Managing sweetpotato plant beds in Australia

Literature review March 2015

For Horticulture Innovation Australia Ltd Project VG13004

Innovating new virus diagnostics and plant bed management in the Australian sweetpotato industry

Hort Innovation Strategic levy investment
VEGETABLE FUND
Australian Sweetpotato Growers Inc
Queensland Government

This publication has been compiled by Craig Henderson of Horticulture and Forestry Sciences, Department of Agriculture and Fisheries.

This project has been funded by Horticulture Innovation Australia Limited using the vegetable industry levy and funds from the Australian Government.

Contents

Recommendations for further investigation

Improving early sprout production

There may be a role for heat management in the curing, storage and pre-sprouting of storage roots before dispatching to growers for bedding. Literature from the USA suggests the early production of sprouts form storage roots can be enhanced by such pre-treatments, with limited impacts on later bed performance. Perhaps these pre-treatments could be limited to early plant beds.

There were mixed results from the use of ethephon to stimulate sprout production. More intensive discussion with USA researchers, and perhaps some initial laboratory experiments may prove useful in determining if this option could have a role in the Australian system.

Plasticulture, via mulches and hooped beds can certainly promote early sprout production. Black polyethylene is too risky to use; well ventilated clear mulch is the preferred option. Spun or woven materials may be more useful once sprouts have emerged. There may be room for more refinement of the environmental conditions for changing the management of the covers, e.g. from flat to hooped covers, increasing the amount of ventilation, or changing to woven row covers.

Managing fungal and bacterial diseases

Because Australian growers try to prolong the harvest period for their plant beds, minimising the occurrence and spread of disease in the beds is critical. Obvious management decisions such as good aeration, minimising depth of bedding roots, irrigation management, field and handling hygiene are important. There may be a more critical role for cutting height than first anticipated, as well as possibly quarantining initial disease sites from cutting.

Management options for reducing the disease and nematode loads in potential plant beds should be explored, including rotation, fumigation and solarisation options.

Understanding plant bed deterioration and virus reinfection

The capacity of plant beds to provide high performing sprouts as they endure is surprisingly poorly understood. This is perhaps because Australian plant beds are expected to perform much longer than their USA counterparts (where most previous work has been done). The key elements for determining when to switch to new plant beds are (a) a rapid detection method for estimating virus loads of sprouts and (b) a rapid method for assaying the potential yield performance of sprouts. Currently both (a) and (b) are very time consuming, taking many months, and are of very limited use for reactively deciding when plant beds should be retired.

Optimising sprout production

There is little prescriptive information on irrigation, nutrition and other agronomic management for optimising sprout production. To some extent this will rely on a good predictive tool for assessing sprout potential (see above).

Sweetpotato propagation systems throughout the world

In most tropical locations, where sweetpotatoes are grown throughout the year, propagation takes place using field cuttings from sweetpotato vine. Even where virus minimisation schemes exist, these generally use cuttings for multiplication and distribution. It is in temperate regions, where there is a winter period too cold for carryover of sweetpotato plants, that bedding systems, using storage roots to produce sprouts originated, and are still most widely used (Gaba and Singer 2009). Where bedding systems are used, foundation planting material producers are advised to maintain their mother stock by nodal or tissue culture processes, rather than cycles of bedding root based propagation, to reduce the opportunity for genetic drift (Villordon and LaBonte 1996).

The importance of virus-free planting materials in maximising sweetpotato productivity is globally accepted, however most tropical and subtropical sweetpotato growing countries do not have Pathogen Tested (PT) schemes, or if they do, they are still at a very early stage of development and implementation (Akoroda 2009; Bourke 2009; Campilan 2009; Fuentes and Chujoy 2009; Fuglie 2007). Certainly in the Philippines, there has been a concerted effort to implement a PT scheme, based around certified mother plant production by government and aid organisations, supplying cuttings to farmer and community based multiplication systems. Multiplication involves production and distribution of cuttings, rather than bedding roots (Campilan 2009; Laranang and Basilio 2002).

Interestingly, in South Africa, and Israel, specialised nurseries provide commercial growers with cuttings for commercial sweetpotato production (Loebenstein, Cohen *et al.* 2009; Low, Lynam *et al.* 2009; Mtileni 2014). An Indian scheme involves field multiplication; however the initial plant beds have a single row of storage roots in hills 60 cm apart. Sprouts from these 'beds' are further multiplied in field propagation at secondary nurseries to provide field-type vine to commercial growers. It appears the focus of these schemes is on sweetpotato weevil management, so the virus/PT status of these Indian systems is unclear (Edison, Hegde *et al.* 2009).

New Zealand has a PT scheme similar to Australia (Bourke 2009), modelled on the Australian system; however no research has been specifically reported on plant bed management from that country.

The largest sweetpotato producing country in the world, China, has a PT scheme, using bedded storage roots to generate commercial sweetpotato planting material. (Zhang, Wang *et al.* 2009) report that their current protocol is to renew PT material every 3 years on average, due to their perceived view of the rate of virus re- infection (Li-ming, Qing-mei *et al.* 2005). In the Chinese system, they treat their storage roots using a hot water treatment, and fungicides before bedding. When the sprouts are around 30 cm long, they take the apical 20 cm (cutting 10 cm above ground level) for commercial planting.

Pathogen tested sweetpotato systems in the USA

The PT system used in the USA (Anonymous 2015; Barkley, Schultheis *et al.* 2013; La Bonte, Clark *et al.* 2004; Smith, Stoddard *et al.* 2009) is by far the most comparable to the Australian system. The USA PT program does not attempt to meet the full commercial planting area; it provides sufficient material for bedding about 25% of the required sprout production. For the other 75% of commercial production, USA sweetpotato growers use storage roots retained from the previous year. In 2004, (La Bonte, Clark *et al.* 2004) indicated that multiplying in the field for more than 2 generations was problematic; as virus re-infection meant PT status was compromised. Vector management and isolation from infected commercial fields was paramount. USA growers generally use their smaller roots that do not make the marketable grade (Smith, Stoddard *et al.* 2009). The key features of the system used in North Carolina, Mississippi, California and Louisiana are:

Storage roots are pre-sprouted in late winter at 21-29 ^{o}C and 85-90% relative humidity 2-3 weeks before bedding (Smith, Stoddard *et al.* 2009). Storage roots are then laid out in the plant beds, often by dumping mechanically, or if by hand, then relatively roughly and quickly. (Smith, Stoddard *et al.* 2009) estimated around 900-750 kg of bedding roots required to plant 1 ha of commercial crop. They expect to produce around 150-250 sprouts/m^2 of plant bed.

