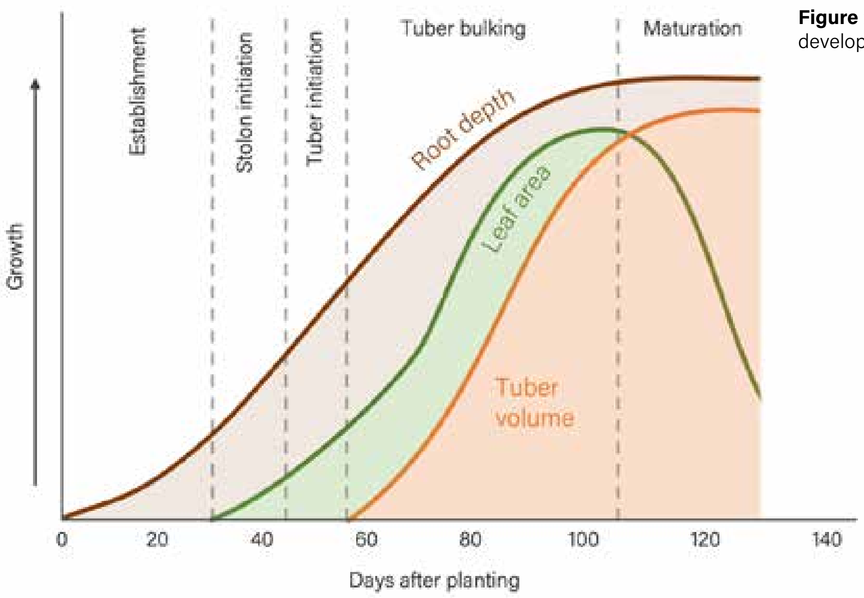


Figure 2. Potato plant development stages.

Potatoes are normally regarded as a cool-climate plant. It was once thought that photosynthesis by potato plants was almost completely inhibited at temperatures over 30°C. However, it is now known that this effect was mainly due to water deficits. In fact, potatoes can adapt to high temperatures (~40°C) and continue to photosynthesise, but only if adequate moisture is available[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). While this cools the leaf canopy, keeping temperatures below the ambient air, it also results in moisture loss.

If the plant closes stomata to reduce moisture loss, 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) depends on photosynthesis exceeding the everyday energy needs of the plant, allowing storage of excess carbohydrate in the developing tubers.

Water deficits also reduce the internal pressure which is necessary for cell expansion and growth. Leaf canopy and root growth can be significantly reduced. 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 6).

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 4). Moreover, avoiding moisture stress is more critical during some parts of the cropping cycle than others – as discussed on the following pages.

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

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

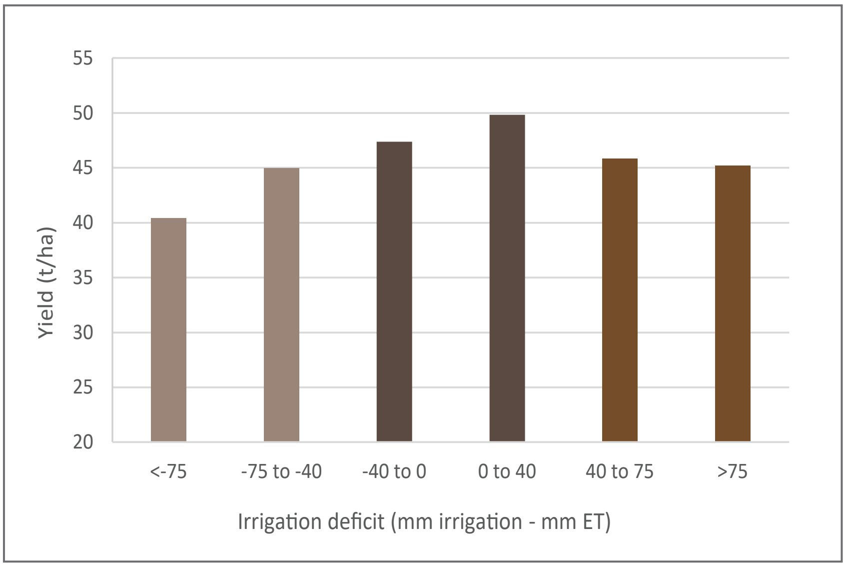


Figure 4. Total tuber yield as influenced by the difference between total irrigation and evapotranspiration (ET). Data from 45 commercial potato farms in Idaho (Stark, 1996[3]). *N.B. divide by 2.47 to convert to t/acre.*

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 5). 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. Puffed lenticels on potatoes harvested from a wet area.

