Helping the Western Australian potato industry capture winter production opportunities in the Mid-West

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Purpose of this Report: To report on field work relating to factors impacting on potato production in the Mid West area of Western Australia

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Frontispiece. Dandaragan, a traditional cereal and sheep farming area, is showing promise for large scale winter potato production

Recommendations of registered chemicals and uses in this project were accurate at the time of the report publication. Please consult the APVMA website (http://www.apvma.gov.au) for the most up to date information regarding the registration or minor use access status of any of the chemicals discussed within this report.

Contents

1 Media Summary

For the WA potato industry to expand it needs to move into new areas outside traditional potato growing areas near and south of Perth. The Mid West area is a promising new area for winter production of potatoes.

Factors limiting yield were assessed by monitoring insects and diseases in crops and providing support for agronomic decisions such as irrigation and fertiliser management on three commercial properties in Dandaragan in 2011 and 2012.

Whilst improvements in agronomic management were identified the main area of improvement needed was in seed quality. In this respect both the sanitary (pest and disease level) and physiological quality (physiological age) of the seed was important

Mid West area growers are both purchasers and growers of seed. The usual supplies of seed from the South West are too physiologically young (immature) for autumn sowings so the Mid West area growers bulk seed for one generation (G4 to G5) and harvest in spring so it is of the right age for the following autumn plantings.

Insect monitoring showed aphid numbers in the Mid West area to be higher than in traditional summer growing seed areas in the South West. Virus monitoring showed the aphid borne potato leafroll virus was often found in crops where aphid control was excellent. In other instances there were high levels of other viruses such as potato virus S in crops grown from seed that was assumed to have very low level of viruses. Growers learnt the importance of obtaining generation four seed of the highest quality such as WA certified seed from the WA scheme for their seed crops and to manage these crops so the resulting generation five was of high quality. So high quality source seed and vigilant seed crop management is vital. Growers were advised to purchase rating 1 certified seed as this has a 100 times lower tolerance for diseases than rating 3 seed.

Areas north of Perth from Mullewa to Carnarvon were identified as potentially more productive and profitable than areas further to the south for winter potato production. These areas were identified using the LINTUL-POTATO model which simulates potential yield based on temperature and the potato crop's light-use-efficiency for producing tubers. The model showed that an area with a climate like Carnarvon might produce a 63 percent higher yield for a 15 June planting date than Dandaragan. More work is needed to validate these predictions with yield data from crops in the field in these locations.

2 Technical Summary

The Dandaragan area of the Mid West area appears suitable for expanding the winter production of ware, crisp and possibly seed potatoes to cover the loss of production areas further south and also for the future expansion of export markets. In this respect there has been expansion in area sown from 120 to 160ha from 2011 to 2012.

Factors limiting yield were assessed by monitoring insects and diseases in crops and providing support for agronomic decisions such as irrigation and fertiliser management on 3 commercial properties in Dandaragan in 2011 and 2012. Insect counts on lower leaves of plants were recorded from 13 crops on the 3 properties over 2 years. At the same time leaf samples were collected from all 28 seed, 10 ware and 1 crisp crop on the 3 properties for virus analysis by ELISA. Volumetric soil moisture was measured under 16 crops using TDR probes inserted at 3 depths. This information was used by growers to adjust irrigation management based primarily on crop factors (Epan). The Croptest™ model (SARDI) was used to assist in interpretation of results from petiole analysis of crops either for general monitoring of the effectiveness of fertiliser programs or in diagnosing problems with crop growth.

The LINTUL-POTATO model was used to predict yield and identify potential areas where expansion of potato production is possible from Dandaragan (30°03´S) to Cape Londonderry (13°08´S), the northern most part of WA.

Measurements from plot and whole field harvests showed yields from 25 to 60 t/ha, including 7 varieties in the area indicating potential for good yields, but also low yields if the crops are not managed properly.

Both sanitary (disease and pest level) and physiological quality or age of seed was identified as important issues in the project. Seed quality therefore became more of a focus in the project relative to general agronomy than originally planned. In the Mid West area own seed is grown from winter to spring for at least one generation, usually G4 to G5, to have seed of the right age for sowing the following autumn. Most South West seed is not of the right age for Mid West area sowing as it is harvested too late (summer to autumn).

Planting times from March to June in the Mid West area was expected to represent a significant risk to sanitary quality of crops due to aphid invasion. Aphid infestation varied between farms and between years. Autumn planted crops on one farm were found to be consistently infested with green peach aphid (*Myzus persicae*) in both 2011 and 2012 (up to 50% and 90% of leaves respectively) but aphids were reported in significant numbers not other farms at this time of year. All farms recorded aphid peaks in spring ranging from 50 % to 80% of leaves inspected. Winter sown crops were therefore not infected early but later in crop growth in spring.

Potato leafroll virus (PLRV) infection ranged from 0% to 10 % in selected ware crops and from 0% to 4.5% in seed crops. Infestation of aphids and incidence of virus was not always correlated as at times PLRV infection was reported when aphid numbers were very low highlighting the importance of source seed being clean. By contrast at times a high aphid infestation late in the season was associated with zero viruses detected in some seed crops.

Systemic insecticides should be applied if seed crops are autumn sown with winter sown crops monitored weekly to ensure low aphid numbers during crop growth or controlled if needed. These applications are unlikely to be of value in winter sown seed, crisp or ware crops due to later infestations of aphids. Chemical control of aphids in non seed crops post planting will probably not be necessary due to lower action thresholds compared to seed crops. As well natural enemies of aphids was found to be high and would most likely limit aphid numbers in these crops.

Growers needed to ensure South West seed used for bulking was of high sanitary quality as well as the higher incidence of aphids compared with the South West made spread of viruses such as PLRV more likely. Seed source for these crops should therefore be WA certified, rating 1 as this has the lowest level of disease infection.

Although pan evaporation and crop water demand is higher and rainfall is lower than in traditional areas further south there was no indication from the irrigation results that irrigation water application limited crop yield. Although there was no records of high levels of salt in soil prior to sowing irrigation water quality varied from EC (1:5 H2O) from < 75 to 100 mS/m (480 to 640 mg/L) with the upper value being close to the tolerance for potato yield decline(650 mg/L). Salinity management is important in the area, therefore, as during dry periods in winter or spring % Cl in petioles increased from 4 - 5%, where yields were not limited, to 8 to 11%, where they were. Irrigation should be managed to apply extra water above crop demand to flush salts out of the root zone when needed.

The LINTUL-POTATO model was useful in predicting potato yield from winter crops in the temperate areas such as Dandaragan but underestimated yields in the tropics such as at Kununurra unless it was assume photosynthesis continued to 43 °C above the model maximum (33 °C). Of interest is the model predictions of much higher yields in the lower latitude areas such as the Murchison and Gascoyne than in traditional areas further south. More field work needed to validate these predictions.

3 Introduction

3.1 Background

There is an opportunity to expand the fresh, crisp and seed potato industry sectors to meet demand through increased ‘out of season’ or winter production north of Perth in the Mid West area (MWA). For the purposes of this study the MWA is defined as the area between Lancelin and Dongara. The focus of production is currently Dandaragan (140 km north of Perth and 75 km SE of Jurien Bay) where 160 ha of potatoes were sown by 3 growers in 2012. Department of Agriculture and Food, Western Australia (DAFWA) natural resource management data indicates there is adequate arable land and water of suitable quality to enable this increased production in the MWA (Figure 3.1).

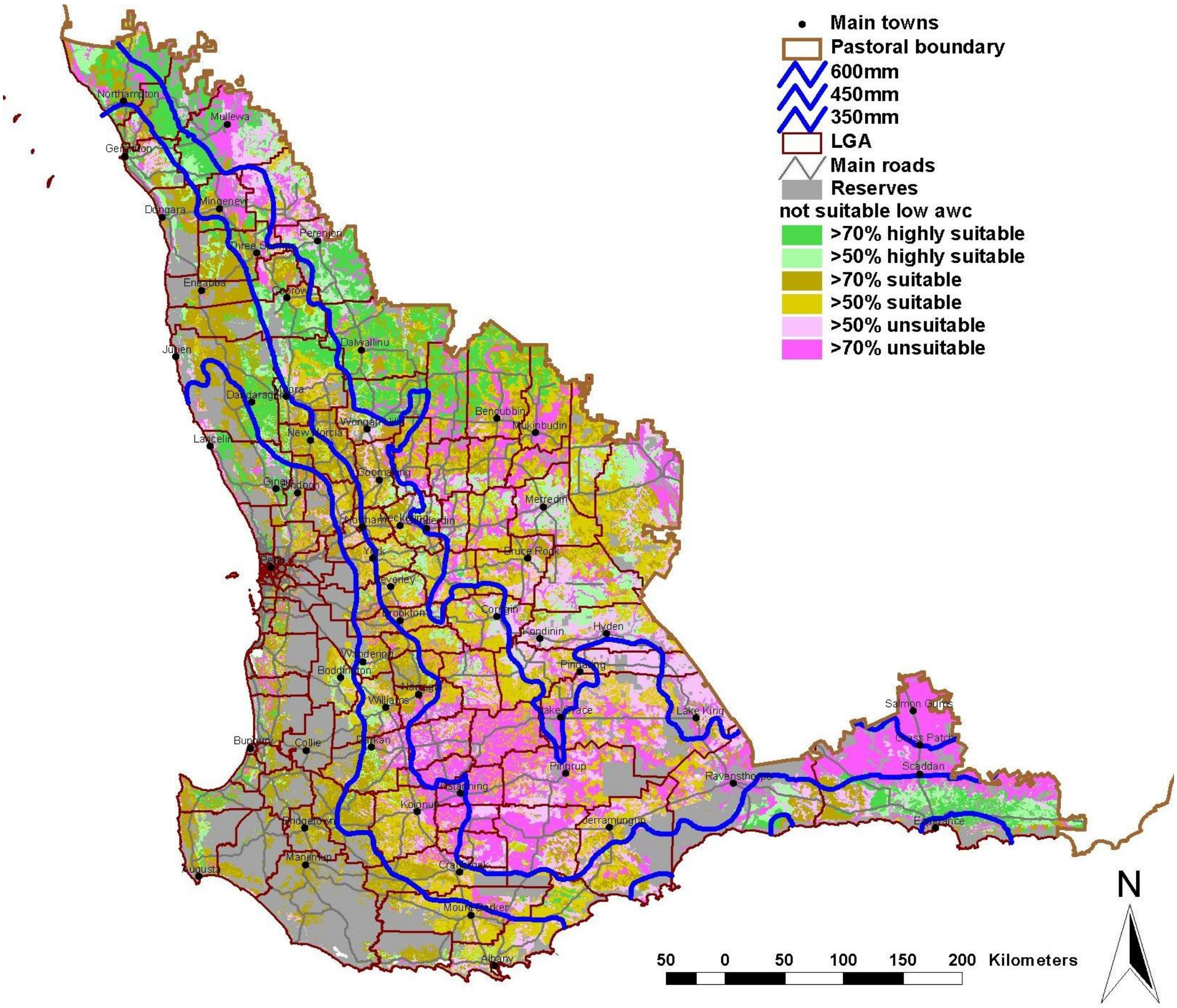

Figure 3.1. Map showing suitable soils for potato production. The green areas indicate extensive areas where > 50% of the soils are *highly* suitable for potato production whereas the current major SW potato production areas have > 50% of soils are merely suitable for potato production. Note the map does not consider water availability or climate.

Dandaragan has large areas of suitable soil with large property sizes which allows for large scale potato production with rotations and isolation. There are economic drivers for existing farmers wanting to diversify from dry land cereal cropping. Some infrastructure for cereal cropping can be used for potato production. Dandaragan soils will have low pathogen levels because there is no history of potato production.

New potato production would occur through the autumn, winter and spring months with plantings from March to July and harvests from August to November. Exports of WA seed to SE Asia and interstate has increased steadily since 2000 to 6,200 tonnes in 2010 (Radhakrishnan 2012). Winter production in the MWA would enable WA exporters to compete directly with Northern Hemisphere suppliers in Asian markets as WA seed could be harvested from August to October, the same time as the European seed potato harvest. Fresh potatoes in these months are also in short supply in WA and the MWA is becoming an important location for this supply. Crisp potatoes, although not a direct target in this project, are in demand at this time of year and could be supplied from this area. There could be synergy between crisp growers and seed exporters because the seed potato exports are mainly for crisping varieties such as Atlantic.

Climate in the MWA may provide better conditions for winter crops than the traditional areas near Perth. For example yield outputs using the LINTUL-POTATO crop growth model (Kooman & Haverkoort 1995) show a potential of up to 12% higher yield from April plantings in Dandaragan compared to Medina south of Perth, probably due to warmer temperatures and higher light intensity (Table 3.1). The use of the LINTUL-POTATO model is further investigated in Section 8.

Table 3.1. LINTUL-POTATO model output of potato yield at Medina, traditional winter production area near Perth and Dandaragan.

Planting date	Maturity date	Yield		
		Medina	Dandaragan*	Dandaragan/Medina (%)
15 March	15 July	54.9	59.9	109
15 April	15 August	45.7	51.4	112
15 May	15 September	51.2	54.1	106
15 June	15 October	67.2	69.6	104

*Weather data from Badgingarra used as similar distance from coast.

However winter production further north of Perth may pose specific challenges for potato production as shown from experience gained from pioneer ware and seed crops. For example the aphid infestations maybe higher in the MWA than in the other areas. This has implication for the both ware and seed production via aphids directly damaging the crop through feeding or as vector for viruses such as potato leafroll virus (PLRV) and potato virus Y (PVY).

Seed availability is another important issue for growers in this area. The main crop is sown from March to June. Seed for the main crop needs to come from seed crops harvested in October to be of the right physiological quality (‘age’) at sowing time. As seed from traditional seed growing areas of the South West (SW) is harvested later, potato growers in the MWA need to produce their own seed from an autumn planted crop. Where seed is grown locally for only one or two generations management must ensure high sanitary quality to minimise the risk of poor crop performance. If commercial seed production is to develop in this area high sanitary requirements will be needed to meet seed certification standards.

The higher temperature and evaporation as well the lower rainfall at Dandaragan leads to increased crop water and therefore irrigation demand compared with areas closer to Perth. The soils may have different properties to other areas which may influence irrigation and fertiliser management programs

3.2 Significance to Industry

The expansion of winter potato production in the MWA will increase the value of the potato industry in WA and will also increase the period of the year when additional supplies of ware, crisp and seed potatoes are available. It will also create opportunities for the WA industry gain significant access to interstate and export markets counter to the main cropping season in WA.

3.3 Aims

The main aim was to assist the development of crisp, seed and fresh potato sectors in the MWA by providing technical support to optimise crop agronomy in particular i.e. irrigation, fertiliser and pest and disease management and to provide a guide to Best Management Practices for potato production in the area. The incidence and level of aphid infestation and viruses in the area during the cropping period from March to November was recorded to assess its impact on potato production. This was also used to assess the potential of the area for the winter production of seed for both local and export markets.

In addition the potential for potato production into areas north from Dandaragan to Kununurra was to be explored using actual yield records and yield outputs generated by the LINTUL-POTATO model.

4 Comparing Seed Sources

Ian McPharlin, Tony Shimmin and David Tooke.

4.1 Introduction

Potato production will expand into areas north of Perth such as the MWA as southern horticultural land is increasingly used for urban expansion. Winter production (autumn and winter sowings producing winter and spring harvests) is the main focus of this area as spring to autumn harvest is supplied from SW crops. Potatoes produced in MWA are likely to replace winter production at Wanneroo and Baldivis.

Growers in Dandaragan can't always obtain adequate supplies of seed of the correct physiological age (maturity) from the SW for their autumn plantings. For example seed harvested in January in Albany may be too physiologically young, or immature, for March plantings in Dandaragan. For this reason growers often grow the generation four (G4) SW seed for one generation (to G5) in Dandaragan from a June planting in order to harvest G5 seed in October to have seed of the required maturity for planting of the main ware or crisp crop in March the following year. An example of this seed flow is illustrated in the Figure 4.1.

Figure 4.1. Months of main cropping at Dandaragan showing timing of seed crops to supply seed of suitable physiological age. Nadine requires longer seed storage than other varieties and so seed crops must be planted in June.

Months (year 1)												Months (year 2)								
M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
			G4 Nadine seed crop					--> Seed cool stored				--> G5 Nadine main crop								
				G4 Ruby Lou seed					--> Seed cool stored				--> G5 Ruby Lou main crop							

Physiological quality or age (PA) of seed is difficult to assess on an un-germinated tuber so plant measurements such as sprout number, length, width and position on the germinating tuber are used as a gauge of seed PA (van der Zaag & van Loon 1987). For example a seed tuber that produces 1 to 3 sprouts close to the rose end of the tuber (apically dominant) is considered physiologically younger compared with a tuber that produces a larger number of sprouts spread over the tuber (not apically dominant). Whilst chronological age (CA) is related to PA it is not the sole determinant of PA and field and storage temperature are key factors influencing PA. For example two seed lots of the same CA may have different PA if growing in different temperature regimes. Higher temperature regimes usually result in physiologically older seed.