According to (Barkley, Schultheis *et al.* 2013), their plant bed storage root densities vary from 3 kg/m^2 to 23 kg/m^2. That compares to an Australian average in standard beds of around 15-17 kg m^{-2} (Henderson *et a*l unpublished). In their experimental work (Barkley, Schultheis *et al.* 2013) produced 260-310 sprouts > 20 cm in length in their best treatments (around 20 kg m^{-2} of bedded storage roots), depending on cultivar. Similar to Australia, their bedded roots are covered with 25-75 mm of soil.

Because the system in the USA is a relatively compressed growing season, it is critical that the sprouts are produced as quickly as possible. Growers use plastic mulch (generally clear, but occasionally black early in the season) to heat the beds and generate rapid sprouts. There is no current determination on flat versus hooped plastic mulch, the latter being more common in California (Smith, Stoddard *et al.* 2009). All mulches have 50 mm holes every 1-1.5 m to maintain bed aeration.

Sprouts are harvested at 6-8 weeks, and only 2-3 cuts are required before planting ceases. Sprouts are either cut by hand, or more recently, there are several machines for bed harvesting and trimming (Smith, Stoddard *et al.* 2009). However, the labour savings are not as great as anticipated; as the machine harvested sprouts require individual sorting before they can be used for commercial planting. Cultivars that produce uniform and high density sprouts are best suited to mechanised sprout harvesting.

Pathogen tested sweetpotato systems in Australia

The Australian sweetpotato commercial system is the most intensive and highest yielding plant bed type system in the world. It is well described by (Lovatt 2013) and (Dennien, Homare *et al.* 2013). (Bourke 2009) identifies the current PT scheme as the major contributor to industry expansion in the last decade.

Growers source bedding roots from the mother nursery in Rockhampton, Australia. At this facility, tissue-cultured, virus-free mother plants are multiplied up in controlled conditions, until the final stage, where the plants are field grown. The bedding roots are sourced from this field production, with small, oversize and misshapen roots currently excluded from delivery to growers. Some bedding root lots may be pre-sprouted in hot rooms set at 25-30 ^oC, particularly for July-September bedding, or when cultivars are known to be slow to sprout.

Growers are advised to plant in raised beds around 1 m wide, with roots hand-placed (not touching) and covered with 20-30 mm of soil. Current recommendations are 100 g m^{-2} of complete fertiliser (5:6:5). Beds are lightly irrigated to encourage sprout emergence, but not cause waterlogging and rotting.

Early season beds may be warmed using plastic covers, which require aeration to prevent over-heating, CO_2 toxicity, or excessive humidity. Generally growers poke holes in the plastic every few metres. Plastic is removed once sprouts are growing well, or daytime temperatures cause excessive burning of sprout tips.

Once sprouts begin to appear, growers may trim the initial flush to promote uniform regrowth and increase overall sprout density. Sprouts are generally harvested when the bulk of the bed comprises tips between 20 and 50 cm long. Most growers will harvest at least 4 cuts from a bed, however many growers will continue to cut from beds until sprout appearance and vigour declines, or beds are obviously badly affected by fungal or virus diseases.

Australia is a unique sweetpotato producer, in that it is using an annualised storage root / plant bed system to produce sweetpotatoes year round. In contrast to other temperate areas, where there is a clearly defined planting period of around 2-3 months, Australian growers are planting for 9 months, from September through to May.

Features of the Australian system that are not reproduced anywhere else in the world are:

- Most growers use G1 storage roots, sourced from the PT nursery based in Rockhampton, to directly supply all their commercial planting material via sprouts from on-farm plant beds.
- Plant bed production of sprouts is highly input intensive, from soil preparation, chemical treatment, storage root placement and planting, nutrition, pest management, and sprout harvesting.
- Many Australian growers use plant beds to generate commercial material for 6-8 cuts, nearly twice as long as internationally. Some growers try and maintain plant beds over winter for early production in the following season.

Unfortunately, because of the unique operating environment of the Australian plant bed system; there has been little investigative work of direct application to the Australian system!

Organisms causing plant breakdown in plant beds

The predominant causes of storage root breakdown in sweetpotato plant beds are soil borne pathogens, or post-harvest diseases that infect the roots during storage and manifest themselves within the plant bed. Both soil borne and post-harvest diseases are exacerbated by injuries during the harvesting, handling in storage and bedding procedures (Clark, Holmes *et al.* 2009).

(Clark, Holmes *et al.* 2009; Overstreet 2009; Sorensen 2009) provide excellent reviews of the important diseases (fungal and bacterial), nematodes and insect pests in sweetpotato plant beds.

Summary of organisms important in Australia

Diseases – fungal and bacterial

Sclerotium rolfsii – (Sclerotium blight) causes circles of infection, wilting and death in the plant bed. In humid conditions, white mycelia cover the soil, and the base and lower stems of young plants. Warm temperatures, waterlogging, decaying vegetation all promote sclerotia germination and infection (Clark 1989). Decaying roots or leaves left on the surface can be problematic. The organism tends to infect via points of sprout emergence, rather than initially penetrate the storage root in the bed (Clark, Holmes *et al.* 2009).

Monilochaetes infuscans – (Scurf) causes superficial purple-brown spots on the periderm of the storage root. It can spread from an infected storage root up onto the lower sections of the sprout at or below the ground surface. Spread and infection is enhanced by animal manure incorporation in the soil (Clark, Holmes *et al.* 2009).

