Herbicides for the Australian sweetpotato industry: a review of possible products

Nil herbicide treatment

Herbicide treatment

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Summary

Essential to the maximisation of sweetpotato yield is the minimisation of production constraints. Weeds are recognised as a constraint affecting growth and productivity, that if not controlled, can cause severe yield losses.

In Australia, there are currently only six (6) herbicides registered for use in sweetpotato crops. Three are weed pre-emergent herbicides, two are herbicides specifically for grass control, and one is a non-selective contact herbicide for spraying off the crop prior to harvest (pre-harvest crop desiccation).

This review identifies herbicide options that are currently available or being researched in other countries with highly commercialised sweetpotato systems, in particular the United States of America (USA) and Canada. There are fourteen (14) herbicides available to north American sweetpotato growers. Seven are applied to the soil before transplanting sweetpotato vines. There are four herbicides registered for post-transplant application. Three herbicides are registered for grass control. Five of these registered herbicides are also able to be used as directed sprays between rows before the plant canopies cover all crop and interrow areas.

The review also identifies six herbicides which have been researched for use in sweetpotato but are not registered in Australia and four herbicide mixes that have been trialled though not yet registered for use in Australia.

While no single herbicide will solve weed problems in sweetpotato production systems, further research and validation of a number of the reviewed products (bicyclopyrone, flumioaxin, clomazone, metribuzin, oryzalin) could potentially increase the weed control options in Australia. By having a wider range of herbicide ‘mode of action’ groups available, growers would be strengthening their defence against weeds developing herbicide resistance.

Introduction

Sweetpotato is a year-round crop in Australia, with 102,754 tonne worth $73.9 M being produced in the year ending June 2021 (Hort Innovation 2023). Globally, Australian sweetpotato growers produce the highest commercial yields per hectare of sweetpotato (100/t/ha) (Dennien et al. 2017). Essential to maximising yield is minimising production constraints, weeds are widely recognised as a constraint affecting sweetpotato growth and productivity.

If not controlled, weeds can cause severe yield losses. Nedunzhiyan et al. (1998), quotes research identifying 22% yield loss in Hawaii, 91% in Nigeria and 70% to 91% in India. In the USA, La Bonte et al. (1999) found yield loss due to weeds could be between 55% and 63%. This is supported by Harrison and Jackson (2011), whose trials showed weeds caused 50% yield loss.

After the vines reach row closure, sweetpotatoes suppress weeds well, so the critical period for weed control occurs pre-row closure (Nedunzhiyan et al. 1998, Seem et al. 2003). Research indicates the important period to control weeds is between two weeks after transplanting (WAT) and six to eight WAT (Nedunzhiyan et al. 1988, Levett 1992, Seem et al. 2003, Harrison and Jackson 2011). This time-period can change with variety and seasonality or time of planting, and other environmental conditions that affect both sweetpotato and weed growth (Levett 1992, Harrison and Jackson 2011). From a practical production aspect, planting into weed free fields is an important first step in growing sweetpotato (Dutta et al. 2018, Phillips 2022).

Currently in Australia, there are only six herbicides registered for use in sweetpotato crops. Three of them are weed pre-emergent herbicides (chlorthal-dimethyl, metolachlor and S-metolachlor [different isomer of metolachlor]). Two are herbicides specifically for grass control (fluazifop-P [minor use permit till 30 November 2027] and sethoxydim), and one non-selective contact herbicide for spraying off the crop prior to harvest (diquat) (APVMA 2022, Infopest 2022). In October 2023, diquat is under review by APVMA with a proposed regulatory decision expected in May 2024 (APVMA 2023). In addition to these chemicals, there are several herbicides that can be used in fallows and in preparation of a clean bed for sowing. There are no registered herbicides that can be sprayed over the sweetpotato crop canopy to control broadleaf weeds (APVMA 2022, Infopest 2022).

To date, Australia has 48 weed species (21 grasses and 28 broadleaf) recorded as having resistance to at least one herbicide mode or action group (Anon 2022b). With sweetpotato registered herbicides only covering four herbicide mode of action groups, (groups 1, 3 15 and 22), the concern of herbicide resistance does need to be respected by the Australian sweetpotato industry.

This review will provide the sweetpotato industry with knowledge of herbicide options that are available in other countries with highly commercialised sweetpotato systems, in particular the USA and Canada. The report also looks at herbicide trials that have been conducted for products that are not yet registered in these and other production systems.

This document does not recommend the practices or herbicides being reviewed, or whether they should be used in Australian sweetpotato farming systems. By law only chemicals that have been assessed and registered for Australian use can be used on Australian farms. This review does provide some background information, that may assist the sweetpotato industry in deciding whether there may be benefit in facilitating the process having these herbicides registered.

Herbicide currently available for sweetpotato farmers in USA and Canada

Herbicides applied to the soil before transplanting sweetpotato vines

There are eight herbicides available to north American sweetpotato growers that are applied to the soil before transplanting sweetpotato vines. Six of these herbicides, caprylic acid + capric acid, carfentrazon-ethyl, glyphosate, paraquat, pelargonic acid and pyraflufen-ethyl are plant contact herbicides that are registered for pre-crop, post-emergent weed control. The other herbicides, bicyclopyrone and flumioxazin have both pre-emergent and post-emergent activity.

There herbicides are discussed below in terms of their current or potential use in Australia, highlighting key information about their use in the USA and Canada.

Bicyclopyrone has systemic pre-emergent and post-emergent broadleaf weed control and may partially control some grasses. Care needs to be taken when using it on low organic matter soils. While bicyclopyrone has APVMA approval for use in Australia, it is currently only available as a herbicide mixture in the product Talinor®. Talinor® is registered for post-emergent control of broadleaf weeds in wheat and barley (APVMA 2023). Bicyclopyrone belongs to group 27 herbicide mode of action group (MoA) (previously H) (APVMA 2017a).