Growers need to match PA to the needs of the crop and, as a general rule, older seed produces crops with a larger number of smaller sized tubers than a crop grown with young seed (Struik & Wiersema 1999). Young seed may suit a French fry crop where large tubers are needed whilst older seed may be needed for a seed crop where higher numbers of smaller tubers are needed. Growers must be careful to differentiate between young seed and juvenile seed as well as senile versus old seed. In both cases the selection of seed too young or too old will have yield and quality penalties.

4.2 *Materials and Methods*

4.2.1 *Location*

Experiment 1 (exp.1) was located on a section of the east pivot at 'Ardens Fleet' Farm 8 km north of Dandaragan (30°40' S, 115°42' E) and the other 2 experiments were located on sections of the south (exp. 2) and north (exp. 3) pivots of 'Jameson Farm' 2 kms north of Regan's Ford (30°57' S, 115°51' E).

4.2.2 *Seed*

For exp. 1 the small, whole G5 Nadine seed was either from that grown at 'Arden Fleets' farm Dandaragan using registered G4 seed from Albany in 2011 (sown 7 July 2011 and harvested 26 October 2011) or G5 seed from Pemberton (previously G4 from Albany) which was harvested on 7 January 2012. The Dandaragan G5 seed was shed stored in ambient conditions for 3 weeks in Dandaragan to enable wounds to heal and 7 weeks in Pemberton to enable cuts to heal and then graded and stored at 4 °C in a cool room for 10 weeks and taken out of the cool room 2 weeks before sowing. The Pemberton G5 seed was shed stored in ambient conditions for 3 weeks after harvest (7 January 2012) to enable cuts to heal and then graded and stored at 4 °C in a cool store for 6 weeks and taken out of the cool room 2 weeks before sowing.

For exp. 2 the small, whole G5 Nadine (Jameson) seed used was grown on Jameson farm using registered G4 seed from Busselton harvested 15 October 2011was cool stored in Busselton 2 weeks after harvest and removed from cool store 2.5 weeks before planting in Dandaragan in April. The registered G4 (Busselton) seed was harvested in December 2011 in Busselton, cool stored two weeks later and removed from cool store two weeks before planting.

For exp. 3 the small, whole G5 FL1867 seed used on was either from that grown at Jameson farm Dandaragan using registered G4 seed from Busselton and harvested in October 2011 or registered G4 seed from Busselton which was harvested in December 2011 and cool stored as for exp. 2.

4.2.3 *Land preparation*

For exp. 1 the land was ripped, then ripped across workings, deep hoed, with water applied during this process according to need. For exp. 2 and exp. 3 the land was deep ripped twice at a 30 degree angle and 40 cm depth using an AgroPlow™ and then rotary hoed twice to 25 cm depth.

4.2.4 *Experimental design*

The experimental design was 2 seed sources x 6 replicates x 3 sites. Each plot was a single row 6 m in length and each block of 6 plots were located in sections of a commercial crop of the 2 seed sources sown in adjacent areas at each site. The four metre central section of the plot was used for measurements.

4.2.5 *Planting*

In exp.1 whole seed (40 - 50 g) of Nadine was treated with Maxim™ at recommended rates and sown in a single row on 3 April 2012 at an in-row spacing of 22.5 cm and a between-row spacing of 75 cm.

In exp.2 whole seed (40 - 50 g) of Nadine was treated with Rizolex™ at 2 kg/t and sown in a single row on 10 April 2012 at an in-row spacing of 18 cm and a between-row spacing of 75 cm.

In exp. 3 whole seed of FL1867 was treated with Rizolex™ at 2 kg/t and sown in a single row on 3 April 2012 at an in-row spacing of 20 - 25 cm and a between-row spacing of 75 cm.

4.2.6 *Fertilisation*

In exp. 1 a range of single and compound fertilisers were applied at planting and then every three weeks after emergence for 12 weeks to a final total (in kg/ha) of; N (250), P (260), K (255), Ca (140), S (127) and Mg (204).

In exp. 2 and 3 fertilisers were applied at planting and after emergence on a weekly basis for 12 - 15 weeks to a final total of (in kg/ha) of; N (350), P (150), K (400), Ca (200), S (200) and Mg (60).

4.2.7 *Irrigation*

Irrigation was applied via centre pivot irrigators at about 90 to 100% of the previous days pan evaporation (Epan) until full crop emergence and at about 120 - 130% until maturity (Table 7.4).

4.2.8 *Weed control*

In exp. 1 weeds were controlled pre-planting by cultivation and Sprayseed™ was applied at 3L/ha to emerged weeds after sowing at 5% crop emergence. At exp. 2 and 3 metham sodium was applied pre plant, Sprayseed™ was applied at early emergence at 2 L with 1 L Linuron /ha for general weed control and Select™ was applied post planting 3 times at 500 ml/ha (with ammonium sulphate at 1%).

4.2.9 *Pest and Disease control*

Integrated Pest Management (IPM) was used at all sites for insect control based on reports of insect numbers in crops provided on a weekly to fortnightly basis for the growers by DAFWA project staff. Where chemical control was necessary insecticides such as Confidor Guard™, Dominex™, Aphidex™ or Movento™ (see Table 4.1 for active ingredients) were used at recommended rates but infrequently. Fungicides applied included Amistar™ in-furrow, Bravo™, Tri-Base Blue™, Aero ™ during mid growth and Score™/Filan™/Tri-Base Blue™ at later stages.

4.3 Measurements and Harvest

The date of 100% emergence was recorded from the central 4 m of each plot for each site as was the % emergence, plant and stem number and stems/plant for each plot. After chemical spray off tubers were harvested from 6 m of row in each plot, separated and counted into weight grades for the fresh (0 - 30, 31 - 120, 121 - 320, 321 - 450 and > 450

g) or crisp (0 - 50, 50 - 80, 80 - 300, 300 - 430 g) and yield for each grade recorded. Tubers were rejected if they were green, damaged by insects, diseased or malformed according to industry standards for the fresh (Potato Marketing Corporation 2004) or crisp (Dawson & Mortimore 2003) markets. Marketable yield was the weight of blemish free tubers weighing between 30 and 450 g (fresh crops) or between 50 and 300 g (crisp crops). The number of tubers/plant and tubers/stem were also recorded.

Table 4.1. Active ingredient and Trade name and of fungicides and insecticides applied to potato crops grown in Dandaragan 2011 and 2012.

Active ingredients	Short Trade Name (™)
Fungicides	
azoxystrobin (250g/L)	Amistar
boscalid (500g/kg)	Filan
chlorothalonil (720g/L)	Bravo
copper sulphate (190g/L)	Tri-Base Blue
difenoconazole (250g/L)	Score
metiram (550g/L), pyroclostrobin (50g/L)	Aero
Insecticides	
alpha cypermethrin (100 g/L)	Alpha Duo (various companies), Dominex.
imdacloprid (350 g/L)	Confidor Guard
pirimcarb (500g/kg)	Aphidex
spirotetramat (240g/L)	Movento

4.4 Total Revenue, Costs and Gross Margins

Total revenue (TR) for Nadine was calculated assuming marketable yield (MY) comprises Class 1, 52% @$970/t, Class 2, 26% @$420/t, Smalls, 22% @ $705/t (Potato Marketing Corporation of Western Australia (PMC), pers. comm.). TR for FL1867 was assumed to be $398/t of MY including a bonus of 98/t for high tuber quality (SG > 1.090 and high cooking quality, low bruising and correct size) above a base price of $300/t. Local seed was assumed to cost $100/t (or $375/ha) more than SW seed due to higher storage costs and direct costs. Total cost (TC) of production (not overheads) were assume to be $12,000/ha for Nadine and $10,000/ha for FL1867 with gross margin (GM) the difference between TR and TC for each experiment.

4.5 Statistical Analysis

Yields in each size grade as well as total and marketable yield, the number of stems and tubers/plant and tubers/stem from both seed treatment from the plot harvests and observations in each experiment were compared using a paired t-test. Statistical differences were reported at the $P < 0.05$, 0.01 or 0.001 level.

4.6 Results

4.6.1 *Yield of Experiment 1*

In exp. 1 Nadine grown from local (Dandaragan) seed had significantly greater total and marketable yield ($P < 0.01$) than that grown from the SW (Pemberton) seed (Table 4.2). The marketable (30 – 450 g) yield improvement was 14% and the total yield improvement was 10%.

The higher yield of Nadine grown from local seed in exp. 1 was achieved through this seed producing plants which emerged 14 days before the SW seed and which had a significantly greater number of stems. These stems set significantly more tubers than the SW seed (Table 4.2). Tubers were the same average weight from the two seed sources (Table 4.2) thus the yield improvement of local seed can be attributed to longer growth due to earlier emergence and greater tuber production due to increased stem number.

The earlier emergence and greater stem number show the local seed had more advanced physiological age (Struik and & Wiersema 1999) compared with the SW seed. The number of day degrees > 4 °C is considered to be an effective measure of physiological age (O'Brien *et al.* 1983). The day degrees experienced by the seed sources were estimated to be 2,319 for the local seed and 1,293 for the SW seed (Table 4.2 & Appendix Table 5). This confirms that the local seed was much physiologically older than the SW seed and provides an indication of the degree of aging of seed that is required for April planted crops at Dandaragan.

Grower records of yields of their commercial crop harvests grown with the same seed treatments as exp. 1 showed yields similar from both seed sources. This is probably due to factors other than seed source, for example variation in soil due to the seed being planted in separate areas of the pivot.

4.6.2 *Yield of Experiment 2*

In exp. 2 the marketable and total yields of Nadine were not significantly different between seed treatments of the local (Jameson Farm) seed and the SW (Busselton) seed (Table 4.2). In exp. 2 the Nadine from local seed emerged 7 days before the SW seed. The SW seed produced more tubers per plant ($P < 0.05$, Table 4.2) but not more tubers per stem or stems per plant (Table 4.2) but the higher tuber number but did not result in a higher yield than the crop grown) from local seed.

Grower records of yields of their commercial crop harvests were similar to experimental plot yield in exp. 2. The experimental yield of local seed in exp. 2 was just 55% of that in exp.1 which may indicate that other constraints to production, other than seed physiological age, affected the experiment. Also grower records about the seed treatment were imprecise and the exact storage treatment of the seed sources was not accurately

Table 4.2. Seed source comparison results from 3 experiments. Date includes seed harvest date, storage periods and emergence, with plant population data and tuber set and yield data. An estimate of day degrees > 4 °C is given for experiment 1.
More yield details can be found in Appendix Tables 1 & 2.

Experiment & seed treatment	Harvest date	Shed storage (weeks)	Cool storage (weeks)	Warm up (weeks)	Day degrees > 4°C †	Planted	Emergence (Date)	Emergence (%)	Plant # / plot	Stem # / plot	Stem/plant	Tubers/plant	Tubers/stem	Tuber av wt (g)	Mkt yield (t/ha)	Total yield (t/ha)
Exp. 1	Nadine at Arden Fleets															
Local seed G5	26-Oct-11	14	10	2	2,319	3 Apr	18 Apr	99	16.8	49.5	3.0	11.2	3.8	109	43.9	45.3
SW seed G5	07-Jan-12	7	6	2	1,293	3 Apr	3 May	98	17.0	28.5	1.7	10.4	6.3	107	38.4	41.1
Significance								ns	ns	***	***	ns	**	ns	**	**
Exp. 2	Nadine at Jameson Farm															
Local seed G5	15-Oct-11	2		2		10 Apr	24 Apr	83	17.0	30.5	1.8	7.9	4.5	72	24.0	26.0
SW seed G5	01-Dec-11	2		2		10 Apr	1 May	72	15.5	29.5	1.9	9.8	5.1	84	31.7	33.5
Significance								ns	ns	ns	ns	*	ns	ns	ns	ns
Exp. 3	FL1867 at Jameson Farm															
Local seed G5	15-Oct-11	2		2		3 Apr	17 Apr	100	16.8	39.4	2.3	9.6	4.1	83	27.7	29.5
SW seed G5	01-Dec-11	2		2		3 Apr	27 Apr	84	15.2	38.2	2.5	13.5	5.4	34	11.9	15.5
Significance								ns	ns	ns	ns	*	*	**	**	**

† Based on 10 cool storage of local seed & 6 weeks for SW seed with 2 weeks warm-up pre-plant with the reminder as shed storage prior to cool store. Further details in Appendix Tables 1 – 2.

established. Future work should include funding to allow automated temperature monitoring of seed storage treatments.

4.6.3 *Yield of Experiment 3*

In exp. 3 the plots grown from the local seed emerged 10 days earlier than the plots grown from the SW seed. The marketable and total yields of FL 1867 were 191 - 234% higher (P < 0.01) when the local (Jameson Farm) seed was used compared SW (Busselton) seed (Table 4.2). The very low yield of FL1867 from SW seed in the plot harvest in exp. 3 was considered atypical of the whole crop area due to excess weeds establishing in the SW seed plots due to this treatment's late emergence. Grower records of yields of commercial crop harvest were different in exp. 3 with yields similar from both seed sources reported. Grower yields were excluded from the economic analysis as it was considered the yields from replicated and randomised plots in the experiments was more accurate. The FL1867 plots from SW seed produced more tubers per stem and per plant (P < 0.05, Table 4.2, Appendix Table 1C) but not stems per plant (Table 4.2). The greater tuber number did not result in a higher yield than the local seed plots.

4.6.4 *Revenue, costs and gross margins*

In exp. 1 use of local Nadine seed resulted in a 7% increase in gross margin (GM) based on project yield estimates (due to 13% higher yield). Farmers reported a 2% higher GM for SW seed due to lower SW seed costs and similar yields. It must be noted that the farmers did not randomise their seed sources and differences in yield observed and the subsequent GMs could be attributable to factors other than seed source, for example variation in soil due to the seed being planted in separate areas of the pivot.

Table 4.3. Marketable yield, total revenue, total cost and gross margin of potato crops grown from local or SW seed at 'Arden Fleets' farm in Dandaragan in 2012. The seed from 'Arden Fleets' exp.1 and is referred to as local seed and from Pemberton (exp 1) referred to as SW seed.

Exp. & variety	Seed source	Marketable yield (t/ha)	Total revenue ($/ha)	Total costs ($/ha)	Gross margin ($/ha)
1 Nadine	Local (G5)	44	33,823	12,375	21,448
	SW (G5)	39	29,979	12,000	19,979
2 Nadine	Local (G5)	28	21,524	12,375	9,124
	SW (G5)	28	21,524	12,000	9,524
3 FL1867	Local (G5)	28	11,144	10,375	769
	SW (G5)	12	4,776	10,000	-5,224

*Total revenue for Nadine calculated by assuming marketable yield made up of Class1, 52% @$970/t, Class 2, 26% @$420/t, Smalls, 22% @ $705/t after PMC (pers. comm.) Assumed general total costs of production of 10,000/ha for ware (Nadine) crops (not including overheads) with local seed cost $100/t (or $375/ha) more than SW seed.

4.7 *Discussion*

Potato crops in Dandaragan can be grown from seed brought in from SW seed areas outside Dandaragan or from grower's own seed produced on their own properties. This latter option is preferred as the local seed will be of a more suitable PA compared with the later harvested SW seed, for the early autumn sowing in the area. This local seed, if of high sanitary quality, as well as the appropriate PA should be cheaper than the SW seed and, if yields are comparable or higher, more profitable. Currently, because of lack of cool store facilities in the area, cost advantages of local over SW seed is somewhat negated by the transport costs associated with this storage. Comparisons in the field on 3 sites showed crops grown from seed grown in Dandaragan could yield as well as or better than crops grown from SW seed but results were variable. For example in exp. 1 the Nadine grown from local seed crop out-yielded the Nadine grown from SW seed by 14%, with a 7% higher gross margin, but on 'Jameson Farm' in exp.2 the seed sources produced yields which were not significantly different. In exp 1 the local seed crop emerged earlier and had more stems and more stems/plant than the crop from SW seed, but the latter crop compensated for having lower stem number by producing more tubers/stem such that tuber number/ plant were similar from both seed sources. This is not surprising as potatoes are known to compensate for low or high plant or stem density by varying tuber number per plant or stem (Struik and Wiersema 1999). The higher stem number/plant suggests local seed in exp.1 was physiologically older (Struik & Wiersema 1999) than the SW seed which could be explained primarily by more accumulated heat units and estimates show the local seed accumulated nearly twice the heat units that was experienced by the SW seed (Table 4.2, Appendix Table 5). Results from 'Jameson Farm' with both the Nadine and FL1867 showed little difference in PA between the two seed sources with the Busselton seed slightly more aged in terms of stems/plant than the Jameson seed but this was not statistically different.

Records of yields from the farmer's harvest of the whole area of the pivot where the experiments were located did not always reflect the experimental plot yields. For example the higher yield of the FL1867 crop grown from the local versus the SW seed from the experimental plot harvests was not reflected in the yields recorded by the grower for those sectors of the pivot which apparently showed a similar yield for each seed source. A variable and greater level of weed (*Lolium rigidum*) infestation was noted in the area where the Busselton seed was sown compared with the Jameson seed in the SW section of the North pivot on 'Jameson Farm' and where the plot harvests were located and may have contributed to the yield differences. Slow and patchy germination from physiologically immature seed may allow weed growth to 'get ahead' of crop growth and cause yield loss due to weed competition with the crop and may have been a contributing factor.