Fusarium oxysporum f. sp. Batatas - (Fusarium wilt), infects the vascular tissue of the sprouts, causing wilting and eventual death. In storage roots, usually associated with vascular discolouration near the proximal end of the roots (Clark, Holmes *et al.* 2009). Many cultivars grown in Australia, e.g. cv. Beauregard, are resistant to this organism (La Bonte, Wilson *et al.* 2008; Rolston, Clark *et al.* 1987; Wolfenden, Dennien *et al.* 2014).

Fusarium solani – (Fusarium wilt and stem canker) causes a 'dry' rot in storage roots. This disease can become very aggressive in bedded roots that were carrying the infection. This disease can infect emerging sprouts, and cause cankers in the lower portions of the stem. It can thus readily spread into commercial fields. The disease can survive for long periods in the soil. In commercial production it commonly infects storage roots that are wounded during harvesting, particularly if conditions are cold and wet (Clark, Holmes *et al.* 2009). Co-infection with *Dickeya dadantii (Erwinia chrysanthemi)* is particularly aggressive, and can decimate a plant bed or commercial crop (Duarte and Clark 1993).

Rhizopus stolonifer and *Rhizopus arrhizus* – (Rhizopus soft rot) is a rapidly progressing soft rot of wounded storage roots. Generally occurs during harvest and storage, prior to bedding, thus diseased roots are generally removed from the PT chain. However, as these are ubiquitous fungi in air and soils, freshly wounded bedding roots in the plant bed may be vulnerable (Clark, Holmes *et al.* 2009). Crush wounds are more vulnerable than clean cuts (Holmes and Stange 2002). As with other diseases, many cultivars grown in Australia, e.g. cv. Beauregard, are variably resistant to this organism (La Bonte, Wilson *et al.* 2008; Rolston, Clark *et al.* 1987; Wolfenden, Dennien *et al.* 2014).

Dickeya dadantii or (*Erwinia chrysanthemi*) – (Bacterial root and stem rot) often occurs as a latent infection with no obvious symptomology at first, apart from streaks in the lower stem and root vascular tissue. Disease development is favoured by low oxygen and high temperatures (Duarte and Clark 1992). It does not survive in the soil, except in debris or weed hosts. Common sources of infection are other storage roots, contaminated wash water, and handling equipment (Clark, Holmes *et al.* 2009).

Nematodes

Meloidogyne spp. – (Root-knot nematodes) infest the roots (including storage roots in plant beds), generally where laterals branch from the roots; usually causing the symptomatic galls. Severe infections can result in cracks and necrosis, although these roots generally do not move far along the PT chain. Of more concern is sub-symptomatic infection, perhaps only raised bumps on the skin of the storage root (Overstreet 2009). However, most growers are relatively knowledgeable about nematode infections, and so will avoid using infected roots for bedding.

Rotylechulus reniformis - (Reniform nematode) severe infection can cause cracking and necrosis; generally becomes more common when root-knot nematodes are managed by cultural practices or cultivar resistance. Due to the use of resistant cultivars, this type of nematode is becoming the dominant nematode issue in the USA (Smith, Stoddard *et al.* 2009).

Pratylenchus spp. - (Lesion nematode) severely infected storage roots may have brown or black necrotic lesions, that may act as entry points for other disease organisms.

To date we have not found any literature that mentions specific impacts of nematodes on plant bed performance.

Insects

Cylas formicarius (Sweetpotato weevil), *Elateridae spp*. and *Tenebrionidae spp.* (wireworms) larvae infest and damage sweetpotato stems, crowns and storage roots (Akers, McCrystal *et al.* 2014). In plant bed systems, infected roots should never be planted. The current Australian PT system means G1 storage roots should not be infested with any insects. Thus management is around preventing infestation in the plant bed itself.

The other critical element is management of virus vectors, particularly aphids and whiteflies, which are the key vectors of the sweetpotato viruses currently known in Australia (Dennien, Homare *et al.* 2013; Loebenstein, Thottappilly *et al.* 2009).

Plant bed management to reduce pathogen, nematode and insect impact

Hygiene in the PT chain.

Remove obviously infected roots at all stages of the transport chain (Clark, Holmes *et al.* 2009). Disinfect harvesting, handling and planting equipment. Have a disinfection process in any washing procedures – avoid washing roots for use in a PT scheme, unless a stringent hygiene protocol is in place. In China, they advocate treatment with hot water, fungicides and antibiotics (Zhang, Wang *et al.* 2009). They also suggest that the use of PT material can of itself improve resistance to fungal pathogens and nematodes (Feng, Yifu *et al.* 2000). For some nematodes and insect pests, storage roots in the PT chain could be sterilised by hot air treatment at 50 oC for 8 hours (Martin 1962). In Australia, storage roots are routinely treated with a benzimidazole fungicide before shipment (Dennien, Homare *et al.* 2013). Some growers also apply the same fungicide once the roots are bedded and before covering with soil.

Cure PT roots after harvesting to reduce disease entry points, and avoid wounding at all points in the PT chain (Clark, Holmes *et al.* 2009)

Minimise damage to storage roots during all harvesting, handling and bedding processes (Clark, Holmes *et al.* 2009).

Management options

Where possible, use cultivars with known disease resistances (Clark, Holmes *et al.* 2009; Wolfenden, Dennien *et al.* 2014). Ultimately, cultivar choice reflects other factors such as productivity and consumer acceptance.

Avoid locating plant beds in ground previously used for that purpose, or with a known history of soil borne diseases. Also avoid sites prone to waterlogging. Prefer sites with well drained soils (Clark, Holmes *et al.* 2009).

Ensure plant beds are well raised, and continually rebuild beds and wheel tracks to maintain good drainage and runoff.

Keep beds well aerated. In soils prone to crusting, regularly apply 10 t/ha of gypsum to reduce aggregate dispersion and surface sealing. If using plastic mulches during winter and early spring, aerate regularly along the side of the mulch (e.g. punch 25-50 mm holes every metre) to promote gas exchange with the atmosphere. Alternatively, use hooped plastic, with the option to ventilate via the end covers (Dennien, Homare *et al.* 2013). Air temperatures above 28 ^{o}C can cause breakdown of bedding roots underneath plastic mulches (Lovatt 2013)

(Stoddard, Davis *et al.* 2010) evaluated a range of fumigation, fungicide and herbicide treatments in Californian plant beds. They found a combination of 1,3-dichloropropene+chloropicrin and metham sodium was the best alternative to methyl bromide, with a major focus on weed management, as well as impacts on soil insects, nematodes and soil borne diseases. In their case, solarisation was ineffective at managing weeds, potentially because of the 5 month period between treatment and bed planting. The best treatments gave excellent sprout yields of 650-750 m^{-2}. Soil solarisation was effective at reducing root-knot nematode number and infections prior to sweetpotato planting in 1990 (Stevens, Khan *et al.* 1990).