GROWTH STAGES AND IRRIGATION

Stage 1. Establishment

Ideally, soil moisture should be relatively high before planting. If this is the case, irrigation after planting may not be required. 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 saturated soil will restrict the rapid respiration rate of the sprouts. It can also potentially allow infection by soil-borne pathogens. For example, early dying has been linked to high moisture during emergence[4].

Excess soil moisture at planting can also increase seed piece decay and delay emergence, as soils remain colder for longer (e.g. for early spring plantings).

Stage 2. Stolon initiation

Although tubers have not yet started to develop during stage 2, water use increases as the leaf canopy expands. The leaf area index generally reaches around 50-80% row closure during this period, with increased transpiration as a result.

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

> The most critical period for accurate management of irrigation is during 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.

Studies have certainly confirmed strong varietal effects. For example, water stress during early tuber initiation reduced yield by more than 50% for cv. "Luky" whereas cv. "Alpha" was not significantly affected[5].

Similarly, research in Western Australia found that yield and quality of cv. Russet Burbank (indeterminate) and cv. Delaware were significantly reduced by low soil moisture during emergence and tuber initiation, whereas cv. Cadima and cv. Kennebec (determinate) were less affected[6].

While irrigation deficits during tuber initiation can affect yield, it is the effects on tuber quality that are the most significant. Even short periods of dryness that do not reduce total yield can greatly affect tuber quality. Dumbbell shapes, cracks and other deformities all result from uneven soil moisture during tuber initiation and early development (Figure 6).

Another potential effect of water stress during tuber initiation and early bulking is the development of "translucent end" or "sugar end", 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 6).

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 increases the risk of susceptible varieties developing brown centre or hollow heart (Figure 7).

Stage 4. Tuber bulking

Water stress during tuber bulking typically 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 during 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 during stage 4. Mature roots can access water up to around 50cm deep within the soil profile. However, as most roots remain within the top 30cm of the soil, plants are still susceptible to moisture stress.

Moreover, the relatively weak root system of potato plants means they are often unable to penetrate tillage pans or restrictive layers within the soil. Field traffic can cause soil compaction, which also limits penetration depth of roots.

Understanding the depth of root penetration is critical to managing irrigation volume and frequency during this growth stage. Varieties that have greater root branching, better root architecture and increased root depth are likely to be less sensitive to water deficits than those with less efficient root systems.

Tubers enlarge approximately linearly over time so long as environmental conditions are maintained.

All this means that potato plants' water requirements reach their maximum right when it is most critical to avoid water deficits[7].

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

Stage 5. Maturity

Irrigation needs drop as plants begin to die off during 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 fully dry, as this can increase number and hardness of clods at harvest, as well as dehydrate tubers.

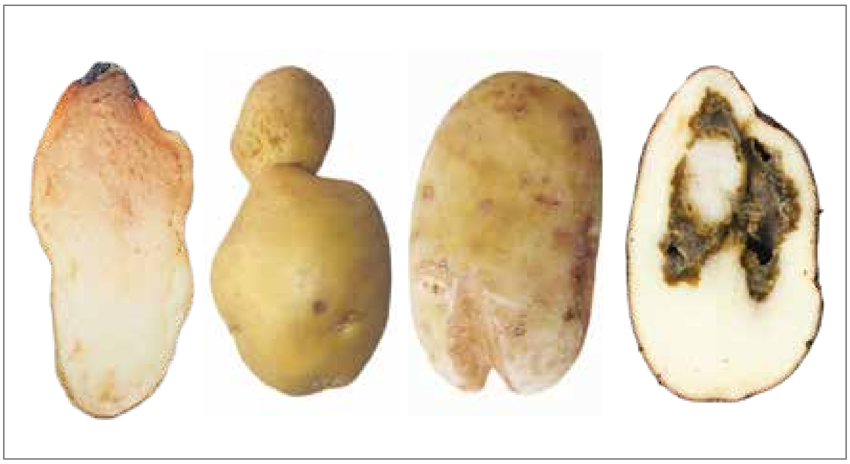


Figure 6. Disorders associated with dry conditions during tuber initiation and bulking include (from left) sugar end (M. Thornton, Uni Idaho); dumbbell (JM Gravouille, INRA); growth cracks (K Bouchek-Mechich, INRA) and internal heat necrosis (A Robinson NDSU).