Syngenta USA label precautions associated with bicyclopyrone (sold as Optogen® in USA) use are;

- The 257 ml/ha rate may be used on coarse textured soils for extended weed control but the risk for unacceptable crop injury is higher than the 190 ml/ha rate.
- If sweetpotato roots are not sealed prior to application, irrigation or rainfall within 2-3 days after application increases the risk of unacceptable crop injury.
- Application to sweetpotatoes grown on sandy loam soils with <1% organic matter (OM) is at a higher risk for unacceptable crop injury than soils with >1% OM.
- Tank mixtures with other herbicides may increase the risk of crop injury.
- Under adverse weather conditions (cool, wet, poor growth), temporary crop bleaching may be observed following application.

Cutulle (2017) identified that there may be some differences in sweetpotato variety tolerances to bicyclopyrone. Smith et al. (2019) showed that this herbicide may have potential use in weed control in seed beds, applied after soil coverage of the mother roots. (Appendix 1)

Flumioxazin controls broadleaf weeds but only suppresses annual grasses. It has pre-emergence activity through root absorption and post-emergence through foliar contact. In the USA the label has a has a number of conditions when used with sweetpotato;

- Do not use with transplants that have been harvested more than two days prior to transplanting.
- Do not use on any variety other than Beauregard without first testing it and checking the variety has an acceptable tolerance level.
- Significant injury can occur from applications made on poorly drained soils or application made under wet conditions.

In Australia, flumioxazin (group 14 MoA, previously G) is registered for use in cotton, several field crops, lucerne and sugarcane. The Valor® 500 WG label (APVMA PubCRIS 2022) identifies a plant back period for sweetpotato of eight months if the product is used in sugarcane at the 700 g/ha rate and the soil has been thoroughly cultivated after the sugarcane has been grown and before sweetpotato is planted. Rates used with sweetpotato crops in north America are much lower than 700 g/ha. In Canada the application rate is 105 g/ha, while in the USA 2 oz/acre (120 g/ha approx.) or less (Note: product and active ingredient [ai] rates differ in both countries). (Appendix 1)

Caprylic acid + capric acid does not have registration or APVMA permit for use in Australia. It is a non-selective, post-emergent weed herbicide that is not translocated in the plant, necessitating good plant coverage for effective weed control. It is registered for use with numerous vegetables, field and tree crops and non-agricultural sites in the USA. Stoddard (2016) found it showed promise as a herbicide for organic sweetpotato production. (Appendix 1)

Carfentrazone-ethyl is a group 14 MoA (previously G) herbicide and has registration in Australia. In cropping situations, it is used in pre-plant broadacre weed control and for broadleaf weed control in winter cereals. It is a rapid knockdown contact herbicide that is non-residual. It is often mixed with other herbicides to broaden the weed control spectrum (NRA 2000). (Appendix 1)

Glyphosate is a group 9 MoA (previously G) herbicide and has registration in Australia. It is a broad spectrum, non-selective, post-emergent systemic herbicide. It kills or suppresses most plants and is used to control annual and perennial broadleaf and grass weeds in both agricultural and non-agricultural settings (APVMA 2017b). In Australian sweetpotato production it is often used in planting preparation

prior to sowing. While effective in controlling a wide range of weeds, it does not control later germinations and emergence (AgAware Consulting 2014). (Appendix 1)

Paraquat is a group 22 MoA (previously L) herbicide and is registered in Australia. It is a non-selective strictly contact herbicide that is applied to emerged weeds. It controls annual grasses and most broadleaf weeds. It is often used to control emerged weeds prior to crop planting or crop emergence. It is also used as a shielded spray to control interrow weeds. (Appendix 1)

Pelargonic acid (also known as nonanoic acid) has registration for use in Australia. Pelargonic acid belongs to the group 0 MoA (previously O) herbicides. It is an organic contact herbicide that is registered for use in orchards, vineyards and fallow soil for control of seedling and young broadleaf and grass weeds. Established weeds and perennial species are generally only suppressed. (Appendix 1)

Herbicides that may be applied after transplanting sweetpotato vines

There are four herbicides available to north American sweetpotato growers that may be applied after transplanting sweetpotato vines (Appendix 2). They are clomazone, chlorthal-dimethyl, napropamide and S-metolachlor.

Clomazone is registered in Australia for use on cucurbits, green beans, Navy beans, potatoes, poppies, rice and tobacco. It is a pre-emergent weed control herbicide belonging to group 13 MoA (previously Q). Cucurbit transplants are sensitive to the chemical as are emerged potatoes.

The Australian label states clomazone should not be applied to soils with organic carbon levels less than 2% and clay content less than 15%. In the USA clomazone is one of the most widely used herbicides on sweet potato, used in 50-85% of the production area (Wadl et al. 2020). It can cause temporary injury (whitening of leaf or stem tissue) to the sweet potato crop, from which the crop will recover (Wadl et al. 2020). Porter (1990) found that sweetpotato was tolerant to clomazone when applied at rates more than 1.7 kg/ha, although at 3.4 kg/ha temporary chlorosis lasting one week was seen. Porter (1990) found clomazone provided good weed control in the weed spectrum he tested, (being the then main weeds in many USA production areas). In 2016, Barkley et al. found it provided poor weed control of Palmer amaranth (*Amaranthus palmeri*), by then one of the most common and problematic weeds in North Carolina. Hughes (2001) found it only provided moderate control to weeds in pumpkin trials in far north Queensland. (Appendix 2)

Chlorthal-dimethyl is currently registered in Australia for use with sweetpotatoes. It is a group 3 MoA (previously D) herbicide. Chlorthal-dimethyl is a general knockdown and residual herbicide that can be sprayed at transplanting and a lay-by application made up to six weeks after transplanting. Harper et al. (1990) review of four sweetpotato herbicide comparison trials between 1984 and 1987 found chlorthal-dimethyl preformed poorly in comparison to the other herbicides, and on one occasion when there was a four-hour delay before incorporation by rainfall, this herbicide caused phytotoxic symptoms in sweetpotato. (Appendix 2)

Napropamide is a group 0 MoA (previously D) herbicide. In Australia, it is registered for use in almonds, grape vines, stone fruit, tomatoes and canola. It also has minor use permits for basil and transplanted brassica vegetables. Napropamide is used for pre-emergent weed control. It is particularly sensitive to photodegradation, so needs to be irrigated or incorporated into the soil soon after application. High temperatures also accelerate its breakdown.
Napropamide is the only herbicide registered in the USA for use in plant propagation beds (Smith et al. 2019). It appears to have shown good results in trials in the 1990's but there does not appear to have been much research done with it since then. A University of Arkansas trial in 2001 found napropamide applied post-transplant to be safe for sweetpotato but was limited in its weed control ability (Talbert et al. 2004). Barley et al. (2016) found it provided inconsistent control of Palmer amaranth. (Appendix 2)

S-metolachlor is a group 15 MoA (previously K) herbicide that is registered for use in sweetpotato crops in Australia. It controls and suppresses a wide range of grass and small seeded broadleaf weeds and in the USA is the only registered herbicide that has activity on yellow nutgrass (*Cyperus esculentus*) (Beam and Jennings 2018). In Australia S-metolachlor is not registered for yellow nutgrass control.