Use a registered fungicide as a preventative if diseases have previously been an issue. Alternatively, fumigate the plant bed – there are several options under development by chemical companies in Australia. Where land area and time allow, soil solarisation could be useful in the hottest months to prepare a potential plant bed for the following season, provided weeds are well managed (Overstreet 2009).

When harvesting sprouts for field planting, ensure the cut is made 2-3 cm above the soil surface, and the cutting implements do not penetrate into the soil (Clark, Holmes *et al.* 2009). Many infective organisms are seldom found in the above ground portion of the sprout, but can be retained if the sprout is pulled rather than cut in the act of harvesting (Smith, Stoddard *et al.* 2009).

Prevent plant beds from being an infestation source of nematodes or soil insects by discarding obviously infected roots, and ensuring plant bed areas are as pest free as possible, via crop hygiene, rotation and preventative and curative application of appropriate chemicals. (Overstreet 2009) provides a review of nematicides used in the USA. Australian growers should refer to products currently registered in this country.

For *C. formicarius*, intensive sex pheromone trapping around plant beds could be a useful additional preventative measure (Dennien, Homare *et al.* 2013; Smith, Stoddard *et al.* 2009). Sticky traps may also be useful for checking for presence of beetle species (Rashid, Abel *et al.* 2010). Other imperatives are hygiene around the plant bed areas, including removal of volunteer plants and crop debris (Sorensen 2009). Also maintain soil moisture to prevent cracking, and cover cracks or exposed roots.

Management of virus vectors such as aphids and whitefly is critical to maximise the performance of plant beds and subsequent commercial crops (Dennien, Homare *et al.* 2013; La Bonte, Clark *et al.* 2004; Loebenstein, Thottappilly *et al.* 2009). Cultural methods include isolation as far as practicable from host crops or weeds, strict farm hygiene, use of windbreaks, and encouragement or possible inundative releases of parasitoids (e.g. *Encarsia formosa* or *Eretmocerus spp.* for whitefly management). Unfortunately such parasitoids are unlikely to survive the regular spraying regime within the plant beds, so are more useful in managing whitefly populations in surrounding vegetation or crops. Also, regularly inspect plant beds for any plants with virus symptoms, rouging those sweetpotatoes (Dennien, Homare *et al.* 2013).

Apart from the cultural methods referred to above, growers currently rely on regular spraying of registered pesticides (see Infopest for specific uses). They are generally prepared to use higher inputs on plant beds, both to prevent contamination when planting out in commercial fields, as well as preserve PT integrity as long as possible.

Improving early season performance of plant beds

Bedding roots require a minimum soil temperature of 15.6 ^{o}C for sprouting to occur (Lovatt 2013). Specialist sweetpotato cutting production nurseries in Israel and the Northern United States use hothouses / greenhouses to provide early season planting materials for commercial growers (Anonymous 2015; Dangler 1994; Loebenstein, Cohen *et al.* 2009; Smith, Stoddard *et al.* 2009). If the Australian industry developed specialist businesses providing planting materials for commercial growers, this may be a viable option. At this stage it is unlikely that current commercial growers would pursue a hothouse option for early sprout production.

In China, northern growers use a system of fires on the tops of plant beds covered by layers of mud and straw to promote early sprout production (Zhang, Wang *et al.* 2009). Again, this system is unlikely to be adopted in Australia.

The other dominant methods for promoting early season sprout production are various heat treatments in storage prior to bedding, and the use of plastic mulches to increase soil temperatures.

Heat treatments during storage

The process for encouraging sprouting by curing, mid storage heating or pre-sprouting is well described in a range of companion experiments (Hall 1992; Hall 1993; Hall 1994), and immediately transferable to Australia. Combinations of curing, mid-storage heating and pre-sprouting at 32 ^{o}C for a total period of 14-21 days appeared to give the earliest and greatest total production of sprouts over a 14 week period from initial bedding. Note that the roots were bedded in a greenhouse, with minimum air temperatures of 24 ^{o}C, and soil temperatures of 24-32 ^{o}C There were no increases in bedding root breakdown due to these in-storage heat treatments (Hall 1993; Hall 1994). The best balance of extended curing, mid-storage heating and pre-sprouting are probably dependent on energy cost distributions, storage availability, and logistics. Differences in impact on sprout earliness and production in these studies were minor; the important factor was total heat units applied. Other USA literature suggests pre-sprouting will increase early sprout production by 2-3 times (Anonymous 2015).

(Hall 1990) found that dipping bedding roots in ethephon (which generates ethylene on metabolism by the roots) before planting brought commercial sprout harvest forward by one week compare to controls, and also resulted in a greater number of total sprouts produced over the nine week harvest period. The authors also found that cutting 1-2 cm off the proximal end of the root promoted earlier sprouting and some cultivars, but not in others. In his study, ethephon was the most effective practice for achieving early sprout production, whilst ethephon and pre-sprouting, or ethephon and root cutting generated the greatest total number of sprouts. Note that these studies were conducted with small bedding roots 2.5-5 cm in diameter and only 5-18 cm long.

Across all these pre-bedding treatment strategies, there were differences in responses between cultivars (Hall 1990; Hall 1992). Fortunately there did not appear to be any adverse impacts of the treatments on bedding root breakdown, so perhaps experimentation within the PT supply chain can be conducted for each cultivar with low downside risk. However, it should be noted that pre-harvest treatment with ethephon increased tip rot incidence in Mississippi (Arancibia, Main *et al.* 2013), and (Clark, da Silva *et al.* 2013) noted differences in cultivar susceptibility to pre-harvest ethephon induced breakdown. More recently, ethylene has been found to have an important constraining influence on adventitious and thus storage root development in some cultivars (Villordon, Clark *et al.* 2012). Thus, investigations to ascertain the best timing, application rate and treatment sequence for ethephon are advised before commercial-scale experimentation.