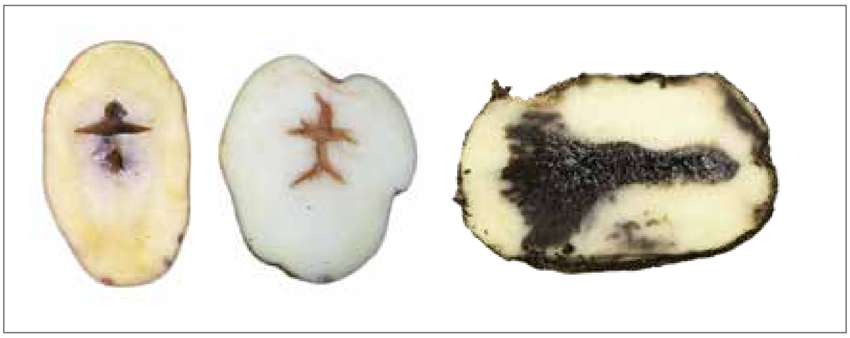


Figure 7. Disorders associated with too much water include (from left) brown centre (JM Gravouille, INRA); hollow heart (JM Gravouille, INRA) and black heart (A Robinson NDSU).

Dehydrated tubers are more likely to suffer bruising during harvest (Figure 8). Blackspot bruises are not visible externally, as the skin itself is undamaged. Instead, the damage is localised in the flesh, close to the vascular tissues. The damage is usually not visible straight away but develops 24 to 48 hours after harvest.

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.

Wet conditions during harvest can lead to cracks and shatter bruise damage.

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

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)[8].

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 current Australian growing practices.

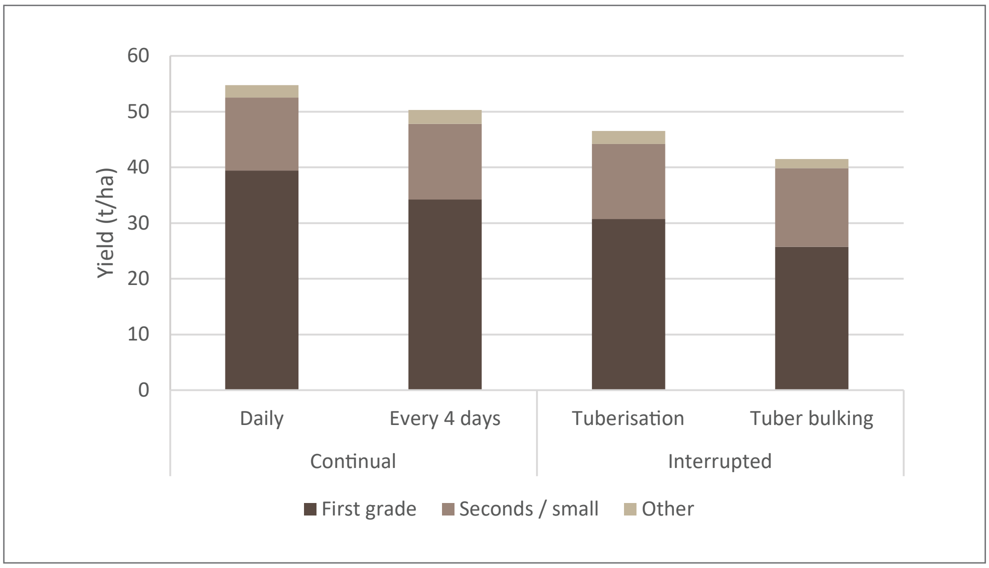


Figure 9. Effect of irrigation frequency (daily or every 4 days) and interruption during either tuber initation or tuber bulking, on average yield divided into grade 1, seconds and smalls (<114g) and waste. Derived from Miller and Martin, 1990[10].

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.

As sprinkler systems wet the leaves, it is often recommended that plants are not irrigated in the late afternoon or evening if leaves will remain wet overnight. Leaf wetness increases risk from diseases such as black scurf, common scab and early blight[9].

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[3], this is most likely with side roll and hand-move sprinkler systems, where soil water holding capacity and root depth may be overestimated.

MEASURING SOIL MOISTURE

See p12 for a comparison of different soil moisture sensors

Tensiometers

Tensiometers work like plant roots in that they measure the 'suction' required to extract water from the soil. Tensiometers are basically 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 0kPa, whereas -40kPa or less indicates the soil is dry.

To get 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.

IN SUMMARY

- **Too little** moisture affects yield more than **too much** moisture
- The effects of water stress vary at different crop growth stages
  - Tuber initiation and tuber bulking are the most critical times to get irrigation just right
  - Water stress during tuber initiation can have major effects on quality
  - Water stress during tuber bulking has the greatest effects on yield
- Too much soil moisture can increase disease and may reduce specific gravity
- Potato plants prefer small amounts of water often, avoiding water stress, compared to large, less frequent irrigation events
- There are lots of devices available to monitor irrigation and get soil moisture into the goldilocks zone: **Not too damp, not too dry, but.... Just Right!**

Figure 10. A tensiometer (Irrometer) and a, TDR sensor (Wildeye), two types of soil moisture probes

	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
Needs calibration by soil type?	No	No	No	No
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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