Care needs to be taken when timing S-metolachlor application. Excessive rainfall, particularly if the herbicide is applied immediately after transplanting, can have a detrimental effect on plant growth. This can be further exacerbated with high temperatures (Meyers et al. 2012, Abukari et al 2015a, Abukari et al. 2015b). Many Australian growers are cautious about using S-metolachlor for this reason.

Between 1984 and 1987 Queensland Department of Primary Industry officers conducted four trials examining potential herbicides for broadleaf and grass control in sweetpotato. Over all trials, metolachlor ranked first for overall sweetpotato yield and third for overall weed control (Harper et al. 1990). (Appendix 2)

Herbicides that may be applied between rows of sweetpotato

There are five herbicides available to north American sweetpotato growers for spay application between rows before the vines reach row closure. These herbicides are all toxic to sweetpotato and must be applied by directed nozzles, covered/hooded/shielded sprayers or wipers to ensure the herbicide does not contact the sweetpotato plants.

Carfentrazone-ethyl, glyphosate and pelargonic acid (nonanoic acid) do have registration in Australia, but not for specific use in sweetpotato. Bicyclopyrone has registration for use in Australia as part of a mixed product herbicide for control of broadleaf weeds in wheat and barley. For more details refer to the section above 'Herbicides applied to the soil before transplanting'. (Appendix 3)

Herbicides specifically for grass control in sweetpotato crops

North American sweetpotato growers have four herbicides available for use in controlling grass weeds in their crops. These herbicides will not control sedges or broadleaf weeds (Appendix 4).

Clethodim a group 1 MoA (previously A) is registered in Australia for control of certain grass weeds in numerous crops but is not specifically registered for use in sweetpotato. In the USA it is used as a post-transplant application for control of emerged grass weeds. (Appendix 4)

Fluazifop-P is a group 1 MoA (previously A) herbicide. It has a minor use permit in Australia for use in sweetpotato crops until 30 November 2027. In the USA it is used as a post-transplant application for control of emerged grass weeds. (Appendix 4)

Sethoxydim is a group 1 MoA (previously A) herbicide. It is registered in Australia for use on sweetpotato. It should be applied when most grasses are in the two to six leaf stage and are actively growing. (Appendix 4)

Herbicides being researched but not yet registered for use in sweetpotato

There are six herbicides which are not registered for use in the USA or Canada, that have been researched for their ability to control weeds in sweetpotato crops.

Fluridone is a group 12 MoA herbicide. In addition to being a herbicide, fluridone can act as a seed germination stimulant to create more uniform weed seed germination, reducing the soils seedbank. It binds to organic matter so is most efficient in low organic matter soils. Until 2000, it was used in Australia under APVMA permits for control of aquatic weeds. It has been trialled as a herbicide for southern Australian field cropping situations (Goggin and Powles 2014) but there is no current registration. In Australia herbicide resistance has been found to group 12 herbicides in populations of wild radish (*Raphanus raphanistrum*) and Indian hedge mustard (*Sisymbrium orientale*) (Anon 2022a).

Field studies by Meyers et al. (2014) found minimal sweetpotato damage (<6%) from pre-plant application of fluridone and good control of Palmer amaranth and red root pigweed (*Amaranthus retroflexus*). Post-emergent application resulted in up to 30% damage levels to sweetpotato. In several

trials yields equalled those of hand weeded plots. Between 2015 and 2017, trials at University of Delaware using fluridone as a pre-transplant application showed variable results. Weed control was not as good as the control treatment and there was significant early season injury to sweetpotato, although this did not necessarily result in final yield reduction. One occasion when higher rates were trialled there was a 24% yield reduction (Scott and VanGessel 2018). 2016 trial results in California found significant injury when fluridone was used pre-transplanting, and less injury when applied post-transplanting. The post-transplant application still caused extensive, although slight, crop injury which was still visible two weeks after application (Stoddard 2016). Data presented to the 52nd Annual Sweetpotato Meeting (UCCE Classroom, Merced CA, February 7, 2017) showed fluridone at all rates caused unacceptable levels of crop injury and poor weed control with significant yield losses.

Fomesafen is a group 14 MoA herbicide (previously G). It is registered in Australia for the control of broadleaf weeds when applied prior to sowing or post-sowing, pre-emergence in chickpeas, narrow leaf lupins, lentils, field peas, faba beans and vetch. It is a soil applied residual herbicide that is absorbed through the roots.

In the USA, in addition to dry beans, it is also registered for use in cotton, potatoes, and soybean. In trials at the University of Delaware, Scott and VanGessel (2018) found that fomesafen provided weed control equal to the standard, although in the 2015 trial it was less effective on morning glory spp (*Ipomoea* spp.) and in the 2017 trial less effective in controlling smooth pigweed (*Amaranthus hybridus*). Barkley et al. (2016) found fomesafen provided good control of Palmer amaranth with minimal injury to sweetpotato.

It should be noted that the USA label, Reflex®, does state the planting time from last herbicide application till sweetpotato planting is 12 months.

Linuron is a group 5 MoA herbicide (previously C). In Australia, it is registered for use in several crops (wheat, barley, oats, potatoes, carrots, parsnips, coriander seed crops, onions, soybean, maize and sweetcorn). From 1984-1987, it was trialled in Australia for use in sweetpotato. In some trials it gave good weed control, but in others there was significantly reduced sweetpotato plant population or severe phytotoxic effects on the plants. Overall, linuron did not consistently perform as well as metolachlor (Harper et al.1990).