It is probably a logistical and handling issue to determine which point in the PT chain is most appropriate to pre-sprout. Whilst the current PT storage root supplier is well positioned to pre-spout, the delivery chain must perform effectively to ensure storage roots are not ‘over-sprouted’ before roots are bedded. There is also the issue that cold soil temperatures will probably limit sprout emergence and growth anyway.

Use of plastic mulches

Although sweetpotato growers use a range of plastic mulches and row covers to enhance early season sprout production, there is only limited literature to support the variety of protocols used. In their PT scheme, South African researchers are currently exploring use of netted structures and plastic mulches (Mtileni 2014). In the USA, growers use black or clear plastic mulches in the eastern and southern States, and hooped plastic in California (Smith, Stoddard *et al.* 2009). Black polyethylene is removed as soon as sprouts have merged, as damage to tips can result if they are retained (Dangler 1994; Porter 1991). Clear polyethylene can be retained for longer without risk, often until the first sprouts are ready for harvest, although it is important that the plastic and beds are well ventilated (Dangler 1994). Clear polyethylene also provides earlier and greater numbers of early sprout harvest than black polyethylene, presumably because the heating benefits can be retained in the production cycle for longer (Porter 1991). Whilst woven polyesters are also useful once sprouts have emerged, they can stick to soils after heavy rain if not suspended by sprouts (cut or growing) above the soil surface (Porter 1991).

Experiments in Louisiana and North Carolina also investigated the use of hooped black polyethylene tunnel covers after sprouts emerged (La Bonte, Villordon *et al.* 2000). In early spring production of sprouts, these black covers caused sprouts to emerge nearly 4 weeks earlier than uncovered controls, and markedly increased the numbers of sprouts cut. However these sprouts were often etiolated. The investigators tried increasing sun exposure from 5-10 days before cutting, to improve chlorophyll content, development and ‘hardiness’ of the sprouts. Often the sprouts grown under the black polyethylene tunnels weighed less than equivalent sprouts from uncovered controls. When planted for sweetpotato production, the black polyethylene sprouts often yielded less marketable sweetpotato than the uncovered controls. Thus the hooped black polyethylene was not recommended for commercial sweetpotato production, except perhaps for attempting very early commercial planting coming out of winter (La Bonte, Villordon *et al.* 2000). Note that the yields reported in these experiments appeared much lower than Australian target commercial yields.

Current Australian recommendations suggest clear plastic, and using structural hoops once sprouts are apparent. Plastic is retained until daytime temperatures exceed 28 ^{o}C; shoots show signs of burning, or within 10 days of the first sprout harvest (so sprouts can harden). Plastic covers must also be well aerated, to prevent excessive heat and CO_2 build up damaging sprouts and bedding roots (Dennien, Homare *et al.* 2013; Lovatt 2013).

In terms of non-plastic mulches, (Beaulieu and Marsh 2002) found a sand mulch produced the highest soil temperatures; however a peat mulch produced the most early sprouts, whilst sawdust had limited impact. Not that this study was using heated beds in a hot house, and producing rooted plantlets, rather than sprouts cut off above ground level.

Decision points for migrating from established plant beds to new plant beds

Because Australia is the only sweetpotato producing country to have an extended commercial planting period coupled with a PT plant bed system, it is not surprising that this is not well explored in the literature. There has been limited work on virus reinfestation rates of plant beds; however this has been at the scale of commercial crops, and over several seasons, not in established plant beds during a season (Bryan, Pesic-VanEsbroeck *et al.* 2003; Bryan, Schultheis *et al.* 2003; Clark, Davis *et al.* 2012; Clark and Hoy 2006; Clark, Hoy *et al.* 2004; Clark, Smith *et al.* 2010; Gibson and Kreuze 2015; La Bonte, Clark *et al.* 2004; Pozzer, Silva *et al.* 1995). Several of these studies found virus loads in plant beds and commercial crops were similar to other non-PT crops by the time the commercial crops were harvested (i.e. after 4-6 months).

(Atu 2014) found plant bed performance (production of sprouts >20 cm in length and 3.5 mm thick) deteriorated significantly after the 5th cut of sprouts. This agrees with the anecdotal experiences discussed with growers during the VG13004 project survey (Henderson et al unpublished).

Current Australian recommendations suggest sprout vigour declines after the fourth sprout harvest (Lovatt 2013).

PT bed management approaches to improve productivity

Site selection and preparation

Extension literature commonly suggests plant beds should be located in well-drained, unshaded sites that have not grown sweetpotatoes for at least 3-4 years. Irrigation water should be clean, and not include runoff from commercial fields, or packing sheds, as these may act as sources of disease (Anonymous 2015).

Beds should be as wide as manageable, as this promotes vertical sprout growth, and reduces elongated sprouts at the side of the bed. However, harvesting staff need to be able to cut and collect sprouts easily, without standing on the beds and damaging the roots. As a practical limitation, most beds are seldom wider than 1.2 m. Bed height and drainage is more important than maximising bed width. Bedding roots need to be covered by 25-75 mm of soil (Smith, Stoddard *et al.* 2009). Too little and sprouts will not develop independent root systems (important for sustainable regrowth); too great and bedding roots are more likely to prematurely rot (Anonymous 2015).

Storage root size in planting beds

Indian plant beds for their initial multiplication use storage roots in the range 125-150 g (Edison, Hegde *et al.* 2009). Sweetpotato growers in the USA often use small storage roots in their plant beds (Smith, Stoddard *et al.* 2009). In beds where they are using retained sweetpotatoes from previous crops, this is a function of using the roots least attractive to the market. They also favour smaller roots, because they are not concerned with longevity of the plant bed. Perhaps they also feel that the smaller roots provide a higher sprout density per kg of root bedded. However, given the range of storage root densities USA growers use in their plant beds (as low as 6 kg/m^2), they do not at this stage appear too concerned with sprout production per m of plant bed (Barkley, Schultheis *et al.* 2013).