Any differences between farmer and experimental yield results were not taken into account and the experimental plot yields were preferred as they were randomised and replicated in a proper experimental design compared with the yield of the whole harvested area. However care must be take in selecting representative areas for experimental sites in large fields. This aside these results show local G5 seed can produce crops as high yielding as from SW seed provided the quality of the G4 seed used to produce it is high.

5 Insect and Virus Monitoring

Stewart Learmonth, Ian McPharlin and Tony Shimmin

5.1 Introduction

5.1.1 *The virus problem*

The production of high yield of good quality potatoes depends on good agronomic practices and the use of high quality seed. For seed both the sanitary quality (disease levels) and physiological quality (physiological age or vigour) are important. Virus diseases are a key part of sanitary quality and therefore virus management is important for the development of the potato industry worldwide. Potato degeneration and poor seed vigour was often associated with virus symptoms in crops. Formal seed schemes were set up primarily to deal with virus infection and to minimise intergenerational transmission of virus which had been shown to cause significant yield loss (Bantari *et al.* 1993).

The MWA of Western Australia (WA) represents a comparatively new area for potato production. The MWA traditionally produces broad acre crops of cereals, lupins, pulses and canola. These crops are host to the green peach aphid (GPA) (*Myzus persicae*), as well as other aphid species that can transmit viruses. The spring and autumn potato cropping program in the MWA will increase the risk of aphids colonising crops because autumn and spring grown potato crops have a greater occurrence of colonising aphids than summer grown crops in the SW of WA (Holland 2005). The suitability of this region for seed potato production in particular depends on the risk of introduction and/or transmission of viruses by insect vectors. In WA the main viruses of concern that can be transmitted by insects are those spread by aphids and to a lesser extent thrips (Holland 2005). The benchmark low aphid risk seed potato area in WA is Albany on the south coast of WA which has noted advantages over the current other areas of potato production in Western Australia (Berlandier 1997).

The main potato producing region of WA is located in the higher rainfall SW. Here, agricultural production including horticulture is more diverse. The MWA represents an environment where cropping is largely restricted to winter when rainfall is highest. There is minimal agricultural production under irrigation in summer which could otherwise result in a build up in vector insects.

Viruses cause systemic infection of the plant either by invading all the living tissue such as potato virus X (PVX) and PVY or only the phloem for PLRV. All viruses invade the developing tuber and thus can be carried over from season to season in the seed tubers. Apart from aphid transmission, viruses can be spread by mechanical or contact transmission such as by transfer of sap of an infected to a healthy plant, by seed cutting, leaves rubbing between plants, human movement or by farm equipment.

A number of aphids can transmit viruses such as PLRV and PVY including, in order of importance; GPA, the buckthorn aphid (*Aphis nasturti*) and the potato aphid (*Macrosiphum euphorbiae*), to name a few. In WA, as in most potato producing areas of the world, GPA is the most efficient and most important vector of potato viruses. Winged aphids which carry virus can introduce virus to uninfected crops. For PLRV aphid transmission is the only means of spread within crops. Whilst aphid transmission is the most important method of spread of PVY mechanical transmission can also occur (Stevenson *et al*. 2001).

Mechanical transmission is the most important method of spread of potato virus S (PVS) and PVX but some aphid transmission of PVS can also occur (Struik and Wiersema 1999). By contrast thrips such as western flower thrips (*Frankliniella occidentalis*) act as the vector in transmitting tomato spotted wilt virus (TSWV).

Viruses provide a unique management problem because they cannot be controlled directly in the infected crop with chemicals, as can fungal diseases. Virus control in potatoes depends on the use of seed containing low virus levels and, for those viruses where aphid spread is important such as PLRV, and to a limited extent PVY and PVS, their management relies indirectly on controlling aphids.

PLRV is transmitted persistently in aphids, i.e. once the virus is ingested from virus infected plants the aphid remains viruliferous for the rest of its life. PLRV transmission from aphid to plant and vice versa requires a long time (de Bokx 1972). This means GPA feeding on potato plants treated with insecticide will be controlled. Systemic insecticides work particularly well due to the long exposure of aphids feeding from the deep phloem tissue. Insecticides control PLRV by preventing the spread of the virus by killing viruliferous aphids and also by killing incoming virus-free aphids.

By contrast aphids transmit PVY in a non-persistent manner i.e. they only retain the aphid for a few hours and become virus free after they transmit the virus. In this situation insecticides are of limited value as in the time it takes for the chemical to kill the aphids they have already infected many plants.

Similarly chemicals are not available as seed treatments for virus management and for this reason selection of seed with very low levels of virus infection via a formal seed scheme is vital to good crop production. Also hygiene is important in reducing the carryover over infection between crops via seed cutters or other machinery by contact by transmission. Hygiene measures to control virus also include roguing seed crops and eliminating self-sown and cull piles.

The effect of the virus on growth and yield depends on virus type, strain and genetic resistance and crop growth stage at time of infection. Crops sown with tubers infected with PVY or PLRV which spreads to 100% of the crop may reduce yield by 50% (Van der Zaag 1987 & Reestman 1970) or possibly higher (Stevenson *et al*. 2001). Single infections with PVS and PVX may lead to yield reductions of 15 and 20% in worse case scenarios (Stevenson *et al*. 2001).

5.1.2 *Activities undertaken to avoid the virus problem*

The seasonal occurrence of insect virus vectors, direct insect pests of potato crops and their associated beneficial insects that occur in other potato producing areas of WA was assessed for three properties (see Horne *et. al.* 2002 for detail on most of these insects that occur in potato crops in WA). This was done to assess the suitability of the region as a seed potato production area as well as the potential damage to crops by the direct insect pests of potatoes. The extent of virus infection in seed, ware and processing crops on these properties in 2011 and 2012 was examined by visual inspection and virus tests of leaflets and sprouted tubers.

5.2 Materials and Methods

5.2.1 *Insect monitoring*

Monitoring for the abundance and species of insects in potato crops grown in the MWA centred on Dandaragan over the 2011 and 2012 seasons was undertaken.

Potatoes were cultivated on three farms during this period. On each farm, potato plants were grown under 40 ha centre pivot irrigators. In 2011, five pivots and one small area under semi-permanent irrigation were monitored. In 2012, six pivots and one small area of minitubers were monitored.

At each pivot, opposite quadrats were checked. A similar walk path within a quadrat was followed each occasion to be representative of that quarter of the pivot across monitoring occasions. The abundance of insects especially aphids and thrips was assessed by destructive leaf sampling, removing a lower compound leaf at regular intervals along the monitoring path. Up to row closure, 50 leaves were examined each monitoring and after this stage, 25 leaves were examined. General observations were made on insect abundance, especially those insects such as leafhoppers and Rutherglen bug likely to be dislodged when leaves were sampled destructively and also where leaf damage occurred in the upper portion of the canopy. For example, if leaf feeding was observed, the insect responsible was identified and the level of leaf loss estimated. This was undertaken to advise farmers if insecticide use against the direct pests was required.

In smaller areas under semi-permanent irrigation, destructive leaf sampling was undertaken and general observations were made.

Insect monitoring commenced after crop emergence and was undertaken weekly in autumn to early winter, fortnightly during winter, then weekly after winter until crop senescence in spring.

Results of the monitoring were emailed to farmers within three days of the monitoring and included suggestions on the need to intervene with insecticides.

The regular monitoring by staff of the Department of Agriculture and Food Western Australia (DAFWA) was supplemented by encouraging farmers to undertake their own monitoring. For this, they were supplied with colour photographs of the most likely insect pests and beneficial insects as an aid to insect identification, a 10 times magnification hand lens, score board and collecting tubes to retain insects they could not identify for subsequent identification by DAFWA staff.

5.2.2 *Virus monitoring*

Seed crops

2011

On ‘Arden Fleets’ farm, seed site, four varieties (Mondial, Nadine, Royal Blue and White Star, 0.5 ha of each) were sown on 7 July 2011 and harvested on the 26 October 2011. In all cases the seed sown was G4 registered seed from the same seed grower’s property in Albany which was harvested in January 2011.

At ‘Lightning Ridge’ farm, Site 3 - fixed sprinklers, five varieties (Lady Crystal, Nadine, Mondial, Ruby Lou and Royal Blue of respectively 2.4, 1.2, 0.4, 0.4 and 0.4 ha) were sown for seed on 13 July 2011 and harvested on 4 November 2011. Also at ‘Lightning Ridge’ at Site 2 pivot, six varieties (Almera, Nadine, Mondial, Red Rascal, Royal Blue and Ruby Lou of respectively 4, 0.2, 0.4, 0.4, 1.0 and 0.8 ha) were sown for seed on 1 June 2011 and harvested on the 31 October 2011. The seed sown was registered G4 seed from Pemberton (Lady Crystal and Mondial) or Albany (Nadine, Royal Blue and Ruby Lou).

2012

On ‘Arden Fleets’, Pivot 2, there were 5 varieties (Nadine, Mondial, Rodeo, Ruby Lou and White Star of respectively 0.49, 0.5, 0.14, 0.54 and 0.4ha) sown for seed on 20 May 2012 and harvested on 30 September 2012.

On ‘Lightning Ridge’, Pivot 1, (first seed planting) six varieties were sown for seed on 7 May 2012 (Almera, Lady Crystal, Nadine, Red Rascal, Royal Blue and Ruby Lou, area, 2.12, 0.68, 0.73, 0.72, 1.08, 0.52 ha respectively) and harvested in September. Also on ‘Lightning Ridge’, Pivot 2, a second series of five varieties (Almera, Lady Crystal, Nadine, Royal Blue and Ruby Lou, area 0.49, 0.67,1.03, 0.50 and 0.49 ha respectively) were sown on 6 June 2012 and harvested on 15 0ctober 2012.

At ‘Jameson Farm’, North Pivot, Atlantic and FL1867 were sown for seed on 7 May 2012 and harvested on 15 October 2012 using registered G4 seed from Busselton harvested on 15 October 2011.

Non seed crops

Selected ware or crisp crops were sampled and tested for viruses at the request of growers in both years where crops appeared unhealthy. In 2011 this included FL1867 on ‘Arden Fleets’ and Lady Crystal on ‘Lightning Ridge’. In 2012 testing was undertaken on Nadine on ‘Arden Fleets’ and Nadine and Royal Blue on ‘Lightning Ridge’.

Also as part of a companion potato project {‘Studies on PVY on potatoes in WA’ funded by the Agricultural Produce Commission – Potato Producers’ Committee (APC - PPC)}, leaflets were collected from three ware crops on ‘Arden Fleets’ (Mondial, Ruby Lou and White Star), six ware crops on ‘Lightning Ridge’ (Almera, Lady Crystal, Nadine, Red Rascal, Royal Blue and Ruby Lou) and three ware crops (Nadine, Mondial and Rodeo) on ‘Jameson Farm’ and tested for the incidence of PVY and PLRV.

5.2.3 *Virus testing*

Virus testing was done to monitor changes in virus levels from the winter planted seed crop to the following autumn planted main crop.

A leaflet (first fully expanded) was collected from a single compound leaf of each of 100 plants in a systematic pattern from all seed crops and selected ware and crisp crops in 2011 and 2012. The leaflets were placed in plastic bags and stored at 4 °C in a car fridge immediately after collection in the field and submitted to *AGWEST* Plant Laboratories (APL) for analyses of 5 viruses: PLRV, PVY, PVX, PVS and TSWV, using the enzyme linked immunosorbent assay (ELISA) on groups of 10 x 10 leaflets to determine incidence.

The samples in the first year were collected after the crop had reached full canopy cover from Mondial, Royal Blue and White Star on 22 September 2011 and from Nadine on 6

October 2011 on 'Arden Fleets' and on 6 October 2011 just before crop spray-off for all other varieties on 'Lightning Ridge' and 'Jameson Farm'.

The leaflet samples on all sites were routinely tested for PLRV and PVY in 3 groups of 15 leaflets sub sampled from the 100 leaflet sample (or 6 groups of 15 leaflets of viruses were detected as a lower cost option compared to the standard 10 x 10 grouping) on 23 August 2012 samples or 10 groups of 10 leaflets for the 2 October 2012 samples using ELISA. In one case only (FL1867 from 'Jameson Farm' on 19 July 2012) was 20 groups of 10 leaflets used. The 100 tubers/seed variety sample collected from each site (except 'Jameson Farm') were tested for PLRV and PVY by ELISA in 10 groups of 10 leaflets from germinated tubers for 'Lightning Ridge' and 'Jameson Farm' or all 5 viruses by polymerase chain reaction (PCR) quantitative PCR (qPCR) for tuber tests analysis on 1 cm^2 of peel from 100 tubers/variety (Saturn Biotechnology) for 'Arden Fleets' only.

Virus testing was also done as a technology transfer exercise to familiarise growers with seed certification procedures in a 2012 'Seed Crop Health' field walk. Here a visual inspection was carried out by two inspectors from the WA seed potato scheme on 19 July to assess all seed crops as though they were to be classified as certified seed crops. Virus infected plants identified during the visual inspection had leaflet samples submitted to the laboratory for confirmation. These plants included Rodeo on 'Arden Fleets', Ruby Lou on 'Lightning Ridge' and FL1867 on 'Jameson Farm'. Following the visual inspection (except Rodeo on 'Arden Fleets') leaflets were collected from all crops on 'Arden Fleets' and 'Lightning Ridge' just prior to crop spray-off on 23 August 2012 and on 2 October 2012 on 'Jameson Farm'. Tubers were collected from the crops harvested on 15 September 2012 on 'Arden Fleets' and on 4 December 2012 from 'Lightning Ridge'.

5.3 Results

Details of aphid presence and virus incidence on all sites monitored for the two seasons are given in Figs. 5.1 to 5.3 and Tables 5.1 to 5.3.

5.3.1 *Insect monitoring*

The most abundant insects present in the potato crops which may have affected crop health or vigour were GPA and tobacco looper (*Chrysodeixis sp*.). Other insects that also attack potatoes but present at what was considered to be below damaging levels included Rutherglen bug (*Nysius vinitor*), potato tuber moth *(Phthorimaea operculella*), leafhoppers (species not identified), Heliothis (*Helicoverpa sp*.), thrips {species not identified but most likely to be onion thrips, (*Thrips tabaci*)}, mirids (species not identified) and whitefly (species not identified). Beneficial insects observed in the crops included the GPA parasitoid wasp (species not identified), ladybirds (species not identified), brown lacewing (*Micromus tasmaniae*), damsel bug (*Nabis kinbergii*), predatory shield bug (*Cermatulus nasalis)* and parasitoid flies (Family Tachinidae, species not identified).

Tobacco looper was present at what was considered to be pest levels in one pivot crop only. This occurred in late autumn early winter, 2011. This insect was present at low levels in all other crops in both years.

With respect to the presence of insect vectors of potato virus diseases, the only species found to colonise the MWA potato crops consistently and at levels that could require management was GPA. In the second year of monitoring, nearby crops of canola were heavily infested with cabbage aphid, but this species was not observed within the potato crops. Cabbage aphid can transmit PVY in a non-persistent manner, but at a very low level of efficiency (Anon. 2013).

The abundance of GPA varied in time and location for each season. Generally, GPA was present in autumn and again in spring. Despite the relative proximity of the farms to each other, aphids were present occasionally at very different levels at the same time of year on the different farms. In 2011, GPA was virtually absent in the autumn sown crops on 'Arden Fleets' and 'Jameson Farm', and in 2012, no aphids were detected in the autumn sown mini tuber and centre pivot crops on 'Ardens Fleet' and absent in the earlier sown crops on 'Jameson Farm' until near crop die off.

The main insecticides used in the MWA potato crops during 2011 and 2012 to control GPA were acetamiprid (Intruder™, Supreme™), alpha-cypermethrin (Dominex™, Dominex Duo™ and others), imidacloprid (both as soil application to seed at planting as Confidor Guard™ and foliar application as Confidor™), pirimicarb (Aphidex™, Pirimor™), pymetrozine (Chess™) and spirotetramat (Movento™). The properties of each of these active ingredients in terms of safety to natural enemies of pest insects are discussed below (see also Table 5.4).

The situation regarding GPA was different for the three farms in 2011 (Figs. 5.1 to 5.3). At 'Arden Fleets', GPA was detected at minor levels only at site 1, but at moderate to high levels in the later planted crops at site 2 and especially on the smaller area under semi-permanent irrigation at site 3. At site 3 insecticide application was not successful in controlling GPA, however the crop was not monitored on 25 August when the aphid invasion may have commenced in earnest and when more a more timely start to applying insecticides may have lead to a better result. Site 3 was well away from the centre pivot site 2 and may have been closer to a source of winged aphids. On 'Lightning Ridge', crops planted in March under the centre pivot at site 1 were infested early and crops planted later at the second site on this farm were subjected to an infestation in late winter. In the single centre pivot on 'Jameson Farm', aphids were present late in the season only and at a low incidence.