In the USA, trials have been conducted with Linuron alone or combined with other herbicides to control Palmer amaranth a significant weed pest which can reduce sweetpotato yield by 80-85% if left uncontrolled. These trials have shown increased phytotoxicity as the linuron rates are increased and in some cases crop stunting (Beam et al. 2018, Scott and VanGessel 2018, Moore et al. 2021). Scott and VanGessel (2018) found linuron applied as a single application gave poor weed control, although when a second application was made 14 days later weed control was acceptable. If a level of crop injury is accepted, it may have a role in herbicide combination strategies to control Palmer amaranth.

In a research study in Brazil (dos Santos et al. 2018) saw that while there were some cultivar differences, linuron treatments yielded 24% less than mechanical weeding.

Metribuzin is a group 5 MoA herbicide (previously C). It is registered in Australia for selective weed control in barley, chickpeas, faba beans, lentils, vetch, lupins, and some broadleaf weeds and may be used pre- or post-emergent depending on the crop and situation. Metribuzin may cause damage to crops grown on sandy soils or those low in organic matter.

Meyers et al. (2017) noted that multiple trials in the 1980's and 1990's showed minimal toxicity from metribuzin applied pre- or post-transplant, when applied at ai rates of less than 900 g/ha, although there was some varietal sensitivity to the chemical. Meyers et al. (2017) trials indicated that metribuzin provided good control of Palmer amaranth and sweetpotato injury was limited when applied at 140g/ha and the application was delayed until at least two weeks after planting.

Oryzalin is a group 3 MoA (previously D) herbicide. In Australia, oryzalin is registered for pre-emergent control of certain annual grasses and broadleaf weeds in fruit and nut orchards, vineyard, nursery stock, ornamentals, amenity plantings and turf. Areas to be planted need to be free of established weeds. It kills plants by inhibiting cell division in the roots stopping development of germinating weed seeds (Chaudhari et al. 2018).

Glaze and Hall (1990) found that oryzalin controlled a level of weeds and had no effect on sweetpotato yield of variety 'Georgia Jet'. On susceptible varieties, oxyzalin will cause plant stunting and leaf distortion for up to 10-14 weeks after planting. Less injury is caused when the herbicide is applied directly after transplanting (3-7%) than when applied two weeks later (11-13%) (Meyers et al. 2017, Chaudhari et al. 2018). Plants grow out of the injury and the stunting and distortion does not seem to affect marketable yields which were found to be comparable to the hand-weeded control (Meyers et al. 2017, Chaudhari et al. 2018). It is sill unknown what effects soil incorporation and/or rainfall that may place oxyzalin in direct contact with sweetpotato during the root initiation phase could do to crop development (Chaudhari et al. 2018).

Pendimethalin is a group 3 MoA (previously D) herbicide. It is a pre-emergent selective herbicide for control of annual grasses and some broadleaf weeds. In Australia, it is registered for use in numerous vegetable, field and tree crops. Meyers et al. (2019) conducted multi-site trials in the USA on using pendimethalin for weed control. They found that pendimethalin caused a minimal level of plant stunting which the plants outgrew and reduced the cannery grade yield but not other sizes or total marketable yield. Meyers et al. (2019) also noted that pendimethalin would need to be used with other herbicides, as alone it did not provide enough long season weed control. Trials in New Zealand by Lewthwaite and Triggs (2000), did not find any evidence of plant damage by pendimethalin, but storage root yields were significantly less than the best treatments in the trial. A trial by Hughes (2021) provided support to the theory that pendimethalin may have a detrimental influence on root development in the early stages of plant growth.

Herbicide Combinations

With few new herbicides suitable for sweetpotato production being made available, a number of researchers have studied the effects of herbicide combinations to better manage weeds in sweetpotato crops. Much of the USA research has been to find a method to control Palmer amaranth, a serious weed for sweetpotato farmers. Palmer amaranth is such a serious pest, American growers are willing to accept a small level of damage to their sweetpotato crops if the weed can be controlled.

Atrazine + S-metolachlor De Lima et al. (2022) studied post-emergent herbicides for application to sweetpotato being grown for biofuel in Brazil. They found a mixture of atrazine and S-metolachlor applied at 3.5 L/ha, despite showing some initial effects, did not affect yield quantity and quality parameters. They also noted Nigerian studies that did show a decrease in yield when using rates higher than 1.5 kg/ha ai (de Lima et al. 2022). Unfortunately, the ai rates were not given in the publication, so it is not known if both authors were comparing the same products (Appendix 5). In an earlier Brazilian study, Lima et al. (2020) found a mixture of atrazine (370 g/ha ai) and S-metolachlor (290 g/ha ai) while affecting some early growth did not affect yield of sweetpotato variety 'Duda', a variety bred for ethanol production. This trial also showed no significant difference with the single S-metolachlor treatment (Appendix 5).

Note – due to recognised health risks, the European Union banned the use of atrazine in 2003 (Berthsass and Colangelo 2013). In 2008 the Australian Pesticides and Veterinary Medicines Authority (APVMA) completed a review on atrazine and was satisfied that atrazine registered products continue to meet the conditions prescribes by the Agvet Codes (APVMA 2008).

Clomazone + flumioxazin Kelly et al. (2006) trialled a combination of clomazone (840 g/ha) and flumioxazin (three rates – 36, 72 and 109 g/ha) as both pre- and post-transplant applications. The pre-emergent application showed no damage to sweetpotato plants at any of the three rates of flumioxazin. Post-transplant application showed increasing injury to sweetpotato as the rate of flumioxazin increased. The combination provided high control rates for broadleaf signal grass (*Urochloa platyphylla*) and morning glory. Their recommendation was the combination be applied pre-transplant for improved broadleaf and grass weed control. (Appendix 5)

Linuron + S-metolachlor Smith et al. (2018) studying weed control in plant propagation beds found that the combination of linuron (560 g/ha ai) + S-metolachlor (800 g/ha ai) too phytotoxic to recommend for sweetpotato production. (Appendix 5)

S-metolachlor + clomozone Lima et al. (2020) trialled the mixture S-metolachlor (960 g/ha ai) and clomazone (500 g/ha ai) on the Brazilian bioethanol variety 'Cuda'. Thery found the herbicide mix did not affect sweetpotato productivity, although there was also no significant difference between the mixed treatment and single application of either S-metolachlor or clomazone. (Appendix 5)

Follow on sprays

USA sweetpotato growers are faced with several difficult to control weeds, in particular Palmer amaranth and pigweeds. Palmer amaranth has resistance to glyphosate in 28 USA states and there are reports of resistance in South America and Asia. Samples have also shown resistance to eight herbicide MoA groups (Noguera et al. 2021).