(Atu 2014) found that although small sweetpotato storage roots (65-100 g) produced high numbers of sprouts, these sprouts were often sub-optimal; less than 20 cm in length and thin. He found that medium (230-665 g) and large roots (>1140 g) produced significantly more premium sprouts than small storage roots in plant beds, and carried that premium sprout production through for a greater number of cuts and regrowth. On the basis of his findings, (Atu 2014) recommended a medium storage root as the most economic grade for sprout production (given that all storage roots for bedding cost the same per kg).

Density of storage roots in plant beds

In the Indian sweetpotato multiplication system, they plant single rows of roots 60 cm apart, with 20 cm between the roots. This is producing cuttings for further multiplication, not commercial production (Edison, Hegde *et al.* 2009). In systems more reflective of the Australian systems (Barkley, Schultheis *et al.* 2013; Edison, Hegde *et al.* 2009) varied density of storage roots in plant beds from 3 kg/m^2 to 23 kg/m^2 and found that the optimal sprout production was at 20 kg/m^2, which is about 25% greater than currently employed in Australia. Visually there is substantial overlap of roots at 20 kg/m^2. In the Australian system, this may prove problematic late in the plant bed cycle, as it would potentially promote disease dispersion through the plant bed. Because this is not so much an issue in the USA system, perhaps they can get away with the overlap. Current Australian recommendations involve standardising the size and shape range of bedding roots, and then placing roots within the bed with around 10 mm separation (Dennien, Homare *et al.* 2013; Lovatt 2013).

Cultivar impacts on management of plant beds

Grower evidence suggests cultivars have different sensitivities to factors such as coverage depths and densities of bedding roots, soil temperatures, and pre-sprouting management.

(Barkley, Schultheis *et al.* 2013) showed that Evangeline produced longer sprouts than Covington when grown using the same plant bed practices. This has implications for both optimal bedding root density, and time to sprout harvest (see below).

Optimal sprout characteristics driving plant bed management

Sweetpotato growers vary in the types of sprouts they are seeking. This in turn can drive the best plant bed arrangements and management to most efficiently deliver the greatest quantity of specified sprouts. In the USA they are targeting sprouts 20-30 cm long, to maximise productivity whilst minimising blockages of planting machinery (Anonymous 2015; Smith, Stoddard *et al.* 2009).

However, in the USA they may use sprouts between 13-18 cm long, classified as marginal (Barkley, Schultheis *et al.* 2013). In their best bedding root density (20 kg/m^2), in a once-over harvest of sprouts, Evangeline produced 310 usable sprouts m^{-2} greater than 18 cm in length, with an additional 22 marginal sprouts m^{-2}. In contrast, Covington had a much greater proportion of marginal sprouts (96 m^{-2}), with 257 usable sprouts m^{-2} greater than 18 cm in length (Barkley, Schultheis *et al.* 2013). In such instances, depending on the desired sprout specifications, the grower may have to delay harvest of Covington sprouts for example.

Sprouts with apical tips have consistently been shown to be the highest yielding plant materials (Coleman, Maltby *et al.* 2006; Hossain and Mondal 1994), so unless planting material is in short supply, only these should be used. Back-cuttings from long sprouts should be discarded.

Australian references suggest 35-45 cm sprouts are most desired, although this can depend on the planting process and equipment (Coleman, Maltby *et al.* 2006; Dennien, Homare *et al.* 2013). Generally sprouts in the range of 20-50 cm are considered acceptable, and will be planted.

Post-harvest sprout management

Sprouts are general used within 1 day of harvesting. They should not be dipped in a water bath, as this can spread disease (Anonymous 2015). In some instances, growers prefer to store the sprouts in cool shade for 48 hours, to enhance early root initiation prior to planting (Edison, Hegde *et al.* 2009). In contrast, (Dennien, Homare *et al.* 2013) suggest that roots kept longer than 24 hours may have problems with damage to roots initiating from the stored cuttings.

Cutting height

In China they advocate cutting at least 10 cm above the bed surface, although no reason is given for this practice (Zhang, Wang *et al.* 2009). In the USA they advocate cutting 2-3 cm above ground level, to avoid spreading disease from plant beds to the commercial field (Smith, Stoddard *et al.* 2009).

Nutrition

In the USA, they advocate 0.5 kg m-2 of complete fertiliser (8:8:8) raked into the tops of beds, or alternatively 4 t/ha incorporated into the soil pre-bedding. They follow up with 60-180 kgN/ha after sprout cutting or leaching rain (Anonymous 2015; Smith, Stoddard *et al.* 2009).

(Thompson, Thornton *et al.* 2010) didn't find any impact of source of K in yields of commercial Covington or Evangeline. Whether this applies to plant bed sprout production is unknown.

Australian recommendations are much lower. At bedding, 100 g m-2 of complete fertiliser (5:6:5) is applied, with 30-40 kgN/ha (e.g. as potassium nitrate following each sprout harvest (Lovatt 2013)).

Irrigation and drainage

Adequate drainage of plant beds is critical to reduce plant bed decline, particularly through fungal and bacterial diseases. In grower experience waterlogging appears to be the greatest factor contributing to rapid plant bed decline. Many growers are increasing the heights of their plant beds to try and mitigate this issue.

Rapid growth and regeneration of sprouts depends on adequate water supply. Both drip and sprinkler irrigation systems can be effectively used, as demonstrated in the USA (Smith, Stoddard *et al.* 2009). The advantage of drip is better uniformity and operation in windy weather. It is however more prone to damage from the sprout harvesting operations. Drip irrigation can also be used to supply nutrients as required. Over-irrigating is probably more hazardous than under-irrigating, particularly at the early stages, when soils are cool (Lovatt 2013).

Application of commercial sweetpotato agronomy studies to plant bed systems

Recent work at Louisiana State University on understanding sweetpotato storage root initiation; nutrients as triggers; and early determination of plant yield potential, may have fascinating consequences for plant bed management. Examples are:

Analogous to commercial sweetpotato root system production, how do plant beds, roots and sprouts respond to nutrient availabilities and distribution within the plant bed?