In 2012 there was a difference in both the time and level of infestation by GPA across the three farms (Figs. 5.1 to 5.3). No GPA was detected in the earlier planted crops on 'Arden Fleets' and 'Lightning Ridge'. GPA was present in the earliest planted crops on 'Lightning Ridge', but the infestation declined in later plantings on this site. The systemic aphid active insecticide imidacloprid (Confidor Guard™) was applied during planting to the later potato cops at site 2 (second pivot area) on both 'Arden Fleets' and 'Lightning Ridge'. At the later planted second pivot sites on all three farms, aphid immigration occurred around early to mid August, which was late in the crop cycle (Fig. 5.4). For this reason, little insecticide was used on the later planted crops.

The level of dead aphids as well as live winged aphids, wingless aphids and parasitised aphids (mummies present on leaves) for late winter - spring 2012 is shown for the three farms in Fig. 5.4. During this period, all three farms were subject to invasive flights of aphids at a similar time but many of the immigrant winged GPA died some time after arriving in the crops. The reason for this mortality was not known. While some crops had been treated with imidacloprid at planting, around six to eight weeks earlier, by which time the insecticide level in plants would be expected to be low. In any case, the crops on 'Jameson Farm' had not been treated with imidacloprid. This mortality of winged aphids and the presence of a wasp parasitoid of GPA resulted in a relatively low incidence of wingless GPA in crops in spring 2012.

Parasitism by the GPA parasitoid wasp was observed whenever the GPA was present in reasonable numbers, for example the level of parasitism for early planted crops on ‘Lightning Ridge’ in 2012 is presented in Fig. 5.5. The highest record of parasitoid occurrence was 70% leaves with aphid mummies present.

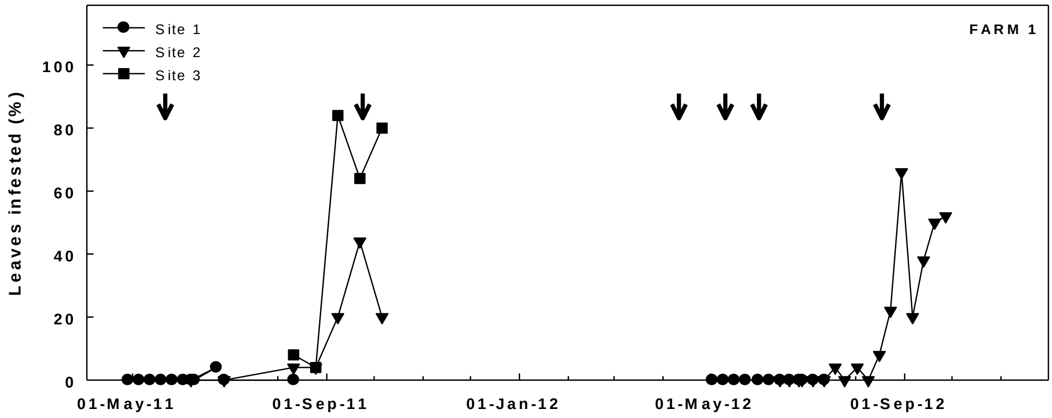

Figure 5.1. The percentage of potato leaves infested with green peach aphid in potato crops on 'Arden Fleets' farm in the MWA of WA in 2011 (three sites) and 2012 (two sites). Arrows indicate insecticide applications.

Table 5.1. Virus incidence (%) in leaflet and presence in tuber samples collected from potato seed (unlabelled), crisp (c) or ware (w) crops grown on 'Arden Fleets' farm, Dandaragan, WA in 2011 and 2012. Leaflet samples were collected after full canopy cover and tuber samples after harvest.

Site/Area	Variety	Leaf test					Tuber test	
		PLRV	PVS	PVX	PVY	TSWV	PLRV PVS PVY TSWV	PVX
		(%)						
2011								
2 – pivot	FL1867 (c)	0	0	0	1	0	-	-
3 – semi permanent	Mondial	0	0	0	0	0	-	-
	Nadine	0	0	0	0	0	-	-
	Royal Blue	0	0	0	0	0	-	-
	White Star	0	0	0	0	0	-	-
2012								
1 – pivot	Nadine (w)	1	0	0	0	0	-	-
2/1 – pivot	Mondial (w)	0	-	-	0	-	-	-
	Nadine (w)	0	-	-	0	-	-	-
	White Star (w)	0	-	-	0	-	-	-
2/2 – pivot	Mondial	0	-	-	0	-	0	0
	Nadine	0	-	-	0	-	0	0
	Rodeo	1	-	-	0	-	0	0
	Ruby Lou	0	-	-	0	-	0	0
	White Star	0	-	-	0	-	0	+

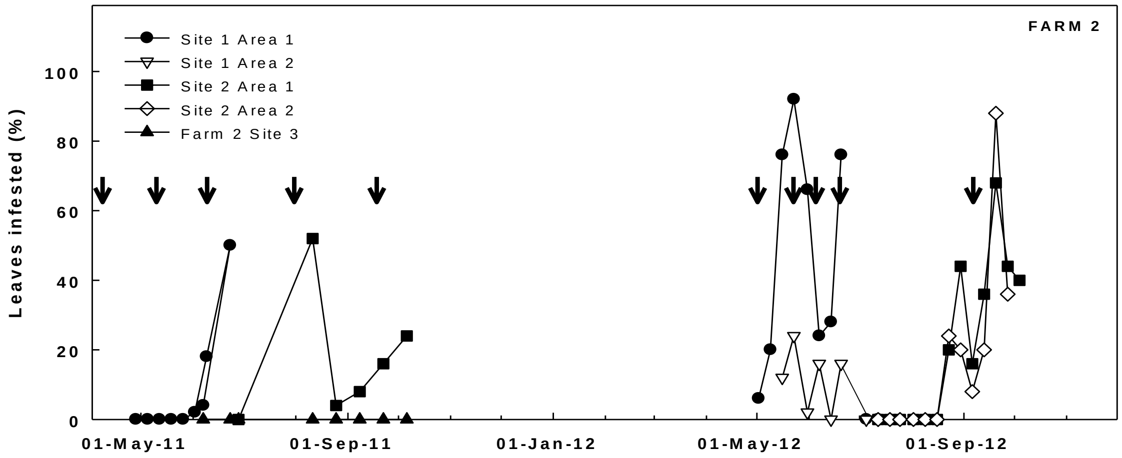

Figure 5.2. The percentage of potato leaves infested with green peach aphid in potato crops on 'Lightning Ridge' farm in the MWA of WA in 2011 (three sites) and 2012 (two sites). Arrows indicate insecticide applications.

Table 5.2. Virus incidence (%) in leaflet and tuber samples collected from potato seed (unlabelled) or ware (w) crops grown on 'Lightning Ridge' farm, Dandaragan, Western Australia in 2011 and 2012. Leaflet samples were collected after full canopy cover and tuber samples after harvest.

Site & area	Variety	Leaf test					Tuber test	
		PLRV	PVS	PVY	PVX	TSWV	PLRV	PVY
		(%)						
2011								
1 - pivot	Lady Crystal (w)	10	0	0	0	0		
2 - pivot	Almera	0	0	0	0	0		
	Mondial	0	3.5	0	0	0		
	Nadine	1	0	0	0	0		
	Royal Blue	0	3.5	0	0	0		
	Ruby Lou	0	0	0	0	0		
3 - semi	Lady Crystal	2	0	0	0	0		
permanent	Mondial	0	>11	0	0	0		
	Nadine	0	0	0	0	0		
	Royal Blue	0	0	0	0	0		
	Ruby Lou	0	0	0	0	0		
2012								
1 - pivot	Nadine (w)	10	3.5	0				
	Royal Blue (w)	0	2.2	0				
2/1 - pivot	Almera	0		0			0	0
	Lady Crystal	0		0			0	0
	Nadine	0		0			0	0
	Red Rascal	0		0			0	0
	Royal Blue (2/2)	4.5		0			0	0
	Royal Blue	0		0			0	0
	Ruby Lou	0		0			0	0

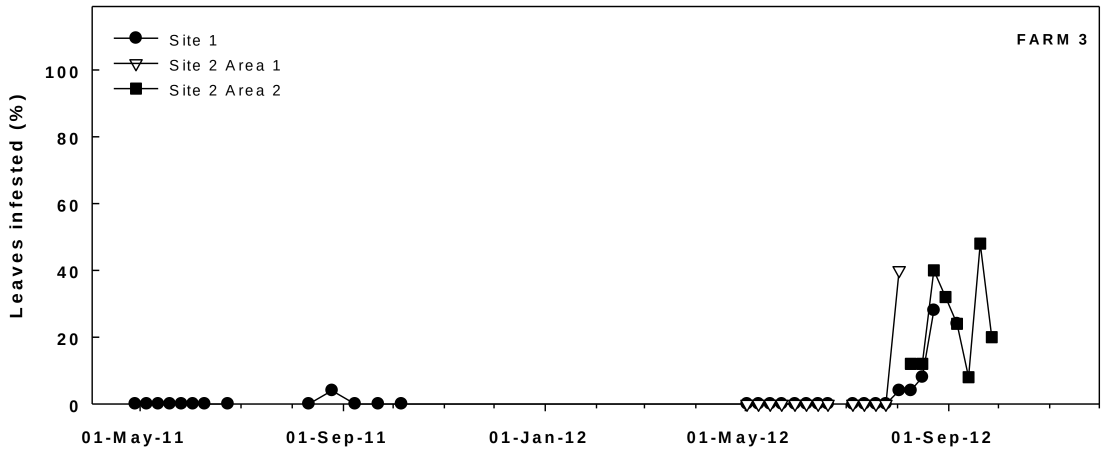

Figure 5.3. Percentage of potato leaves infested with green peach aphid in potato crops on 'Jameson Farm' in the MWA of WA in 2011 (one site) and 2012 (two sites).

Table 5.3. Virus incidence (%) in leaflet samples collected from seed or ware (w) potato crops grown on 'Jameson Farm', Dandaragan, Western Australia in 2012. Leaflet samples were collected after full canopy cover.

Site/Area	Variety	Leaf test				
		PLRV	PVS	PVX	PVY	TSWV
		(%)				
1 - pivot	Atlantic	0	0	0	0	0
	FL1867	0	0	0	0	0
2 - pivot	Mondial (w)	0	-	-	0	-
	Nadine (w)	0	-	-	0	-
	Rodeo (w)	0	-	-	0	-

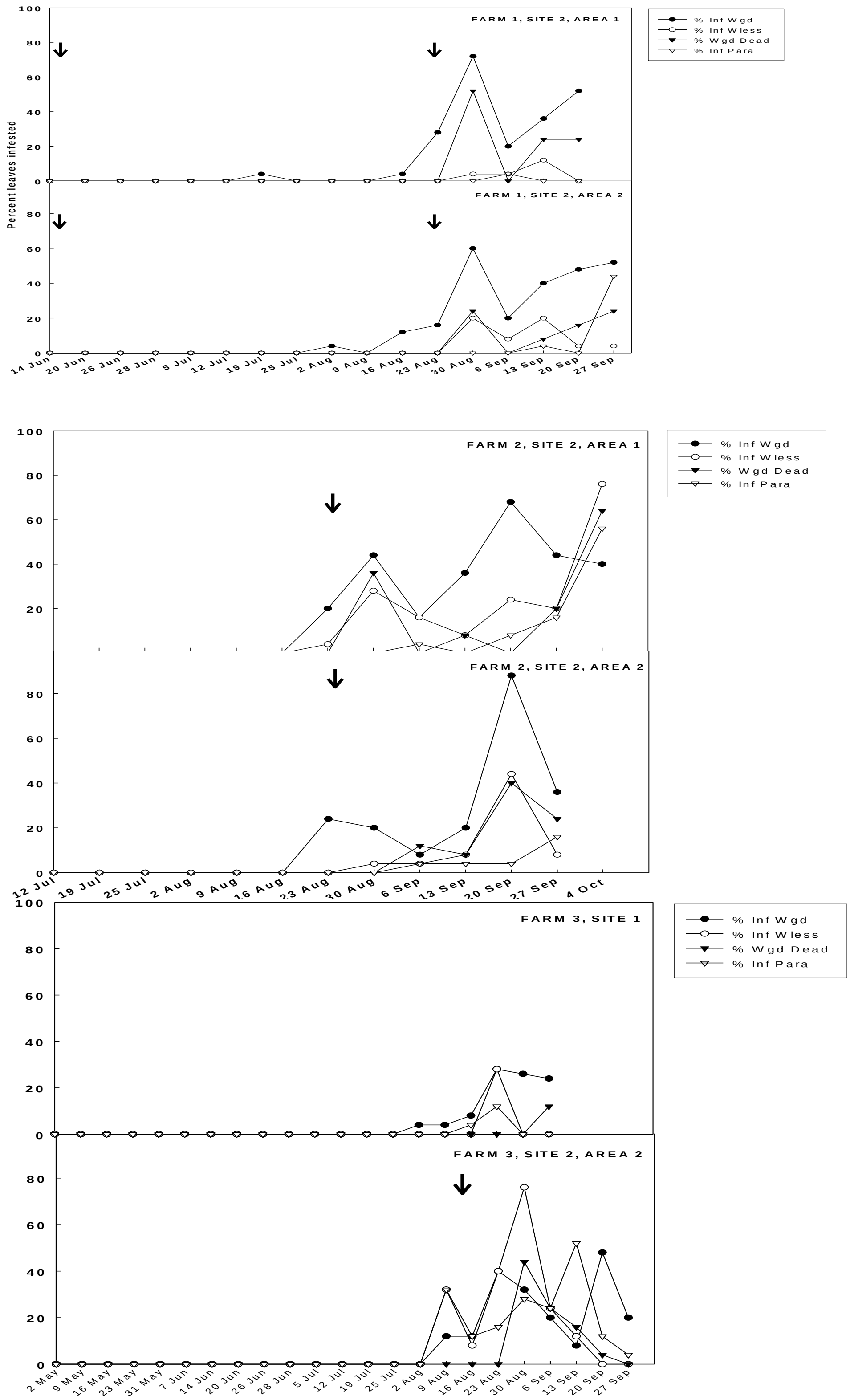

Figure 5.4. Percentage potato leaves infested with winged, wingless, dead winged and parasitised green peach aphid in winter planted crops on three farms at Dandaragan in 2012. Arrows indicate insecticide applications.

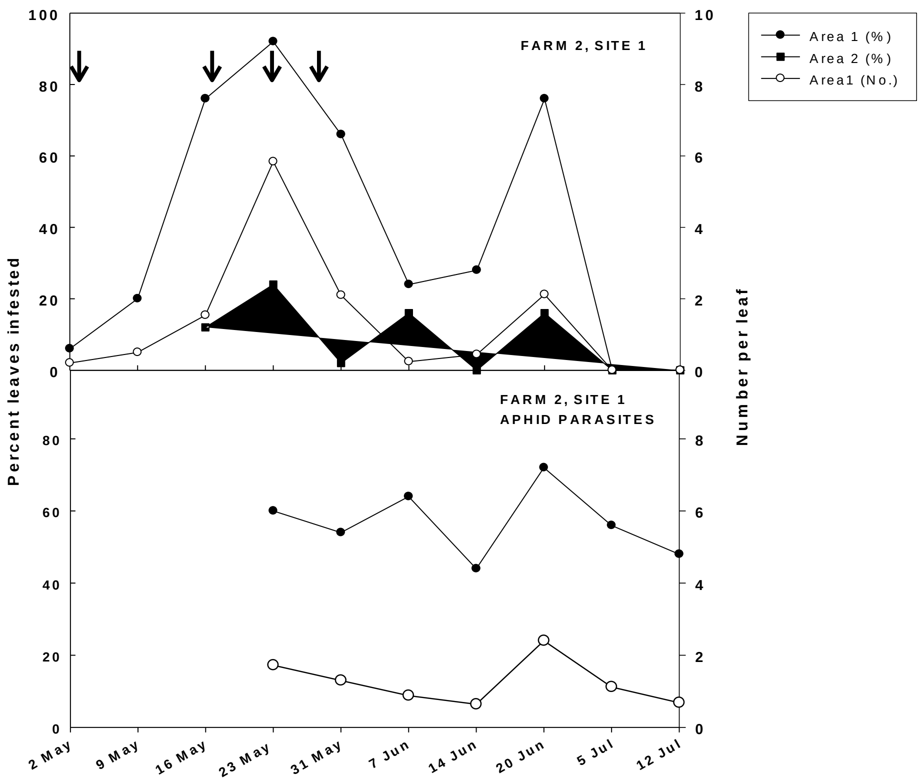

Figure 5.5. Percentage of potato leaves infested with green peach aphid (GPA) and GPA average number per leaf in two areas at the earlier planted site on 'Lightning Ridge' farm in 2012 and percentage of leaves with parasitised aphids and the average number of parasitised aphids per leaf. Arrows indicate insecticide applications.