Traditionally USA sweetpotato growers have tended to only rely on one herbicide application to control weeds, and most information available to producers revolves around single herbicide application (Meyers et al. 2013). Meyers et al. 2010, found that application of flumioxazin pre-transplant followed by S-metolachlor after transplanting could provide effective control of Palmer amaranth. Unfortunately, this result was not consistent in all the trials that were conducted in that study. In a later trial series (Myers et al. 2013), the results were verified. By 2020, flumioxazin (107 g/ha) followed at seven to ten days post-transplant by S-metolachlor (800 g/ha) had become the current recommendation for Palmer amaranth control (Lindley et al. 2020, Moore et al. 2021).

Other trials studying herbicide follow on application such as. Pre-plant clomazone followed by post-transplant S-metolachlor and pre-plant linuron followed by post-transplant S-metolachlor have had mixed results (Lindley et al. 2020, Moore et al. 2021).

Discussion

Worldwide there are still no 'silver bullet' herbicides for weed control is sweetpotato, particularly those that control broadleaf weeds during crop growth. Effective weed control relies on an ongoing integrated management system, of which herbicides are one of the multiple tools used. The vision for integrated weed management systems is that the practices would be implemented using an area wide/regional approach including by farmers, councils, state authorities, environmental groups and other bodies (refer – YouTube - Beyond the fenceline. An area wide approach to weed management).

As regional scale approaches are typically difficult to implement, at least a 'whole of farm' approach to weed control needs to be considered. This should include but is not limited to herbicides, non-chemical control (tillage, rod weeding, rouging, cleaning of machinery to stop weed seed spread, etc.) and agronomic techniques (crop rotation, narrow row spacing of grains or green manure crops in the rotation, use of mulches, use of stale seedbeds [where seeds are allowed to germinate and then killed prior to planting the crop]).

Weed spectrums change with time, farming practices and in some cases as resistance to herbicides develops. Palmer amaranth is the most problematic weed in USA sweetpotato production (Moore et al. 2021). This weed has resistance to multiple herbicides in both the USA and worldwide (IHRWD 2023). Much of the herbicide research conducted in the USA has focused on managing this weed. Fortunately for the Australian sweetpotato industry, Palmer amaranth is not yet in country. This does not mean that the Australian industry can afford to be nonchalant about herbicide use and weed control, as Australia already 48 weed species with some level of herbicide resistance (Anon 2022b).

Herbicide performance is also affected by environmental factors such as sunlight, temperature, humidity, moisture stress and physical barriers (Hughes 2020). Sweetpotato varieties may also have different tolerance to herbicides (Cutulle et al. 2017, Campbell et al. 2018, Wadl et al 2020). Excessive moisture after herbicide application can also be an issue. S-metolachlor, metolachlor and oryzalin are all capable of movement in the soil with high rainfall and should not be applied if more than 12.5 mmm of rain is forecast. This is an important consideration for most Australian producers. Table 1 shows that on average the four months, April, July, August and September have less than one day with 12.5 mm in Bundaberg. This suggests that these soil leachable herbicides may have a role in Bundaberg production systems, although careful observations of weather forecasts would still be required due to rainfall variability. Much greater

caution is needed if using these herbicides in the Cudgen region. Table 2 indicates that on average, all months of the year have at least one day with greater than 12.5 mm rainfall. Again, careful monitoring of forecasts and local knowledge will be important factors when considering if and when to use leachable herbicides.

Table 1. Bundaberg rainfall statistics 2000 - 2022

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average number of days per month with rainfall > 12.5 mm	2.8	3.4	2.9	0.7	1.0	1.3	0.4	0.7	0.7	1.6	2.1	3.4
Median rainfall per month (mm)	40.6	42.6	31.0	19.0	12.2	13.4	8.4	7.6	8.8	18.0	29.6	32.2
Highest daily rainfall recorded in the month (mm)	252.0	169.0	101.2	82.2	91.8	172.0	5802	105.0	85.0	238.8	114.0	165.2

Data calculated from Bureau of Meteorology data for Bundaberg Post Office.

Table 2. Cudgen rainfall statistics 2000 - 2022

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average number of days per month with rainfall > 12.5 mm	3.3	3.5	4.4	2.6	2.7	3.4	1.0	1.0	1.1	2.0	2.3	3.2
Median rainfall per month (mm)	40.0	64.2	62.6	30.6	29.0	32.0	13.8	15.0	15.8	27.6	20.0	37.8
Highest daily rainfall recorded in the month (mm)	164.0	295.0	260.0	157.2	90.6	240.8	70.2	74.0	69.8	129.0	127.0	228.6

Data calculated from Bureau of Meteorology data Kingscliff (Woram Place).
Data for years 2008, 2009, 2010 &2011 is missing.

Conclusion

This review has identified several herbicides, some registered in Australia for use on other crops and some not, that could potentially find a role in Australian sweetpotato production systems. None of these herbicides are going to solve all problems nor are they without considerations for their use. As they are from different mode of action groups to those already registered for sweetpotato in Australia (groups 1, 3, 15 and 22), they would provide further tools to reduce the likelihood of weeds developing herbicide resistance.

Bicyclopyrone (group 27 MoA) has shown an ability to control weeds in seedbeds, although there are a number of precautionary statements with its use, and some sweetpotato varieties may be affected by it. Flumioxazin (group 14 MoA) used pre-transplant at low rates may be worth investigating although it does have precautions on varietal effects and application to poorly drained soils or in cool wet conditions. Although it did not stand out in Hughes (2001) north Queensland trials, clomazone (group 13 MoA) is the most widely used herbicide on sweetpotato in the USA. It may be worth re-evaluating for weed control effectiveness in the major sweetpotato production regions. Although the herbicides metribuzin and oryzalin are not registered for use in north America, they have had some success in weed control if farmers are willing to accept a level of injury to their crops.