Does the form of fertiliser (e.g. nitrate versus ammonium N), impact on the initiation and development of sprouts, as it does with root development? Are there cultivar differences in responses?

Can we develop a system for predicting the potential performance of plant bed sprouts, based on a protocol of assessment in a controlled environment? Can we prescribe an optimal sprout configuration?

Bibliography

Akers D, McCrystal R*, et al.* (2014) Integration of crop and soil insect management in sweetpotato. Horticulture Australia Ltd, No. VG09052, Sydney, NSW, Australia.

Akoroda M (2009) Sweetpotato in West Africa. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 441-468. (Springer Netherlands)

Anonymous (2015) Growing Your Seedstock. In. Vol. 2015'. pp. North Carolina sweetpotato grower advisory factsheet. (North Carolina Sweetpotato Commission: North Carolina Sweetpotato Commission)

Arancibia RA, Main JL, Clark CA (2013) Sweetpotato Tip Rot Incidence Is Increased by Preharvest Applications of Ethephon and Reduced by Curing. *Horttechnology* **23**(3), 288-293.

Atu LL (2014) Studies on propagation materials and growing conditions for sweetpotato [Ipomoea Batatas (L.) Lam] production. University of Queensland, Brisbane, Australia

Barkley SL, Schultheis JR, Jennings KM (2013) Optimizing sweetpotato seed bed density for plant production. *Hortscience* **48**(9), 1.

Beaulieu JC, Marsh DB (2002) Influence of bed cover types on production time and quality of sweetpotato slips. *Horttechnology* **12**(4), 691-694.

Bourke RM (2009) Sweetpotato in Oceania. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 489-502. (Springer Netherlands)

Bryan AD, Pesic-VanEsbroeck Z, Schultheis JR, Pecota KV, Swallow WH, Yencho GC (2003) Cultivar decline in sweetpotato: I. Impact of micropropagation on yield, storage root quality, and virus incidence in 'Beauregard'. *Journal of the American Society for Horticultural Science* **128**(6), 846-855. [In English]

Bryan AD, Schultheis JR, Pesic-VanEsbroeck Z, Yencho GC (2003) Cultivar decline in sweetpotato: II. Impact of virus infection on yield and storage root quality in 'Beauregard' and 'Hernandez'. *Journal of the American Society for Horticultural Science* **128**(6), 856-863. [In English]

Campilan D (2009) Sweetpotato in Southeast Asia: Assessing the Primary Functions of a Secondary Crop. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 469-481. (Springer Netherlands)

Clark CA (1989) Influence of volatiles from healthy and decaying sweet potato storage roots on sclerotial germination and hyphal growth of Sclerotium rolfsii. *Canadian Journal of Botany* **67**(1), 53-57.

Clark CA, da Silva WL, Arancibia RA, Main JL, Schultheis JR, van-Esbroecle ZP, Jiang C, Smith J (2013) Incidence of End Rots and Internal Necrosis in Sweetpotato Is Affected by Cultivar, Curing, and Ethephon Defoliation. *Horttechnology* **23**(6), 886-897.

Clark CA, Davis JA*, et al.* (2012) Sweetpotato Viruses: 15 Years of Progress on Understanding and Managing Complex Diseases. *Plant Disease* **96**(2), 168-185. [In English]

Clark CA, Holmes GJ, Ferrin DM (2009) Major Fungal and Bacterial Diseases. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 81-103. (Springer Netherlands)

Clark CA, Hoy MW (2006) Effects of common viruses on yield and quality of Beauregard sweetpotato in Louisiana. *Plant Disease* **90**(1), 83-88.

Clark CA, Hoy MW, Kokkinos CD (2004) Yield decline of sweetpotato cultivars and virus infection. *Phytopathology* **94**(6), S19-S20. [In English]

Clark CA, Smith TP, Ferrin DM, Villordon AQ (2010) Performance of Sweetpotato Foundation Seed after Incorporation into Commercial Operations in Louisiana. *Horttechnology* **20**(6), 977-982. [In English]

Coleman E, Maltby J, McCrystal R, O'Donnell B, Playford C (2006) Developing smooth skin easy to peel sweetpotatoes. Horticulture Australia Ltd, No. VG02114, Sydney, NSW, Australia.

Dangler JM (1994) Rowcovers improve sweetpotato transplant production in field beds and hotbeds. *HortTechnology* **4**(1), 57-60.

Dennien S, Homare D, Hughes M, Lovatt J, Coleman E, Jackson G (2013) 'Growing healthy sweetpotato: best practices for producing planting material.' (Australian Centre for International Agricultural Research: Canberra Australia) 176 pp.-176 pp.

Duarte V, Clark CA (1992) PRESENCE ON SWEET-POTATO THROUGH THE GROWING-SEASON OF ERWINIA-CHRYSANTHEMI, CAUSE OF STEM AND ROOT-ROT. *Plant Disease* **76**(1), 67-71. [In English]

Duarte V, Clark CA (1993) INTERACTION OF ERWINIA-CHRYSANTHEMI AND FUSARIUM-SOLANI ON SWEET-POTATO. *Plant Disease* **77**(7), 733-735.

Edison S, Hegde V, Makeshkumar T, Srinivas T, Suja G, Padmaja G (2009) Sweetpotato in the Indian Sub-Continent. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 391-414. (Springer Netherlands)

Feng G, Yifu G, Pinbo Z (2000) Production and deployment of virus-free sweetpotato in China. *Crop Protection* **19**(2), 105-111.

Fuentes S, Chujoy E (2009) Sweetpotato in South America. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 415-440. (Springer Netherlands)

Fuglie KO (2007) Priorities for Sweetpotato Research in Developing Countries: Results of a Survey. *HortScience* **42**(5), 1200-1206.

Gaba V, Singer S (2009) Propagation of Sweetpotatoes, In Situ Germplasm Conservation and Conservation by Tissue Culture. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 65-80. (Springer Netherlands)

Gibson RW, Kreuze JF (2015) Degeneration in sweetpotato due to viruses, virus-cleaned planting material and reversion: a review. *Plant Pathology* **64**(1), 1-15.