5.3.2 *Virus monitoring*

Potato viruses were found on all farms but not in all varieties (Tables 5.1 to 5.3). Viruses detected were PLRV {7 of 39 (18%) varieties tested by leaf sample and none in 5 tuber tests}, PVS {5 of 26 (19%) varieties tested by leaf sample and none in 12 tuber tests}, PVX (0 of 19 varieties tested by leaf sample and one in 5 tuber tests) and PVY {1 of 39 (2.5%) varieties tested by leaf sample and none in 5 tuber tests}. TSWV was not detected in any of the varieties tested (19 varieties tested by leaf sample and 5 tuber tests).

Seed crops

Aphid infestation (winged GPA) of seed crops in 2011 on 'Arden Fleets' farm (Fig. 5.1, site 3) increased to about 80% of plants by late August 2011 yet no viruses were detected in leaflet samples collected in late September or early October just before spray-off (Table 5.1) which was 2 weeks before the harvest on 26 October 2011. This indicated seed was free of virus or contained a very low level and the growing crop was also free of virus so aphid spread was insignificant either because they are not viruliferous or because of the old physiological state of the crop when the phloem is less active and therefore accessible to the aphids.

By contrast on 'Lightning Ridge' (Fig. 5.2, site 3) in 2011 no aphids were detected in the seed crops but PLRV was detected in Lady Crystal (2%) (Table 5.2) indicating this infection was of seed origin (secondary infection). No doubt the spread of PLRV could have been much worse in the already infected varieties and also spread into the adjacent uninfected varieties had aphid control not been as good. This emphasises the importance of seed sanitary quality because if a crop has seed borne virus, aphid spread of the virus infection has the potential to occur and increase to levels above those allowed for WA certified seed.

In 2011 on 'Lightning Ridge' PLRV was detected at 1% in Nadine seed crops at site 2. PVS was detected at 3.5% in both Mondial and Royal Blue on site 2 and > 11% in Mondial at site 3 (Table 5.2). As aphids were not detected on site 3 it was concluded that the PLRV in Lady Crystal was most likely of seed origin. Also, no viruses were found in five other varieties tested. It was noted that the Lady Crystal crop on site 3 with 2% PLRV would not have been passed as a certified seed crop and the Royal Blue at 1% would have been given a rating of 3 meaning it could not be further multiplied for seed (Holland & Spencer 2012). Despite the apparent lower virulence of PVS when it infects crops alone compared to other viruses (Reestman 1970) , the Mondial crops on site 2 and 3 and the Royal Blue on site 3 would not have been passed as certified seed and the Nadine on site 3 could not have been further multiplied within the seed scheme. Based on these results the grower decided not to further multiply any of these infected crops for seed, except the Nadine, and sold the crops off as wares.

In 2012, winged GPA infestation of seed crops on 'Arden Fleets' (Fig. 5.1, site 2) increased to about 60% of plants by late August 2012 with viruses (PLRV) only detected in leaflets from one variety (Rodeo at 1%) by visual inspection on 19 July 2012 with subsequent ELISA confirmation (Table 5.1). Based on the WA certified seed potato scheme production rules (Holland & Spencer 2012), this crop would not have passed as certified seed. The grower decided not to use the Rodeo crop for seed and harvested it for the ware market. Neither PLRV nor PVY were detected in either subsequent leaflet samples or in tuber samples from any of the other seed varieties but PVX was detected in the tubers of White Star (% not determined) after harvest using PCR analysis. This showed the high sanitary quality of the seed enabled the grower to produce seed with low or no virus despite the high abundance of winged GPA in the crops. No doubt the quick removal of the virus infected Rodeo enabled management of the other varieties such that they did not become PLRV infected. Aphids were present only late in the life of this crop. Because no other seed varieties tested positive for viruses it was concluded the source of the virus was from the seed used.

GPA (winged) infestation on 'Lightning Ridge' (Figure 5.2, site 2) in 2012 increased to about 90% of plants by mid September with PLRV detected in Ruby Lou by visual inspection on 19 July 2012 and subsequent ELISA confirmation at 4.5% of leaflet samples. It should be noted that the PLRV infection of Ruby Lou was not confirmed by ELISA tests of sprouted tubers after harvest which may indicate mature plant resistance occurred where leaf infection ceases to be translocated to the tubers as the plant matures (de Bokx 1972) before crop senescence. Despite the high percentage of plants infested with GPA the PLRV did not spread from the Ruby Lou to other varieties. It was concluded the source of the virus was from the seed used as no other seed varieties tested positive for viruses. This crop would also not have been passed as certified seed.

GPA (winged) infestation on 'Jameson Farm' (Figure 5.3 site 1) in 2012 increased to about 30% of plants by late August. No PLRV or PVY was detected by visual inspection of Atlantic and FL1867 crops on the 19 July 2012 which was confirmed by subsequent ELISA tests of leaflets (Table 5.3). It was concluded the source of the virus was from the seed used because no other varieties tested positive for virus. This crop would not have been passed as certified seed.

Non seed crops

In non-seed potato crops in 2011, on 'Arden Fleets', winged GPA infestation increased to about 40% of plants by mid September (Figure 5.1, site 2) in the FL1867 crop (sown 13 July 2011) where 1% PVY was detected. The PVY infection was probably too low to have contributed to the lower than expected yield in this crop as a 1% PVY infection would reduce yield by just 0.5% (Reestman 1970). Poor seed physiological quality may have been an issue as physiological quality was attributed to an even lower yield of an adjacent Atlantic crop which showed no visual signs of virus infection.

In non-seed crops in 2011 on 'Lightning Ridge', winged GPA infestation increased to about 50% of plants by mid June 2011 (Figure 5.2, site 1) in the Lady Crystal crop that had > 10% PLRV infection. This infection was identified by visual inspection by a private consultant on 1 May 2011, DAFWA staff on 5 May 2011 and confirmed by ELISA testing of leaflets. This PLRV infection may have contributed to the poor yield of the Lady Crystal crop and may have spread to other varieties on the pivot area although no widespread testing was carried out. No seed was grown on this pivot so these crops were not directly at risk. PLRV was detected at lower % in seed crops on 'Lightning Ridge' but on separate sites sown later (13 July 2011) where aphid control was excellent. The PLRV infection was most likely to have been of seed origin in the seed areas as discussed above and not from incoming aphids.

In 2012, on 'Arden Fleets' (site 1) 1% PLRV was detected in a Nadine ware crop sown from Dandaragan 2011 grown seed (which was tested for PLRV but no virus was detected, see 2011 Nadine in Table 5.1) but no virus symptoms were observed in an adjacent Nadine crop where Pemberton seed was used[1]. Despite the detection of PLRV in the Dandaragan crop, plot harvests showed yield was higher from the Dandaragan than the Pemberton seed (Figure 5.1, site 1). There was no further virus testing done on site 1 so no conclusions can be drawn about the spread of PLRV to any other varieties although there were no aphids observed on this site so aphid spread would have been unlikely. Also there was no obvious spread to site 2 (which was an adjacent pivot area to site 1) where the seed crops were grown. No PVY or PLRV was detected in the 3 ware crops (Mondial, Ruby Lou and White Star) tested on the same pivot area as site 2. Winged GPA infestation increased to 70% of plants by late August 2012 in the ware crops (Fig 5.2 site 2). Despite this there did not appear to be spread of PLRV from Rodeo on site 2 or from Nadine on site 1 to other crops.

[1] Before the identification of PLRV the cause of leaf curling was suspected to be due to copper deficiency. Petiole tests confirmed copper levels were adequate although copper sprays were applied on the advice of a private agronomist.

In 2012 on ‘Lightning Ridge’ site 1, poor growth of Nadine was associated with a PLRV infection of 10% and PVS infection of 3.5%. Also in a ware crop of Royal Blue an infection of 2.2% PVS was recorded. Both these crops were on the side of a pivot area closest to seed crops on adjacent pivot. Winged GPA infestation reached about 90% of plants in this area in May. After virus testing of crops in site 2 where only 1 of seven varieties tested was found to be infected (Table 5.2), it appeared that aphid transmission was not the cause.

On ‘Jameson Farm’ site 2 in 2012, three ware varieties of potatoes tested showed no sign of virus infection and aphids arrived very late at this site.

5.4 Discussion

After two seasons of monitoring for insects and viruses in potato crops in the MWA of WA, some general trends were apparent so that the pest status of insects both as virus vectors and direct pests and guidelines for their management can be considered.

Only two insect species were present in sufficient numbers to be considered pests. These were GPA and tobacco looper.

The confirmation of the occurrence of a suite of natural enemies of GPA and the level of abundance of GPA in potato crops was such that this insect is unlikely to be a direct pest of ware or crisp potatoes here and the intervention with insecticides is likely to be unnecessary. While natural control of aphids would be expected in MWA potato crops, if insecticides were considered necessary, those safest to these beneficial insects should be selected. The insecticides currently registered for use in potatoes that have activity against aphids are listed in Table 5.4, together with their rating for safety to beneficial insects. By applying insecticides as a last resort option and then selecting those that are safest to beneficial insects, insecticide use for aphid control would be minimal.

Table 5.4. Insecticides registered for use in potato crops in Western Australia and their toxicity to natural control agents (beneficial insects).

Active ingredient and group	Product (™)	Toxicity
acetamiprid 4A	Intruder, Supreme	Toxic to beneficial
alpha-cypermethrin 3A	Dominex, Dominex Duo, plus others	Toxic to beneficial
imidacloprid 4A	Confidor Guard	Soil application less toxic than foliar
	Confidor	Toxic to beneficial
dimethoate 1B	Rogor plus others	Toxic to beneficial
phorate, 1B	Thimet, Umet, Zeemet	Soil application
pirimicarb 1A	Aphidex, Pirimor	Low toxicity to beneficial
pymetrozine 9B	Chess	Low to moderate toxicity to beneficial
spirotetramat 23	Movento	Low to moderate toxicity to beneficial

For MWA seed potato crops, which must have no or very low levels of virus infection, further consideration of the pest status of GPA and the possibility of other aphid species visiting potato crops as virus vectors is required.

The importance of obtaining seed potatoes with no or very low virus levels was evident in this study. Where virus was detected, it was concluded that the introduction was secondary that is, seed-borne. In this respect growers should purchase rating 1 certified seed as this has the lowest level of disease infection of the 3 certified seed categories as well as having a nil tolerance for PVY (Table 5.5). This give the best chance of growing good quality crops in the MW with its higher level of aphid infection than SW seed areas.

Table 5.5. Maximum tolerance for foreign varieties (% of plants) and diseases (% plants infected) in WA certified seed potato at the second field inspection for each seed rating (1 to 3) (after Holland & & Spencer 2012).

Factor	Rating 1*	Rating 2	Rating 3
Foreign varieties	0.00	0.01	0.10
Viruses	0.01	0.10	1.00
Other diseases	0.10	0.25	2.00
Total	0.10	0.25	2.00

* All rating 1 crops must be 0% for PVY at the first and second crop inspections.

Of viruses tested for in potato crops during this study, those recorded were PLRV (18% leaf samples), PVS (19% leaf samples), PVX (not recorded in leaf samples and presence detected in one of five tuber samples) and PVY (5% leaf samples). TSWV was not detected in any of the varieties tested. Seed is an important source for introduction of all these viruses, but aphids are important vectors for PLRV and PVY.

With the exception of 'Lightning Ridge' in winter 2011, GPA was present either in autumn or spring. This is the usual situation recorded for aphid occurrence in WA where the change of season from summer to autumn and again for winter to spring is the time where aphid immigration occurs (Learmonth 2002, Holland 2005). Nevertheless, the presence of aphids through winter on at least one farm emphasises the need for continued monitoring.

When seed crops are grown in this area, a monitoring and management plan needs to be designed and implemented to ensure such crops are at low risk of having virus levels above the threshold allowed for WA seed crops (Holland & Spencer 2012). The management plan could include the soil applied imidacloprid to protect at-risk crops – those planted in early autumn. Virus infection and spread within potato crops is at its maximum in the early stage of crop growth. If viruliferous aphids invade a crop at this time, virus infection and spread as the aphids multiply will be high.

While GPA was present in one crop during winter, this appeared to be the exception and therefore the use of soil applied imidacloprid for late autumn/winter planted crops would not appear to be beneficial.

For all seed potato crops, a regular monitoring program is required. This should be undertaken weekly and representative areas of crops need to be included. Destructive leaf sampling is the recommended basis for such monitoring. While following a monitoring path, other issues of crop health could be included – such as the occurrence of other pests such as tobacco looper or diseases.

The MWA traditionally produces broad acre crops of cereals, lupins, pulses and canola. These crops are host to GPA as well as other aphid species that can transmit viruses. The issue of non-inhabiting species of aphids that do not breed within potato crops, or species other than GPA that may occasionally breed within potato crops, needs to be taken into account with respect to the possibility of introducing or spreading PVY (Anon, 2013). While PVY is at relatively low levels in WA, continued vigilance is required to maintain high quality seed potatoes.

Volunteer potato plants were also observed during this study and they must be controlled so they do not become a source of primary virus infection.

While monitoring potato crops for insect vectors of virus, the occurrence of other insect pests that may be seasonally important can be detected. During this study, only tobacco looper was recorded as causing sufficient leaf loss to have warranted control. Other important pests of potatoes such as potato tuber moth, Rutherglen bug and *Heliothis* occur and should be included in any monitoring program (see Section 7 'Best Management Practices for Potatoes in the Mid West Area of WA' for further details on this).

6 Irrigation monitoring

Ian McPharlin and Tony Shimmin

6.1 Introduction

Potatoes require adequate irrigation with good quality water to produce high yield of high quality tubers. Potatoes should neither be under or over-irrigated as both situations are detrimental to yield and quality.

Under-irrigation lowers yield due to inhibited crop growth and development and premature senescence and lower marketable yield due to misshapen and otherwise distorted tubers. Under-irrigation can also result in increase in incidence of some diseases such as early blight (*Alternaria solani*), which contributes to early senescence, and common scab (*Streptomyces scabies)* which decreases marketability (Curwen 1993). Under-irrigation has been implicated as probably the primary cause of a number of internal tubers disorders such as internal brown spot, translucent end, stem end discolouration and black spot bruising.

By contrast over-irrigation can lower yield by leaching fertilisers or promoting diseases such as *Sclerotinia,* stem and tuber rots and *Pythium* and decrease marketable yield due to in an increase in internal disorders such as brown centre, hollow heart, as well as lenticel enlargement and shatter bruise.

High yields of good quality potato crops grown on sandy soils through the winter in WA requires supplementary irrigation due primarily to the low water holding (WHC) or field capacity (FC) of the soils. Even the better quality (finer textured) coastal sands such as the Spearwood (or Cottesloe) sands only have about 2 to 3% (w/w) clay or 4% clay plus silt (Hegney & McPharlin 2000) with associated field capacity of about 9.5 to 10% (McPharlin & Luke 1989). The clay and silt content of Karrakatta (Hegney *et al*. 1997) and Bassendean (McPharlin & Robertson 1998) sands are lower as is their corresponding FC. These soil moisture conditions usually require at least daily or twice daily irrigation for potato crops during summer and frequent irrigation, at least daily, during rain free periods in winter.

Given the low WHC of the soils and the high frequency of irrigation scheduling of water application is usually based on the previous days pan evaporation (Epan) multiplied by a 'Crop Factor'(CF) according to crop growth stage to determine crop demand and irrigation requirements. Studies have shown that on coarse sands potato crops required from 125 to 150% of Epan (previous day's pan evaporation) i.e. the CF supplied as irrigation or rainfall, from emergence to the early senescence, for maximum yield (Hegney & McPharlin 2000). If soil moisture content is used for scheduling irrigation, water should be applied when the available water (AW) in the soil has been depleted no more than 30 to 40% or less at more sensitive stages (Curwen 1993). AW is the difference between the FC and the wilting point (WP). For example on a soil with a FC of 9% and a WP of 5% (typical of a good quality sand) the AW is 4% so irrigation should occur after a depletion of 1.6% (40% of 4) or when the soil water content has decreased to about 7 - 7.5%. Whilst Epan is used as the primary parameter on sands in WA on which to base rates of irrigation to meet crop demand soil moisture monitoring is used as a secondary check on check on the efficacy of the Epan/CF based program.

Winter potato production in WA has moved, due to urban expansion, from traditional areas around Wanneroo to northern coastal regions such as Guilderton and Lancelin. There has also been a move in the last few years into traditional wheatbelt areas such as Dandaragan where suitable soils and water are available. Crop water demand in these areas further north is higher as pan evaporation increases. For example the average Epan for the last 2 years was 35 - 40% higher in Moora than on the coast from Perth to Myalup and 17% higher than in Lancelin or Gingin (DAFWA 2013). As well water supply from rainfall is 40 - 50% lower consequently irrigation management will be an important part of crop production in these areas. This project used climatic data and soil water monitoring to assist growers with irrigation management on 3 properties in Dandaragan in 2011 and 2012.

6.2 Materials and Methods

6.2.1 *Soil samples*

After hill formation soil samples (25 x 0 - 15, 15 - 30cm) were collected in a grid pattern in a 10 m square around each of 16 monitoring sites in 2011 (9 sites) and 2012 (7 sites) on 3 farms and submitted to a commercial laboratory (CSBP) for particle size analysis (% w/w, sand, fine sand, coarse sand, silt and clay).