It is not a given that these products will work in the Australian sweetpotato production systems and their environments. Further research, ideally on-farm and multi-locational would be required to ensure their effectiveness and value both agronomically and economically.

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Appendix 1 – Herbicides available for use in the USA and/or Canada that may be applied before transplanting vines

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
bicyclopyrone	Systemic pre-emergent and post-emergent broadleaf weed control. May partially control some grasses. Do not apply to sweetpotatoes grown on sand or loamy sand soils with less than 1% organic matter. Dry conditions may reduce pre-emergent activity. If 6 mm rain is not received in 7-10 days, rotary hoeing may activate the herbicide. Minimize the movement of treated soil during the transplanting process. For best results apply irrigation prior to transplanting and avoid tillage after application.	Approved for use in Australia - not available as a single ai product.	When mixed with other ai's is used to control broadleaf weeds in wheat and barley.
caprylic acid + capric acid	Non-selective, non-systemic, post-emergent weed control. Effective on grasses and broadleaf weeds. May have potential in organic sweetpotato production (Stoddard 2016).	Not registered in Australia.	Not registered in Australia.
carfentrazone - ethyl	Post-emergent weed control. Applied as a pre-plant burndown for emerged broadleaf weeds. There is no pre-transplant interval. When applying post-transplant, apply as a hooded spray in-row as the chemical will cause damage to sweetpotato stems and leaves.	Carfent, Carfentrazone, Carfentrosix, Chipper, Clobbertime, Consort, Elevate, Fullguard, Pummel, Rage, Squatter	For improvement in the control of marshmallow and certain other broadleaf weeds prior to establishment of broadacre crops, fallows or forest plantations, in commercial, industrial and public service areas, and around agricultural buildings and yards. For the control of certain annual broadleaf weeds in winter cereals and pyrethrum and aquatic weeds in rice.

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
flumioxazin	Flumioxazin controls many broadleaf weeds but only suppresses annual grasses. Tank mix with clomazone for pre-transplant or follow with a residual grass product to improve control of annual grasses. Has both pre-emergence activity through root absorption and post-emergence from foliar contact (minimal translocation). Apply 2- 5 days pre-transplant after all tillage has been completed. Limit disturbance of treated soil with transplant equipment. Do not use with transplants that have been harvested more than 2 days prior to transplanting. Do not apply over the top of sweetpotato. Do not use on any variety other than Beauregard without first testing it, and it having acceptable tolerance. Moisture is necessary to activate the chemical. Significant injury may occur from application made on poorly drained soils or application made under cool wet conditions.	Clipper, Flumioxazin, Payload, Pledge, Spektrum, Territory, Valor	For knockdown and residual control of broadleaf weeds and grasses in a range of broadacre crops and fallow, and in non-crop situations. For rapid knockdown and control of various broadleaf weeds when mixed with certain glyphosate/diquat herbicides and for control of cotton when applied alone, prior to sowing cotton and its rotation crops, or for rapid knockdown and control of various broadleaved weeds when applied as a directed spray in cotton. Note: It has been identified that sweetpotato should not be planted for 8 months after an application rate of 700g/ha has been applied to sugarcane, assuming the soil have been thoroughly cultivated after the cane has been grown.
glyphosate	Can be applied as a preplant treatment for control of broadleaf and grass weeds. To obtain maximum benefit from preplant applications allow seven days before cultivation. For difficult to control weeds may apply glyphosate and 5-7 days later and at least 1 day prior to transplanting may follow up with application of paraquat.	Ancosafe, Blade, Clear up, Cropmaster, Devastate Plus, Di-Bak G, Dry Gly, Eraze, Fortin, Galigan, Glister, Glyphix, Glyphosate, Grown up Knockout, Max out 600 Duo, Musta, Panzer, Roundup, Weed Kill, Wipe out. + numerous other brands	Water soluble herbicide for non-selective control of many annual and perennial weeds in certain situations. For control of annual and perennial weeds prior to sowing of any crop. Edible and non-edible crop, but not prior to transplanting tomato seedlings.

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
paraquat	Post-emergent weed control. Applied to emerged weeds less than 15 cm tall prior to transplanting. Good spray coverage of weeds is required as is strictly a contact herbicide. For fields with difficult weeds, prior to planting apply glyphosate and 5-7 days later and at least 1 day before transplanting, apply paraquat.	Cruze, Dagger, Explode, Para, Paradox, Par-Q, Paraquat, Parashot, Powerquat, Rainquat, Spraytop	Controls annual grasses and most annual broadleaf weeds. Very dangerous, particularly the concentrate. Aid to cultivation – to minimise cultivation and prepare a clean bed for sowing. ○ Where heavy weed growth is present at spraying a better seedbed will result if cultivation is delayed 3-5 days. Row crops, vegetables and market gardens. ○ Pre-planting. – to control weeds in seedbeds. Treat no less than 3 days before sowing. ○ Post-emergence inter-row weed control. Apply after transplanted crops are established. Direct the spray so it does not touch the crop. Use shielded nozzles.
pelargonic acid (also known as nonanoic acid)	A non-selective contact herbicide that controls many weeds. Bio-based herbicide.	Basher, Beloukha, Brut, Neo, Nonanoic Acid, Pelargonic, Slasher, Slayer	For non-selective control of seedling and young weeds, for suppression of established weeds and perennial species, control of moss and algae. Organic contact herbicide. Orchards and vineyards, fallow soil.
Pyraflufen-ethyl (acetic acid)	Contact herbicide requires thorough coverage for broadleaf weed control. Best control on leaves up to 100 mm in height or less or rosettes 75 mm in diameter or less.	Ecopar Forte, Pyraflufen-ethyl, Sledge Acetic Acid – Acetic weedkiller, Farmsafe Boost Plus, N Natural	Early post-emergence contact herbicide with rapid foliar uptake. For the control of annual broadleaf weeds in winter cereals and pastures. For improvement on the brownout of a range of broadleaf and grass weeds, the reduction in seed set and viability of weed seeds prior to harvest of wheat, barley, field pea, faba bean, chickpea, lentil, narrow leaf lupin, the control of volunteer cotton.