Hall MR (1990) Short-duration presprouting, ethephon, and cutting increase plant production by sweet potato roots. *Hortscience* **25**(4), 403-404.

Hall MR (1992) BRIEF EXTENSIONS OF CURING AND PRESPROUTING INCREASED PLANT-PRODUCTION FROM BEDDED SWEET-POTATO. *Hortscience* **27**(10), 1080-1082.

Hall MR (1993) MIDSTORAGE HEATING INCREASED PLANT-PRODUCTION FROM BEDDED SWEET-POTATO ROOTS. *Hortscience* **28**(8), 780-781.

Hall MR (1994) COMBINED HEATING APPLICATIONS INCREASED PLANT-PRODUCTION FROM BEDDED SWEET-POTATO ROOTS. *Hortscience* **29**(9), 1022-1024.

Holmes GJ, Stange RR (2002) Influence of wound type and storage duration on susceptibility of sweetpotatoes to Rhizopus soft rot. *Plant Disease* **86**(4), 345-348. [In English]

Hossain MM, Mondal MAA (1994) Effect of vine parts on the growth and yield of three sweet potato varieties. *Bangladesh Journal of Scientific and Industrial Research* **29**(3), 181-184.

La Bonte D, Clark C, Villordon A, Cannon J, Hoy M, Sistrunk M, Freeman E, Roberts G (2004) Yield of four generations of virus-tested sweetpotato. *HortTechnology* **14**(3), 320-322. [In English]

La Bonte DR, Villordon AQ, Schultheis JR, Monks DW (2000) Black polyethylene tunnel covers affect plant production and quality of sweetpotato transplants. *Hortscience* **35**(2), 202-204. [In English]

La Bonte DR, Wilson PW, Villordon AQ, Clark CA (2008) 'Evangeline' Sweetpotato. *Hortscience* **43**(1), 258-259.

Laranang LB, Basilio CS (2002) Strengthening local systems for producing sweetpotato planting materials. In 'UPWARD Field Notes. Vol. 11'. pp. 8-11. (UPWARD Network: Manila, Philippines)

Li-ming Z, Qing-mei W, Dai-fu M, Yi W The effect of major viruses and virus-free planting materials on sweetpotato root yield in China. In 'II International Symposium on Sweetpotato and Cassava: Innovative Technologies for Commercialization 703', 2005, pp. 71-78

Loebenstein G, Cohen J, Dar Z (2009) Sweetpotato in Israel. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 483-487. (Springer Netherlands)

Loebenstein G, Thottappilly G, Fuentes S, Cohen J (2009) Virus and Phytoplasma Diseases. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 105-134. (Springer Netherlands)

Lovatt J (2013) Producing sweetpotato sprouts as planting material. In. Vol. 2014'. Ed. J Lovatt). (Department of Agriculture, Fisheries and Forestry (QLD): Brisbane, Australia)

Low J, Lynam J, Lemaga B, Crissman C, Barker I, Thiele G, Namanda S, Wheatley C, Andrade M (2009) Sweetpotato in Sub-Saharan Africa. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 359-390. (Springer Netherlands)

Martin WJ (1962) Elimination of root-knot nematodes from infested sweetpotato roots and plants. *Plant Disease Reporter* **46**(1), 21-23 pp. [In not specified]

Mtileni M (2014) Sweet potato nurseries for multiplication. In. Vol. 2015'. (ARC-Roodeplaat Vegetable and Ornamental Plant Institute Pretoria, South Africa)

Overstreet C (2009) Nematodes. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 135-159. (Springer Netherlands)

Porter WC (1991) Bed covers alter temporal distribution of production of sweetpotato transplants. *HortScience* **26**(3), 252-253.

Pozzer L, Silva JBC, Dusi AN, Kitajima EW (1995) Performance of micropropagated sweet potato plants after two field propagations and rate of reinfection by sweet potato feathery mottle virus. *Fitopatologia Brasileira* **20**(3), 464-468.

Rashid T, Abel CA, Adams LC (2010) Insect Population Monitoring and Damage to Sweetpotatoes. *Hortscience* **45**(4), 509-509. [In English]

Rolston LH, Clark CA, Cannon JM, Randle WM, Riley EG, Wilson PW, Robbins ML (1987) 'Beauregard' sweet potato. *HortScience* **22**(6), 1338-1339. [In English]

Smith TP, Stoddard S, Shankle M, Schultheis J (2009) Sweetpotato Production in the United States. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 287-323. (Springer Netherlands)

Sorensen KA (2009) Sweetpotato Insects: Identification, Biology and Management. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 161-188. (Springer Netherlands)

Stevens C, Khan V, Tang A, Bonsi C, Wilson M (1990) Long-term effect of soil Solarization on controlling root-knot nematodes in sweetpotato. *HortScience* **25**(8), 855-855.

Stoddard CS, Davis M, Ploeg A, Stapleton J (2010) Methyl Bromide Fumigation Alternatives for Sweetpotato Hotbeds in California, Year 2. *Hortscience* **45**(4), 506-506.

Thompson WB, Thornton AC, Smith T, Schultheis JR (2010) Yield Response of 'Evangeline' and 'Covington' Sweetpotato to Various Potash Carriers and Rates. *Hortscience* **45**(4), 506-506. [In English]

Villordon A, Clark C, LaBonte D, Firon N (2012) 1-Methylcyclopropene Has a Variable Effect on Adventitious Root Emergence from Cuttings of Two Sweetpotato Cultivars. *Hortscience* **47**(12), 1764-1767.

Villordon AQ, LaBonte DR (1996) Genetic Variation among Sweetpotatoes Propagated through Nodal and Adventitious Sprouts. *Journal of the American Society for Horticultural Science* **121**(2), 170-174.

Wolfenden R, Dennien S, Coleman E, McCrystal R, Henderson CWL, Langenbaker R (2014) Evaluating sweetpotato varieties to meet market needs. Horticulture Australia Ltd, No. VG09009, Sydney, NSW, Australia.

Zhang L, Wang Q, Liu Q (2009) Sweetpotato in China. In 'The Sweetpotato.' (Eds G Loebenstein and G Thottappilly) pp. 325-358. (Springer Netherlands)