6.2.2 *Soil monitoring*

At each of the 16 sites volumetric (%v/v) soil water was measured in 15 minutes intervals at 3 depths (0 - 15, 15 - 30 and 30 cm) stainless steel volumetric water content probes (Campbell Scientific, SC 625, based on time domain reflectometry, 'TDR') inserted at 30 degrees (0 - 15 cm and 15 - 30 cm) or vertically (30 to 60 cm) in the soil midway between plants after early crop emergence. Monitoring ceased when the TDR unit was removed just before chemical desiccation or 'spray-off' of the senescing crop. On each site a tensiometer (Irritrol ™) was placed vertically in the soil with the ceramic tip at 30 cm depth to measure soil tension in kPa via a pressure transducer in 2011. Soil temperature was measured at a depth of 15 cm using a separate temperature probe whilst rainfall and irrigation was recorded in 0.2 mm increments using a 'tipping bucket unit (Ecowatch® 7852). Rainfall collected in gauges located at the monitoring site both in (rainfall + irrigation) and outside the crop (rainfall only) was recorded manually each week as a backup check to automated recordings. All equipment (except the rain gauges outside the crop area) in the crop was installed as soon after crop emergence as possible and removed just before chemical desiccation of the crop (spray-off) (see Plate 6.1 for overview of equipment).

(A) (B)

Plate 6.1. (A) Equipment used for monitoring soil moisture (TDR probes with white ceramic caps and black cables) and tension (tensiometers with green colour below cap and white porous tip, white aerial, black tipping bucket rain gauge, solar panel and yellow carry case) and (B) complete set up in the field.

All the monitoring units were connected to a logger (CR 200) via a cable and data downloaded via a telephone modem (Maxon 5100). Computer software ‘R-Logger’, developed using the freely available ‘R’ program, allowed irrigation timing, depth and soil moisture to be summarized via a graphical interface and emailed as a PDF to participating growers at least 4 times /week. The unit was powered by a 7.5 Ah, 12 volt sealed lead acid battery recharged by a 10 watt solar panel and all components were housed in a safe case made of hard plastic.

6.2.3 *Irrigation decisions*

Growers were provided with general guidance on irrigation of potatoes on sands in WA based on climatic data such as pan evaporation (Epan) and associated CFs for each crop stage, as the primary decision tool, where CF = water applied as irrigation and /or rainfall divided by the previous days Epan*100%. The minimum CF recommended for maximum potato yield at 5 crop stages on sands is given in Table 6.1.

Growers were provided with Epan data as required or directed to access it from the DAFWA weather stations via the website (www.agric.wa.gov.au/weather/real time and historical data). It was suggested that Moora Epan data would be appropriate for properties located between Dandaragan and Moora (<30 km from Moora) but East Lancelin Epan data may be used as an alternative for properties near Regans Ford (46 km south of Dandaragan or 81 km from Moora).

Table 6.1. Irrigation decision tools for each crop stage as a guide for irrigation of potato crops on sands in WA.

		Irrigation decision factor		
Stage No.	Stage name	CF %*	AWC %*	kPa*
1	Germination/Emerge.	90	30	-5
2	Vegetative	125	25	-5
3	Tuber initiation	125 - 150	30	-5
4	Tuber bulking	125 - 150	20	-5 to -8
5	Maturation	90	40	-8

*CF = crop factor used to multiply by Epan (as %) with values based on Hegney and McPharlin (2000), as primary decision tool.
AWC = % depletion in available water content based on Curwen (1998) used to monitor CF but not used as a primary decision tool and tensiometer (kPa) 'trigger points' at which irrigation should occur (Prince & Deyl pers. comm.) as a cross reference for soil moisture readings and not as a decision tool.

Soil factors such as volumetric soil moisture (from the TDR units) with crop stage was measured to monitor the effectiveness of the CF/Epan program and not used as a primary decision tool. For practical purposes a depletion of no more than 35 - 40% of AWC was considered the refill (RF) point based on Curwen (1993). For a typical Dandaragan sand this equated to a decline in volumetric soil moisture from a field capacity of 9% to 7.0 to 7.5% (refill point) assuming a wilting point of 5% (see Figure 6.1).

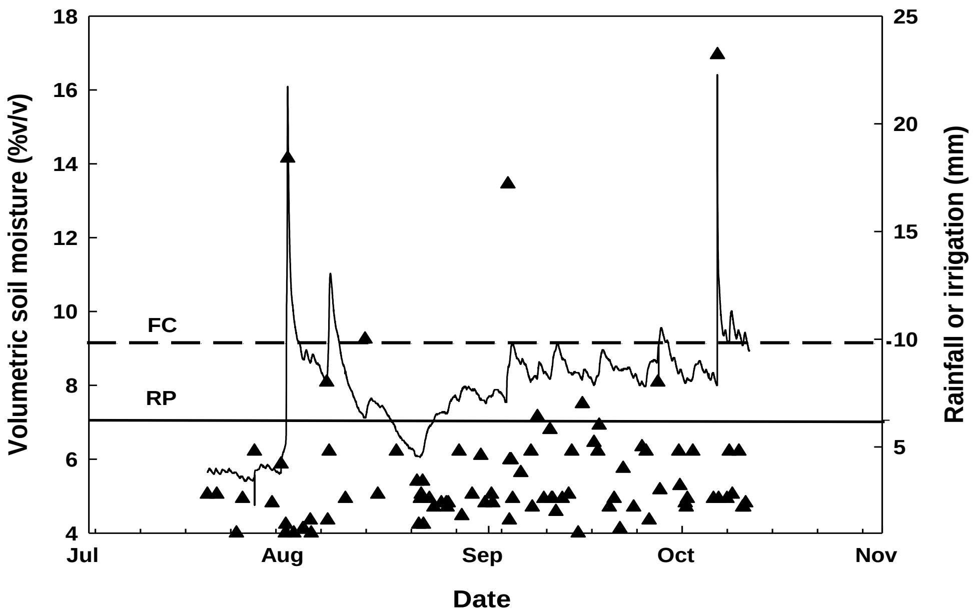

Figure 6.1. Volumetric soil moisture (% v/v as line plot) at 15 - 30 cm depth and water applied (mm as triangles) as rainfall or irrigation with date under potato crop grown on sands at Dandaragan in 2012. *Soil moisture was measured using TDR (time domain reflectometry probes) inserted in the soil beneath the crop and rainfall or irrigation was measured using tipping bucket rain gauges. Horizontal dashed and solid lines refer to field capacity (FC) at 9% and refill point (RF) at 7% respectively.*

6.2.4 *Field capacity estimates*

Field capacity (FC) was estimated at each site from the graphical plots of volumetric soil water versus (% v/v) versus time and with applied water (irrigation and/or rainfall), when applied water in excess of crop needs had been applied and after at least 24 hours of drainage. To achieve this FC this estimate was taken as early in the life of the crop as possible when crop transpiration was low, although there was no attempt to prevent soil evaporation by covering the soil with barriers such as tarpaulins. This was not possible due to the growing crop.

6.2.5 *Crop yields*

Crop yields at each site were estimated either from direct plot harvests (5 or 6 replicates x 6 m strips) where possible or from grower records. At some sites crop yields were recorded for additional varieties planted adjacent to the main target variety at the same site as they were planted and sown at similar times. This resulted in a total of 22 yield estimates for the 16 sites from 7 varieties. Nadine was the main variety monitored accounting for 11 sites followed by Mondial 4, White Star 2, FL1867 2, Atlantic, Ruby Lou and Red Rascal 1 site each.

6.3 Data analysis

Mean, minimum and maximum values for soil parameters (% sand silt, clay, FC) and irrigation (mm rain or irrigation) and crop measures such as irrigation water use efficiency (IWE = kg of tuber yield/ ha/mm of water applied, based on King *et al.* 2011) and yield collected from the 22 sites were calculated using Excel. The period of water application used here was from just after full emergence to just prior to chemical desiccation (‘spray-off’) which is shorter than the period (planting to harvest) used in other studies (King *et al*. 2011 and Hegney & McPharlin 2000). Regression analysis of soil particle size v FC and rain fall + irrigation v yield and IWE was determined using Gentstat v 15 (Rothamstead).

6.4 Results

6.4.1 *Relevant weather data*

Yearly Epan at Moora was 2562 and 2560 mm in 2011 and 2012 (or 7 mm/day) respectively which was 15% (2231 or 6.1 mm/day) and 18% (2165 or 5.9 mm) higher than at Lancelin East (Table 6.2).

In the March to November period (cropping period) monthly Epan at Moora ranged from a minimum of 74 mm in July 2011 and 93 mm in June 2012 (2.4 and 3.1 mm /day) to a maximum of 308 and 325 mm (9.9 and 10.5 mm/day) in the same months. Similar trends followed in Lancelin East with the minimums in the months of July 2011 (74 or 2.4/day) and June 2012 (79 or 2.6/day) and the maximums in March (264 or 8.5/day and 261 or 8.4/day) (Table 6.2).

Table 6.2. Monthly (daily), yearly and cropping season (March to November) pan evaporation (mm) for Moora and Lancelin East in 2011 and 2012.

Month	2011		2012	
	Moora	Lancelin East	Moora	Lancelin East
January	351 (11.3)	306 (9.9)	349 (11.3)	296 (9.5)
February	297 (10.6)	262 (9.4)	284 (10.1)	238 (8.5)
March	308 (9.9)	264 (8.5)	325 (10.5)	261 (8.4)
April	226 (7.5)	185 (6.2)	183 (6.1)	143 (4.8)
May	148 (4.8)	126 (4.1)	143 (4.6)	115 (3.7)
June	93 (3.1)	86 (2.9)	93 (3.1)	79 (2.6)
July	74 (2.4)	74 (2.4)	113 (3.6)	103 (3.3)
August	111 (3.6)	109 (3.5)	105 (3.4)	105 (3.4)
September	145 (4.7)	128 (4.1)	155 (5.0)	154 (5.0)
October	198 (6.4)	174 (5.6)	251 (8.1)	216 (7.0)
November	277 (9.2)	241 (8.0)	256 (8.5)	201 (6.7)
December	344 (11.1)	277 (8.9)	303 (9.8)	255 (8.2)
Total	2562 (7.0)	2231 (6.1)	2560 (7.0)	2165 (5.9)
Mar to Nov	1580 (5.7)	1387 (5.0)	1624 (5.9)	1377 (5.0)

Annual rainfall for Moora was 390 and 376 mm in 2011 and 2012 respectively. For the monitoring period (April to October) rainfall was from 12 to 36% higher on the farm sites than at Moora in 2011 (312 mm) and from 51 to 61% higher on the farm sites than at Moora in 2012 (234 mm) (Table 6.3).

Table 6.3. Monthly and annual (Moora only) rainfall as well as for the monitoring period (April to October) in mm for Moora and 3 farm monitoring sites (F1, F2 and F3) in the Dandaragan area in 2011 and 2012.

Month	2011				2012			
	Moora	F1	F2	F3	Moora	F1	F2	F3
Jan	14.2	-	-	-	31.6	-	-	-
Feb	19.2	-	-	-	55.8	-	-	-
Mar	10.4	-	-	-	0.8	-	-	-
Apr	6	3	6	0	5.4	0	0	3
ay	21.4	11	30	44	10	30	28.3	46.2
June	65.4	97	103	116	91.4	118	143.9	106.8
July	93.4	82	92	103	10.6	20.5	31	28.3
Aug	44	102	56	87	50.4	84	73.3	72.5
Sep	35.6	54	48	53	53.4	85	79	75
Oct	46.6	13	15	22	2	0	4.2	5.2
Nov	13.2	-	-	-	51.2	-	-	-
Dec	20.6	-	-	-	13.4	-	-	-
Total	390				376			
Apr-Oct	312	362	350	425	223	338	359.7	337

6.4.2 *Soil particle size and FC*

The texture of the soils at the monitoring sites were classed as sands with clay and silt contents ranging from 3.72 to 8.95 and 0.01 to 5.73 % (w/w) respectively in the topsoil (0 - 15 cm) and 3.95 to 8.87% and 0.01 to 3.0% (w/w) in the sub soil(15 - 30 cm) (Table 6.4). The total sand content varied between 90 and 95% in both the top and sub soil however the coarse and fine sand fraction varied more especially the fine sand fraction which ranged from 1.72 to 16.38% in the topsoil and 2.22 to 15.39% in the sub soil.

The field capacity (FC) as estimated from the soil moisture data from the monitoring probes ranged from 7 to 14.5% in the topsoil to 7 to 20 % in the subsoil.

Table 6.4. Mean and range of particle size fractions and field capacity in soils on monitoring sites on 3 farms in the Dandaragan area in 2011 and 2012. Data was collected from 9 and 7 sites in 2011 and 2012 respectively and all values are expressed as %(w/w) except for field capacity which is expressed as %(v/v).

Depth (cm)	Fraction	Mean (%)	Range (%)
0 - 15	Sand	93.25	90.55 - 95.12
	(Coarse sand)	85.58	77.62 - 93.40
	(Fine sand)	8.66	1.72 - 16.38
	Silt	1.78	0.01 - 5.73
	Clay	4.98	3.72 - 8.95
	Field capacity	9.35 (v/v)	7.0 - 14.5
15 - 30	Sand	93.51	91.13 - 95.10
	(Coarse sand)	84.60	79.28 - 92.88
	(Fine sand)	8.91	2.22 - 15.39
	Silt	1.01	0.01 - 3.00
	Clay	5.68	3.95 - 8.87
	Field capacity	10.75	7.00 - 20.00

FC was shown to be positively correlated (linear regression) with the ‘fine sand + silt + clay’ fractions ($P < 0.05$) in both the top and sub soil and both depths combined ($P < 0.01$) and with the fine sand fraction alone in the sub soil ($P < 0.05$) and both depths ($P < 0.01$) combined (Table 6.5 and Figure 6.2).

Table 6.5. Regression equations for the relationship between soil fraction (% sand, silt , clay) and field capacity(% v/v) of soils in the Dandaragan area in 2011 and 2012.

Depth (cm)	Fraction	Regression	P	R2
0 - 15	sand	y = 68.90.64x	ns	-
	coarse sand	y = 36.2 - 0.32x	0.034	0.34
	fine sand (fs)	y = 7.2 + 0.25x	0.10	0.18
	silt (si)	y = 9.45 - 0.052x	ns	-
	clay (c)	y = 6.53 + 0.57x	ns	-
	c + si	y = 5.03 + 0.64x	ns	-
	c + si + fs	Y = 4.46 + 0.32x	0.034	0.34
15 - 30	sand	y = -20.0 - 0.33x	ns	-
	coarse sand	y = 58.9 - 0.57x	0.045	0.31
	fine sand (fs)	y = 5.08 + 0.64x	0.025	0.38
	silt (si)	y = 10.18 + 0.55x	ns	-
	clay (c)	y = 11.71 - 0.17x	ns	-
	c + si	y = 10.27 + 0.071x	ns	-
	c + si + fs	y = 1.74 + 0.58x	0.034	0.34
0 - 30	sand	y = -25.60.17x	ns	-
	coarse sand	y = 45.1.0.42x	0.005	0.30
	fine sand (fs)	y = 6.56 + 0.40x	0.008	0.27
	silt (si)	y = 10.18 + 0.08x	ns	-
	clay (c)	y = 8.17 - 0.35x	ns	-
	c + si	y = 7.45 + 0.39x	ns	-
	c + si + fs	y = 3.44 + 0.43x	0.003	0.33

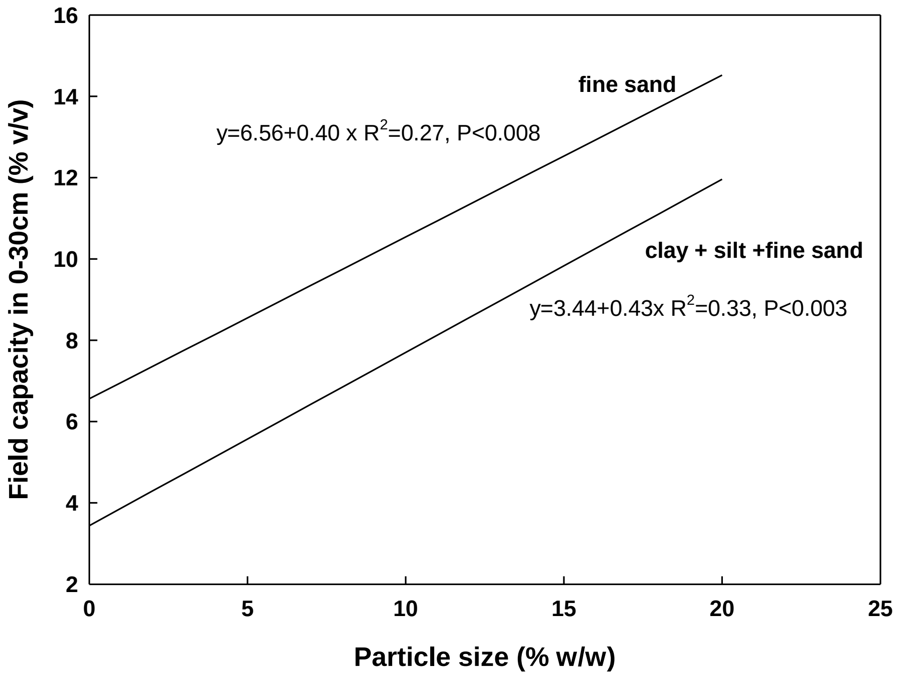

Figure 6.2. Relationship between field capacity (%v/v) and particle size (%w/w) as either fine sand fraction alone or as clay + silt + fine sand on soils on 3 farms in the Dandaragan area in 2011 and 2012.