Appendix 2 – Herbicides available for use in USA and/or Canada that may be applied after transplanting sweetpotato vines

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
clomazone	Pre- emergent weed control. Apply after transplanting and prior to weed emergence. Use lower rates on coarse textured soils low in organic matter and higher rates on fine textured soils and soils with high organic matter. Does not control pigweed sp. morning glory sp. and yellow nutsedge (*Cyperus esculentus*) (in Australia yellow nutgrass is also called yellow nutgrass, tiger nut, rush nut, northern nutgrass, earth almond or yellow nutsedge). Some temporary crop injury (whitening of leaf or stem tissue may occur). Complete recovery will occur from minor early injury without affecting yield or delaying maturity.	Caimen, Chrome, Clearance, Clomazone, Clomaquest, Command, Director, Magister, Soldier	For the control of certain annual broadleaf weeds in cucurbits, green beans, navy beans, potatoes, poppies, rice and tobacco. Do not apply through irrigation. Do not apply to soil intended for seedling transplants with the exception of tobacco. Do not apply to soils with organic carbon content less than 2% and clay content less than 15%.
chlorthal-dimethyl (dimethyl tetrachloroterephthalate)	Pre-emergent weed control. Apply at transplanting to 10-14 days after transplanting. Labelled for applications directly over transplants without injury. If weeds are present the crops should be weeded or cultivated prior to application. Can be applied up to 6 weeks after transplanting as last operation before row closure.	Chlorthal, Chlorthal-dimethyl, Dacthal, Dynamo, Prethal, Pterodactlyl, Lawthal	Registered for use with sweetpotato. For pre-emergence weed control in certain vegetable crops including: brassicas, beans, peas, garlic, onions, carrots, lettuce, potatoes, turnips and for weed control in strawberries, cotton, lawns and ornamentals.

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
napropamide	Pre-emergent weed control. Control of annual grasses and certain broadleaf weeds will be supressed or controlled. Apply immediately after transplanting and prior to weed emergence. Florida can apply as a pre-plant burndown. Rainfall or irrigation within 24 hours of application improves performance.	Devrinol, Napropamide	For pre-emergence control of certain weeds in canola, direct seeded and transplanted tomatoes, almonds, grapevines and stone fruit. Current permit (15/03/2012 – 30/11/2024) for use with Oilseed Mustard. Current permit (22/08/2019 – 31/08/2027) for use with Brassica vegetables (transplanted only). Current permit (16/03/2020-31/10/2027) for use in Basil (field grown only). Restraint – Do not apply to peaty soils. Is particularly susceptible to photodegradation and the rate of breakdown in the soil is greatly accelerated by high temperatures. Irrigate in to 5cm depth after planting or incorporate to 2-5 cm within 10 days.
S-metolachlor	Pre-emergent weed control. Do not incorporate into the soil. Do not irrigate more than 12.5 mm of water in the first irrigation following application. To avoid concentrating the chemical over the top of sweetpotato transplants, fill the transplanter trench prior to application.	Bouncer, Boxer Gold, Boxmate A, Clincher Gold, Chaser S, Dual Gold, Gold, Heist, Hyena, Left Hook, Menace, Metal Gold, Metamore, Metoken Gold, Metolamax, Metola-S, Metor-S, S-Maestro, S-Met, S-Metol, S-Metolachlor, Primextra Gold, Pulsate, Rebelion, Storm	Registered for use with sweetpotato. Controls certain annual grasses and broadleaf weeds in certain crops such as rhubarb, brassica, leafy vegetables, mustard, spinach, silverbeet, spring onions, shallots, culinary herbs. Short residual pre-emergent herbicide. Registered for sweetpotato. ○ Apply immediately after transplanting before weeds have germinated. ○ Sufficient irrigation to wet the soil through the weed zone should be applied within 24 hours.

Active ingredient (ai)	Notes on applications for sweetpotato crops in USA/Canada	Selection of Australian Trade Names (if registered in Australia	Australian label description and other comments
			○ Further weed germination may occur following hilling due to exposure of untreated soil. Restraints: ○ Do not apply to waterlogged soils. ○ Do not apply if heavy rains or storms that are likely to cause runoff are forecast within 2 days of irrigation. ○ Do not irrigate to the point of runoff for at least 2 days after application. ○ Do not harvest sweetpotatoes, graze or cut for stock food for 23 weeks after application.

Appendix 3 – Herbicides available for use in USA and/or Canada that may be applied between the rows of a sweetpotato crop

Active ingredient (ai)	Notes on Sweetpotato crop application in USA/Canada	Selection of Australian Trade Names (if registered in Australia)	Australian label description
bicyclopyrone	Systemic pre-emergent and post-emergent broadleaf weed control. May partially control some grasses. Do not apply to sweetpotatoes grown on sand or loamy sand soils with less than 1% organic matter. Apply after transplanting to row middles. Avoid contacting the sweetpotato foliage during application or crop injury will occur. Use of a hooded or shielded sprayer will minimise crop injury. Add a non-ionic surfactant or crop oil concentrate. For optimal control make application to small weeds less than 50 mm.	Approved for use in Australia - not available as a single ai product.	When mixed with other ai's used to control broadleaf weeds in wheat and barley.
Caprylic acid + capric acid	Non-selective, non-systemic, post-emergent weed control. Effective on grasses and broadleaf weeds. Use with hooded or shielded sprayer as chemical will damage the crop.	Not registered in Australia.	Not registered in Australia.
carfentrazone - ethyl	Post-emergent weed control. Applied as a pre-plant burndown for emerged broadleaf weeds. There is no pre-transplant interval. When applying post-transplant, apply as a hooded spray in-row as the chemical will cause damage to sweetpotato stems and leaves.	Carfent, Carfentrazone, Carfentrosix, Chipper, Clobbertime, Consort, Elevate, Fullguard, Pummel, Rage, Squatter	For improvement in the control of marshmallow and certain other broadleaf weeds prior to establishment of broadacre crops, fallows or forest plantations, in commercial, industrial and public service areas, and around agricultural buildings and yards. Has expired permits for pyrethrum, volunteer potato, blackberry nightshade control.