By contrast FC was negatively correlated with the coarse sand fraction in the top and sub soil ($P < 0.05$, Table 6.5) and both depths combined ($P < 0.01$, Figure 6.3).

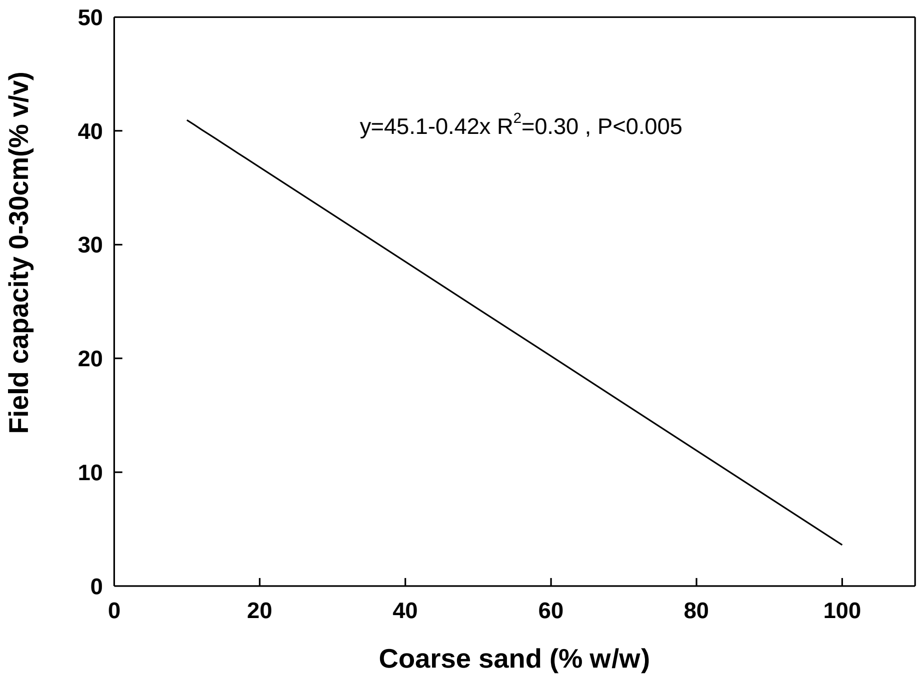

Figure 6.3. Relationship between field capacity (%v/v) and coarse sand content %w/w) on soils on 3 farms in the Dandaragan area in 2011 and 2012.

Applied water and yield

The water applied to crops (rainfall + irrigation), between emergence and senescence (spray off) on 3 farms in Dandaragan ranged from 105 to 542mm in 2011 and from 247 to 552mm in 2012. On the same sites yields ranged from 23 to 65.3 t/ha over both years and water application efficiency (IWE in kg of tubers/ha/mm) from 50 to 286 kg/mm. The mean crop factors of water applied to Nadine crops in 2011 was 90% (range 57 to 115%) and 116% (range 110 to 132%) in 2012 (Table 6.6).

Table 6.6. Water applied (mm) as rainfall or irrigation, from emergence to senescence, irrigation water efficiency (IWE, kg of yield/ha/mm water applied), yield (t/ha) and crop factors (CF%) of potato crops grown on 3 farms in Dandaragan in 2011 and 2012. *Values are means and range for 22 crops (13 in 2011 and 9 in 2012) of 7 varieties (Nadine 11, Mondial 4 White Star 2, Fl1867 2, Atlantic, Ruby Lou and Red Rascal 1 site each).Crop factors are for the Nadine sites only.*

Factor	Units	Mean	Range
	2011		
Rain (R)	mm	210	57 - 341
Irrigation (I)	mm	114	48 - 279
R + I	mm	324	105 - 542
Yield	t/ha	35.77	26.0 - 63.5
IWE	kg/ha/mm	154	52 - 286
CF*	(R + I/Epan)*100%	90	57 - 115
	2012		
Rain (R)	mm	216	137 - 308
Irrigation (I)	mm	211	110 - 247
R + I	mm	427	247 - 552
Yield	t/ha	36.8	23 - 52.5
IWE	kg/ha/mm	88.9	50 - 126
CF*	(R + I/Epan)*100%	116	110 - 132

*CF = Crop factors (mm water applied as irrigation and/or rainfall/Epan*100%) for Nadine crops only

There was no significant relationship between yield and water applied when the data was combined over both years and all varieties (Figure 6.4A). When yield and water data was considered for one variety (Nadine) only, higher yield was linearly correlated ($P < 0.001$) with lower amounts of applied water (Figure 6.4B)

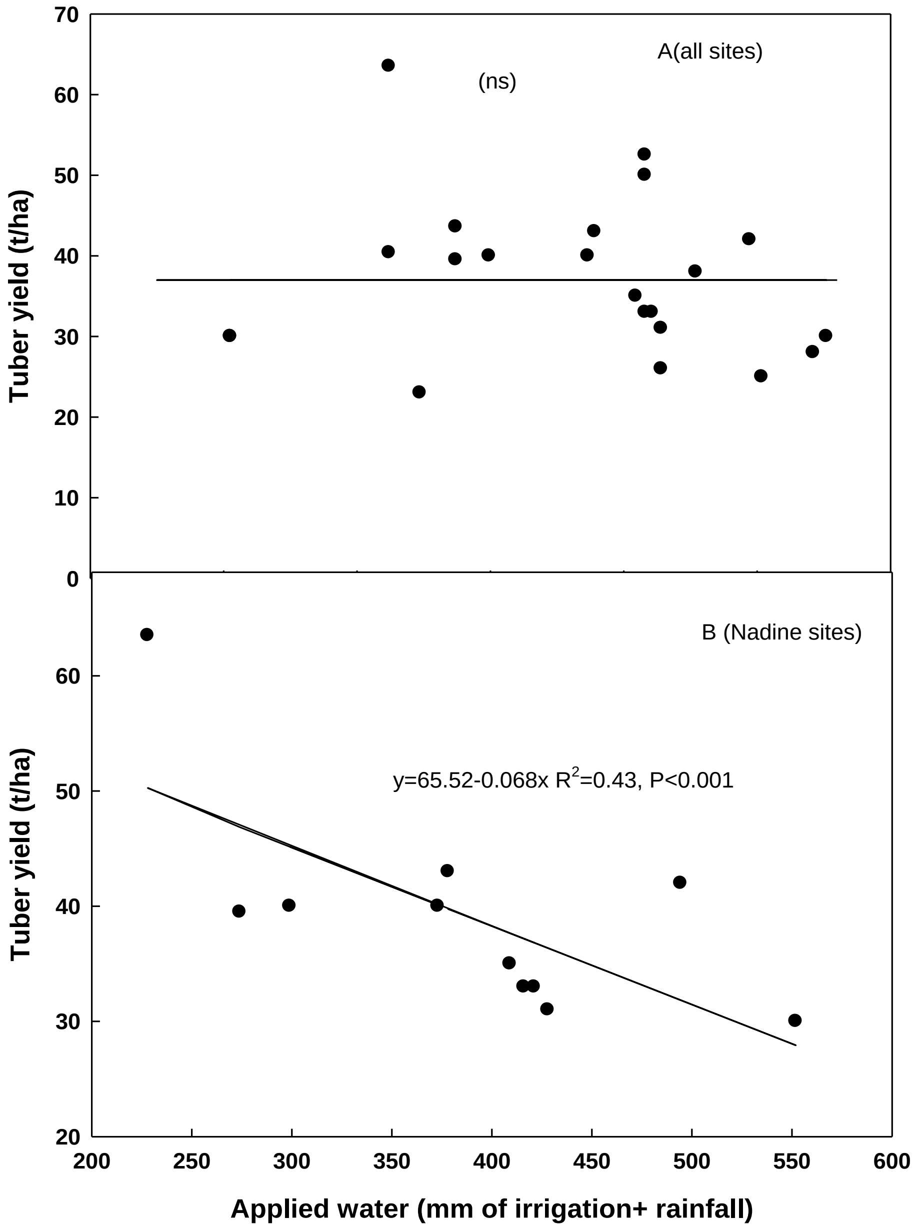

Figure 6.4 Tuber yield (t/ha) with mm of water as irrigation and or rainfall applied to potato crops grown in Dandaragan in 2011 and 2012. *Water was applied from emergence to spray off and data is from 22 monitoring sites (7 varieties) on 3 farms (A) or from Nadine crops only on 11 sites (B).*

IWE decreased significantly ($P < 0.001$ from the linear regression) with mm of applied water over the same 22 sites (Figure 6.5A) and also for the 11 Nadine sites (Figure 6.5B).

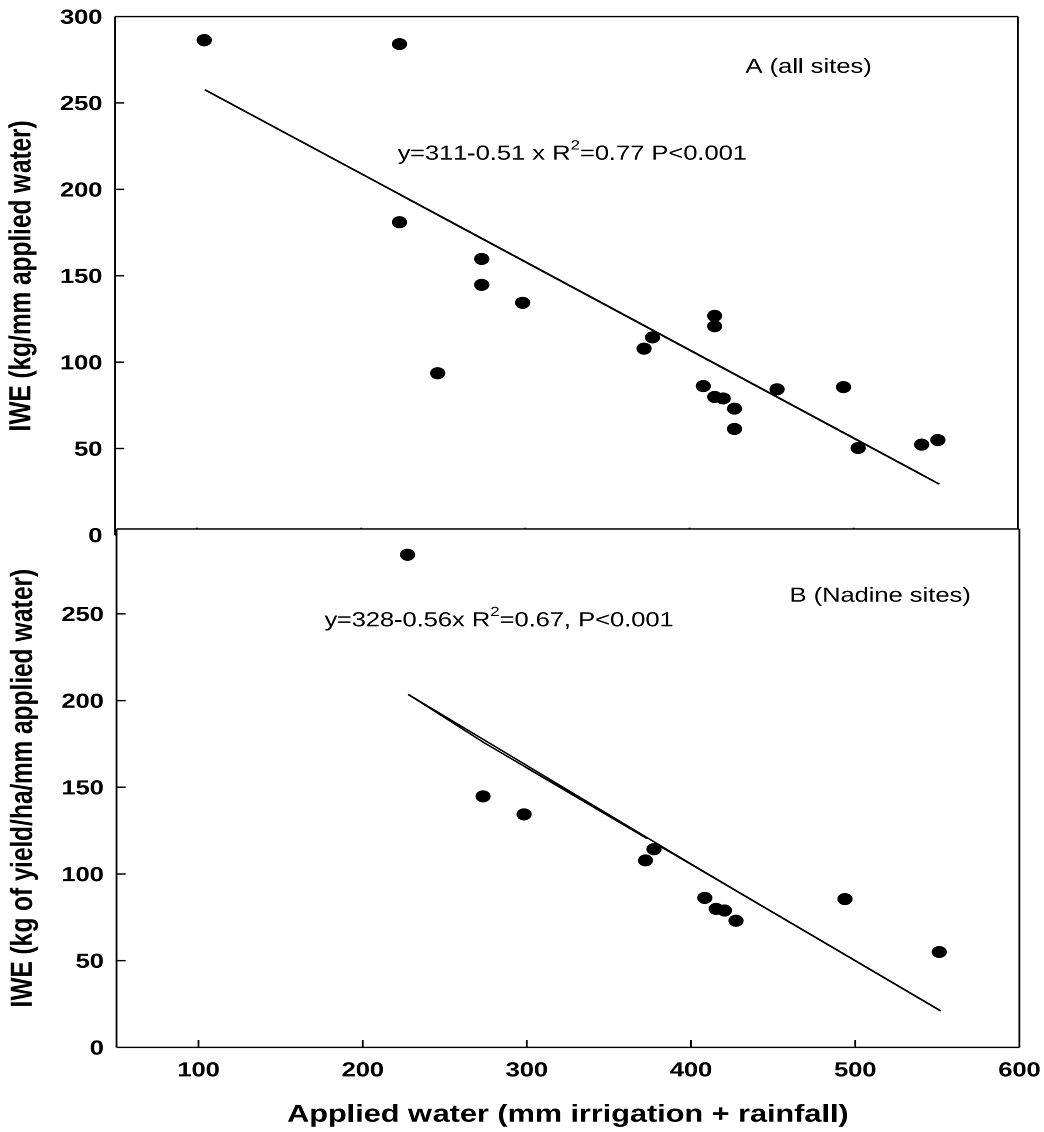

Figure 6.5. Irrigation water use efficiency (kg of tuber yield/ ha/mm water applied) with mm of water as irrigation and rainfall applied to potato crops grown in Dandaragan in 2011 and 2012. *Data is from 22 monitoring sites (7 varieties) (A) or 11 Nadine sites on 3 farms (B). Applied water was recorded from full emergence to chemical desiccation of crop.*

There was no significant relationship between tuber yield and IWE over all 22 sites (Figure 6.6.A but there was a significant ($P < 0.001$ from the linear regression) increase in IWE with yield for the Nadine crops (Figure 6.6B).

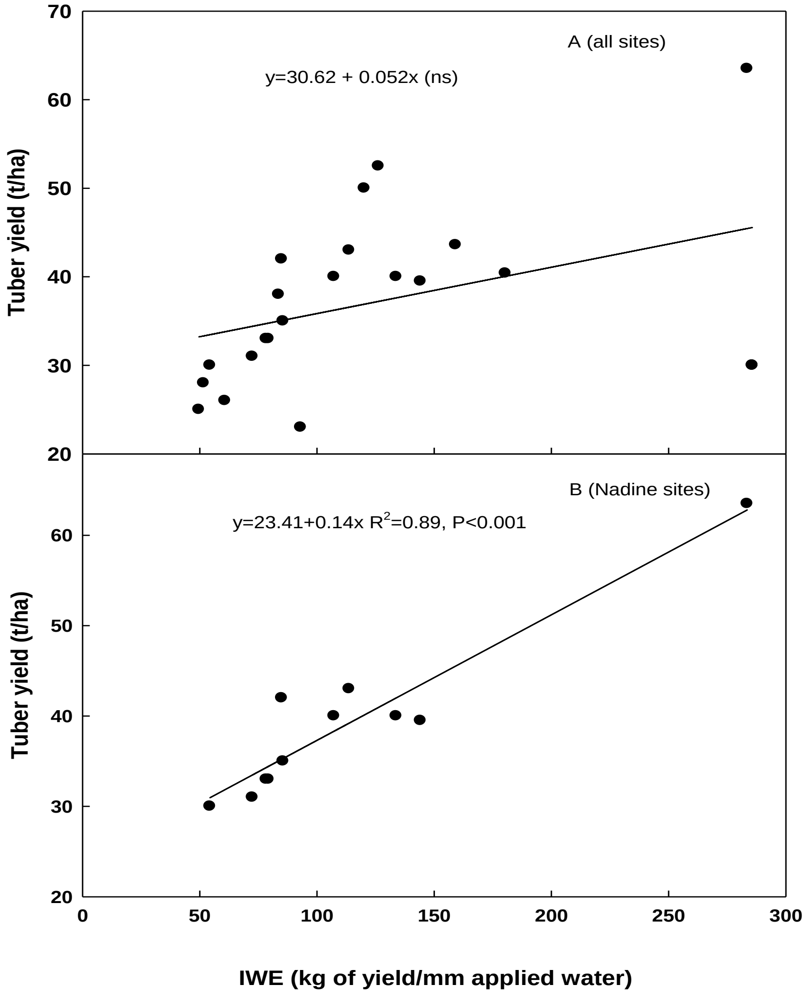

Figure 6.6. Tuber yield (t/ha) with irrigation water efficiency (IWE, in kg/mm) of Nadine potato crops grown in Dandaragan in 2011 and 2012. *Data is from 11 monitoring sites on 3 farms.*

Crop factors for water applied to Nadine crops ranged from 57 to 132% and were negatively correlated with yield over the 11 sites on 2011/2012 (Figure 6.7).