Active ingredient (ai)	Notes on Sweetpotato crop application in USA/Canada	Selection of Australian Trade Names (if registered in Australia)	Australian label description
Glyphosate	Apply between crop rows with wipers or hooded or shielded sprayers.	Ancosafe, Blade, Clear up, Cropmaster, Devastate Plus, Di-Bak G, Dry Gly, Eraze, Fortin, Galigan, Glister, Glyphix, Glyphosate, Grown up Knockout, Max out 600 Duo, Musta, Panzer, Roundup, Weed Kill, Wipe out. + numerous other brands	Water soluble herbicide for non-selective control of many annual and perennial weeds in certain situations. For control of annual and perennial weeds prior to sowing of any crop. Edible and non-edible crop, but not prior to transplanting tomato seedlings.
Pelargonic acid (also known as nonanoic acid)	A non-selective contact herbicide that controls many weeds. Bio-based herbicide.	Basher, Beloukha, Brut, Neo, Nonanoic Acid, Pelargonic, Slasher, Slayer	For non-selective control of seedling and young weeds, for suppression of established weeds and perennial species, control of moss and algae. Organic contact herbicide Orchards and vineyards, fallow soil.

Appendix 4 – Herbicides available for use in USA and/or Canada specifically for grass control in sweetpotato crops

Active ingredient (ai)	Notes on Sweetpotato crop application in USA/Canada	Selection of Australian Trade Names (if registered in Australia)	Australian label description
clethodim	Post-transplant application. Post-emergent grass control. Does not control sedges or broadleaf weeds.	Carbine, Cleth-D, Cleokey, Clethodim, Clethora, Client, Cluster, Cyclops, Exit, Grasdim, Havoc, Icasso, Platinum Xtra, Scalpel, Select, Sequence, Sumistatus, Uproot	For the control of certain grass weeds in beetroot, cabbage, canola, celery, cotton, forestry, lettuce, non-bearing fruit trees, onions, ornamentals, peanuts, pulses (including adzuki beans, broad beans, chickpeas, faba beans, field peas, lentils, lupins and mung beans) potatoes, soybeans, and pasture legume (lucerne, clover and medic), seed crops (and pastures).
Fluazifop-P	Post-transplant application. Post-emergence control of annual and perennial grass weeds. Will not control broadleaf weeds or sedges. Apply to actively growing grasses before they exceed the labelled growth stages. Do not apply within 55 days of harvest.	Cannonade 212, Flare 212, Flazz 212, Fluazifop, Fluazifop 212, Fluazaway 212, Fusilade, Fuzilier, Rootout 212, Salvo 212	Minor use permit for sweetpotato until 30 November 2027. For control of certain grasses in certain crops. Do not harvest sweetpotato for 10 weeks after application.
sethoxydim	Selective post-emergence control of annual and perennial grasses. Will not control broadleaf weeds or sedges. Do not apply within 30-60 days of harvest (depending on state regulations).	Sertin, Sethoxydim	Registered for use in sweetpotato. For control of specific emerged grass weeds in various crops. Apply when most grass weeds are in the 2 to 6 leaf stage and actively growing. No withholding period when used as directed.

Appendix 5 – Herbicide mixes trialled for use in sweetpotato weed management

Active ingredient (ai)	Best rate used in trail / Comments	Selection of Australian Trade Names (if registered in Australia)	Australian label description
370 g/L atrazine + 290 g/L S-metolachlor	Rate unknown – trial product not specified.	**Australian** registered product Primextra Gold	Controls certain annual grasses and broadleaf weeds in maize, sugarcane and sweet corn, also in sorghum when previously treated with Concep® II or Epivio® C sorghum seed safener.
28.1% atrazine (2.67 lb per U.S. gal. of atrazine and related ai) + 35.8% metolachlor (3.33 lb per U.S. gal. ai)	Rate unknown- trial product not specified.	**American** Registered product Bicep II Magnum	---
33% atrazine (3.1 lb per U.S. gal. ai) + 26.1% metolachlor (2.4 lb per U.S. gal. ai)	Rate unknown- trial product not specified.	**American** Registered product Bicep II Magnum, Sharda Atrazine 33% + Metolachlor 26.1% SE Stalwart Xtra	---
atrazine + S-metolachlor	atrazine (370 g ai/ha) + S-metolachlor (290 g ai/ha).	Product unknown	---
clomozone + flumioxazine	clomazone (840 g/ha) + flumioxazine (36 g/ha or 72 g/ha or 109 g/ha).	**Australian** registered product **clomazone** Caimen, Chrome, Clearance, Clomazone, Clomaquest, Command, Director Magister, Soldier **flumioxazin** Clipper, Flumioxazin, Payload, Pledge, Spektrum, Territory, Valor	For the control of certain annual broadleaf weeds in cucurbits, green beans, navy beans, potatoes, poppies, rice and tobacco. For knockdown and residual control of broadleaf weeds and grasses in a range of broadacre crops and fallow, and in non-crop situations.

Active ingredient (ai)	Best rate used in trail / Comments	Selection of Australian Trade Names (if registered in Australia)	Australian label description
linuron + S-metolachlor	Linuron (560 g/ha ai) + S-metolachlor (800 g/ha ai) - used on plant propagation beds.	Australian registered product – **linuron** Leapfrog, Linurex, Linuron **S-metolachlor** Bouncer, Boxer Gold, Boxmate A, Chaser S, Clincher Gold, Dual Gold, Heist, Hyena 960, Left Hook, Menace, Metal Gold, Metamore, Metoken Gold, Metola-S, Metolmax, Metor-S, Pulsate, Rebellion Gold, S-Met, S-Metol, S-Metolachlor, S-Moc, Smart Gold, Storm	For control of certain weeds in wheat, barley, oats, potatoes, carrots, parsnips, coriander seed crops, onions, soybeans, maize and sweet corn. Controls certain annual grasses and broadleaf weeds in broccoli, brussels sprouts, cabbages, cauliflower, canola, cotton, green beans, navy beans, maize, sweet corn, pastures, peanuts, soybeans, sunflower, sugarcane, sweetpotatoes, tobacco, barley, oats, wheat, triticale.
S-metolachlor + clomazone	S-metolachlor (960 g ai/ha) + clomazone (500 g ai/ha).	Product unknown	---

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