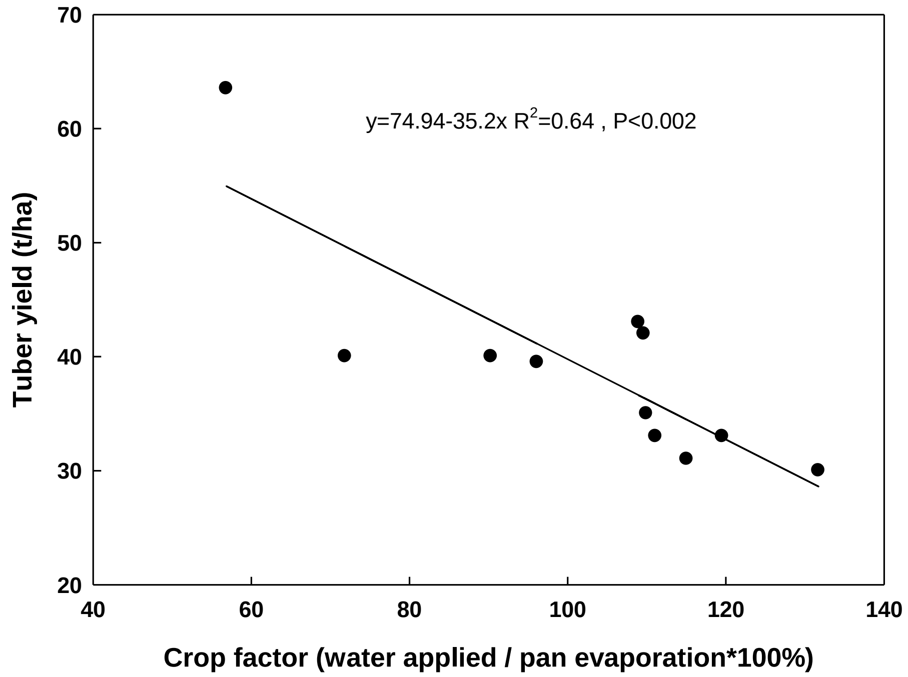

Figure 6.7. Tuber yield (t/ha) with crop factor % (mm of water applied as irrigation and rainfall/ Epan *100%) applied to Nadine potato crops grown in Dandaragan in 2011 and 2012. *Data is from 11 monitoring sites on 3 farms*.

6.4.3 *Soil water content*

The soil water content (%v/v) was on average 7.9, 9.2 and 8.4% in the 0 - 15, 15 - 30 and 30 - 60cm depths across all sites (Table 6.7). The values for the individual sites are listed in Appendix 1.

Table 6.7. Soil water content with depth.

Depth	Mean	Range
	Water content (%w/w)	
0 - 15	7.9	5.0 - 13.0
15 - 30	9.2	6 - 17.6
30 - 60	8.4	6.1 - 13.6

6.4.4 *Soil water status*

The proportion of the irrigation period between emergence and spray off that the soil on the monitoring sites was less than the refill point(<RP), between the refill point and field capacity (RP - FC) and more than FC was on average 24, 42 and 34% on the 11 Nadine sites (Table 6.8). There was no significant relationship the soil water status and yield.

Table 6.8. Mean (range) portion (%) of irrigation period at 3 soil water statuses.

Soil water status*	Portion of Irrigation period (%)	
	Mean (range)	Regression
< RP	24 (0 - 66)	y = 37.22 + 0.082x (ns)
RP - FC	42 (12 - 78)	y = 41.5 - 0.064x (ns)
> FC	34 (3 - 76)	y = 39.48 - 0.012x (ns)

*refers to refill point (RP) and field capacity (FC) respectively.

6.5 Discussion

The particle size distribution of the soils in the Dandaragan area appear to be at least as fine textured in terms of clay and silt content as the most finest textured of the west coast sands such as the Spearwood (or Cottesloe) sands (Hegney & McPharlin 2000) i.e. clay plus silt content of at least 3 - 4%. However the higher % fine sand (FS) fraction appears to contribute to the higher than expected WHC or FC observations on some sites. This is of interest as the sand fraction is not considered the main driver of FC or WHC. WA sands in different location have different FS v coarse sand (CS) proportions and the higher FS contents give the soil a loamy appearance and feel when in fact it is classed as a 'sand' based on normal textural classification. This observation is supported by relationships showing that the FS content was a more important a contributor to WHC than the clay and or silt content in these soils. Conversely WHC/FC was negatively correlated with the CS content showing a contrasting effect of the two sand fractions on WHC. This is not surprising as the FS is close in size to the silt fraction.

There was a wide range in amounts (mm) of water applied to crops as irrigation and/or rainfall (I + R) from emergence to senescence ('spray off') across the 22 crops on the 3 farms. Differences in amounts of I + R is expected between autumn and winter sown crops but whilst irrigation application is expected to decline in winter due to increased rainfall the total amount of I + R was not expected to vary to such an extent. Also in some cases the winter rainfall was lower than expected (i.e. July 2012) necessitating higher irrigation both to satisfy crop needs and also to mitigate against frost damage which often increases in dry winters.

Whilst there was there was no significant association between total water applied as irrigation and/or rainfall (I + R), or expressed as crop factors (CF%), and yield across all sites higher yield on the Nadine site appeared to be associated with lower amounts of I + R. This result is unexpected in a dry climate like WA where yield is normally associated with higher rates of applied water up to a yield plateau at 110 to 150% of Epan depending on soil type (Hegney & Hoffman 1997 and Hegney & McPharlin 2000). If at irrigation of at least 125% of Epan was required for maximum yield (Hegney & McPharlin 2000) then only 2 sites were adequately irrigated over the 2 years which included 1 Nadine site 9 and (This may have indicated overwatering contributing to lower marketable yield due to increased reject tubers resulting from disease, nutrient leaching or other issue such as lenticels enlargement. This was not specifically noted in any DAFWA harvested plots however the lowest yield sites in 2011 on one farm were noted as being 'waterlogged' whilst receiving the highest amounts of I + R.

The irrigation water efficiency (IWE) varied considerably between sites and high IWE was associated with low level of applied I + R across all site as well as the Nadine crops.

Related to this was a positive correlation between high yield and high IWE for all crops. The values of IWE are similar in range although generally higher than that found for irrigated Delaware potatoes on Spearwood sands in WA i.e. from 36 to 123 kg/ha/mm applied water depending on rate of applied N and water (calculated from Hegney & McPharlin 2000) or from 60 to 80 kg/ha/mm for Russet Norkotah in Idaho (King *et al*. 2011). In both these studies applied water values were summed from planting to harvest which would be a higher value, and therefore a lower IWE value, than the period from emergence to senescence which was used here. This variation in IWE values show factors other than water application may limit yield on some sites such as weed control, pest or disease impacts.

7 Best Management Practices for Potatoes in the Mid West Area of WA

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[A] DAFWA Bunbury

7.1 Seed

For either a seed crop or commercial ware or crisp crops use high quality seed of the correct variety. For a seed crop bulked once or twice in the Mid West area (MWA) there is reason to select higher quality 'certified' seed than for a non seed crop and this is discussed below. The correct variety also needs to be chosen to suit the growing conditions and to meet the market requirements whether for the fresh or processing sector. A decision to grow a non approved variety could lead to rejection by the buyer and significant loss of income. Once the right variety is selected it is important obtain seed of high quality. Two aspects of seed quality that are of most importance is the sanitary (pest and disease levels such as viruses) and the physiological quality or age.

7.1.1 *Sanitary Quality*

The sanitary quality of seed is a focus of seed schemes so the purchase of certified or registered seed assures the grower that the seed had met minimum standards with respect to disease and pest incidence and is of high quality. To minimise the risk of viruses and other infections seed used for crop production should be certified or registered seed obtained from Western Australian Seed Producers Inc. (WASPP).

Seed produced by WASPP is subject to either the 'Western Australian Certified Seed Production Rules' or the 'Western Australian Registered Seed Production Rules' (see Further Information). The application of the rules is overseen by DAFWA inspectors who examine the crops twice during growth and the tubers once after harvest. Potato growers can be trained to become Accredited Tuber Inspectors (ATI) which qualifies them to conduct their own tuber inspections.

The number of generations over which seed crops can be multiplied is limited and the maximum is generation 5 (G5) for certified seed. Each generation (G) of seed crops must comply with tight rating standards based on field inspections for disease and foreign varieties and additionally permitted disease/nematode and defects from a tuber inspection.

Growers who wish to purchase seed have access to a list of seed growers which is published annually in the 'WA Grower'. The list provides information such as locality seed crops grown, generation, variety and the expected harvest date. Information of the rating of seed crops can then be discussed with potential seed suppliers. Updated information may also be obtained from the DAFWA Senior Seed Certification Officer at the Manjimup Horticultural Research Institute by phoning 08 9777 0000.

7.1.2 *Physiological age*

In the MWA, the main crop is autumn planted for which seed of an appropriate physiological age (PA) from WA growers are not readily available. Most WA seed potatoes are produced in the SW of the state and are harvested in summer/autumn to suit sowing from winter to spring. This seed is unsuitable for the early autumn sowing in the area. Therefore MWA growers must consider obtaining seed from other producers who can supply seed at the correct PA, or produce their own seed for autumn planted crops using stored seed obtained from the previous year's winter planted crop. For the latter growers will need to grow their own seed for at least one generation, usually from G4 to G5, sowing in winter and harvesting in spring and stored over summer so the seed is of an appropriate PA for rapid emergence in autumn.

If MWA growers plan to sell a portion of the commercial crop for seed (e.g. small fraction of Atlantic crisp crop for seed export) they must buy in G3 seed which after the autumn multiplication will produce G4 seed which can be used to produce G5 (oldest generation permitted for certified seed) from their commercial crop.

PA is not assessed by seed schemes but is important as it is related to dormancy and therefore for planting time, emergence and market requirements with respect to tuber size and number. PA can be inferred from harvest date, post-harvest storage conditions and after sprouting from sprout number, length and position of sprouts on the tuber, from visual inspection by the grower or reports from the seed grower prior to delivery. This is also an opportunity to assess germination percentage and adjust seed rates to account for low percents. Low germination percentage may indicate seed that is too young or dormant or too old or senile.

7.1.3 *Selecting highest quality seed*

It is important that the G3 or G4 seed purchased for bulking in the MWA be of high quality because of the higher aphid infestation and possible virus transmittance compared with seed areas closer to the coast. Within the WA seed potato schemes there is the opportunity to choose seed with different disease ratings determined during field inspection. At each inspection the crop is given a rating of 1 to 3 with rating 1 having the lowers disease incidence and rating 3 having the highest allowable. As MWA growers will need to grow their own seed for at least 1 generation it will be beneficial to purchase seed of rating 1 (Table 7.1) to assure they can achieve high quality seed, after one or two bulkings usually from G3 or G4 to G5 for their subsequent commercial crops.

Table 7.1. Maximum tolerance for foreign varieties (% of plants) and diseases (% plants infected) in WA certified seed potato at each inspection (1st and 2nd) and for each rating (1 to 3). Rating 3 seed cannot be further multiplied within the WA seed scheme (after Holland & Spencer 2012).

	Rating 1*		Rating 2		Rating 3	
Inspection	1st	2nd	1st	2nd	1st	2nd
Factor	% of plants					
Foreign varieties	0.05	0.00	0.1	0.01	0.10	0.10
Viruses	0.10	0.01	0.25	0.1	1.00	1.00
Other diseases	0.25	0.10	0.5	0.25	2.00	2.00
Total	0.25	0.10	0.5	0.25	2.00	2.00

* All rating 1 crops must be 0% for PVY at the first and second crop inspections.

Rating 1 seed has the lowest tolerance level for virus infection (10 and 100 times less than rating 2 or 3 seed respectively) and therefore represents the greatest chance that the virus will not be introduced to farms where seed is produced.

7.1.4 *Soil type*

Most soils in the Dandaragan area are classified as sands even though they vary from coarse sands with low clay (<4%) and silt (<0.05%) content to better quality soils with higher clay (>8%), silt (>5%) and fine sand (>16%) content. The coarse soils will have lower water holding or field capacity and may require more frequent irrigation than the finer textured soils. The variation in soil texture may or may not have a big effect on the fertiliser requirements but soil testing can be used to ascertain the nutrient status of the soil before planting and plant testing can be used to evaluate the effectiveness of the fertiliser program on the growing crop. Potatoes are generally tolerant of low pH soils but if pH is less than 5.5 (measured in water, pHw) Al may increase in soil and plant and limit yield pH so should be adjusted with lime such as dolomite or lime sand. Soil pH has been shown to influence the level of potato scab diseases so if amendments are to be made they should be managed in such a way to prevent an increase in scab risk for this reason it is suggested that lime only to increase soil to pHw 6.0.

7.2 Crop rotation and paddock selection

7.2.1 *Paddock selection*

General

Potatoes can be produced on a wide range of soils but waterlogged, compacted, saline or rocky/gravelly soils should be avoided. Potatoes have little tolerance to salinity or water logging and yield loss will result when grown on these soils. Rocky or gravelly soils are difficult to till and bruising of tubers during harvest and handling operations may result from cropping these soils. Fortunately in the MWA there are large areas of well drained soils with low EC (1:5 H_2O) (< 13 mS/m or 0.13 dS/m) and no gravel so selection of suitable soil types should not be a problem. Herbicide residues in the soil from the previous crop can limit yield and quality of the current potato crop. Of most concern in the MWA are the sulfony ureas applied to cereals and imadiazolines used on oil seeds. Follow the label directions to minimise the impact of herbicide residues applied to other crops on the potato crop.

Seed sites

In producing their own seed, MWA potato growers need to take into account the higher risk of crop invasion by aphid virus vectors compared to summer crops grown in south coastal areas that are at relatively lower risk of such invasions. Seed crops sites should be selected that will be upwind of any other (earlier) sown potato crops, which would be sites closest to the coast assuming prevailing winds in winter will be south westerly to westerly.

7.2.2 *Crop rotation*

Crop rotation or cropping sequence is important in potato production as the condition of the field and the practices employed in the previous crop (or pasture) has an impact on the management of the current crop. The cropping sequence chosen should not only focus on the direct economic returns from the potato crop but also the economic, agronomic and environmental (i.e. soil structure) benefits of other crops in the rotation. Although potato crops are often grown more frequently a rotation of 1 potato crop every 3 or 4 years usually results in the best long term control of pest, diseases and soil management. Consequently it is not recommended that potatoes (or related Solanaceous crops such as tomatoes or capsicum) be continuously cropped on the same land for 2 or more times or years in a row. Continuous cropping potatoes often results in an increase in weeds, pests and diseases with associated higher control costs and yield losses in subsequent crops. On sandy soils in new land areas 2 crops of potatoes in a row maybe accommodated without much yield impact in the second year.

Where seed potatoes are grown there are special rotation requirement for seed crops such that there is at least 5 years of non potato or Solanaceous crops before low generation (G1 to G3) seed can be sown or at least 3 years for higher generations(G4 and G5).

Land preparation

As the harvested portion of the potato grows underground a properly prepared seed bed is required. To achieve this cultivation with ploughs and hoes will be needed but the amount of cultivation will depend on soil type and paddock history. Sandy soils are easier to cultivate than heavier soils and may require less cultivation. Cultivation also provides an opportunity to control weeds prior to planting by using irrigation and shallow cultivation to stimulate germination and then cultivation to kill the weeds when small.

7.3 Planting

7.3.1 *Timing*

Timing of planting will vary according to growing conditions and the planned harvest or delivery date which in turn is set by the market requirements.

In the sandy soils of the MWA planting before early March is risky due to possible poor germination in hot soils. Similarly harvest in hot conditions after mid November may result in excess harvest damage.

7.3.2 *Seed type*

Whole seed is preferred for sowing in the warmer autumn months as cut seed is at higher risk of breakdown in hot soils. Cut seed is an option in the cooler conditions during winter sowings. The ‘in’ and ‘between’ row spacing will be determined by varietal choice and market requirements but whatever the target it is important to get it as accurate as possible. Planting at too low or too high a density may lower yield leading to economic loss. Check the spacing between seeds and rows early in the planting operation to enable adjustments to be made. Be sure you know the likely germination percent/-dormancy of the seed so adjustment can be made to seed rate for low emergence percent.

7.3.3 *Treatment*

It is common to apply a chemical treatment to the seed such as a fungicide to ensure the crop is protected from diseases such as *Rhizoctonia* and *Fusarium* in the early stages. In warm sandy soils it is better to use dry powder rather than liquid formulations of fungicides as seed treatments for on-seeder application. This is so to minimise the risk of seed breakdown that could result from an excess layer of water on the tuber surface.

7.4 Weed control

Potato is a broadleaf crop so it is more difficult to selectively control broadleaf weeds (BLW) than grasses in the growing crop. By contrast it is easier to selectively control BLW than grasses in a cereal crop. Also on sandy soils some selective BLW herbicides used on potatoes have to be used at lower rates to minimise crop phyto-toxicity thereby reducing their herbicide effectiveness. Weed control in the potato crop can be made easier by weed control in the previous crop and pre planting cultivation. Good BLW weed control in the wheat crop will reduce BLW problems in the subsequent potato crop.

It is advisable to use the pasture phase to reduce the incidence of grasses such as ryegrass by using techniques such as ‘pasture topping’ to reduce seed numbers. Light cultivation to cover seeds prior to planting followed by irrigation can be used to stimulate germination of weed seed such as ryegrass which can be then be destroyed prior to planting. This reduces the incidence of weeds in the emerged crop but there will still be staggered germination of weeds through the year that need post planting control. Contact herbicides can be used early post emergence for both BLW and grass control when both the weeds and crop (5% emerged) is small.

7.5 Fertilisation

On sandy soils potatoes need an adequate supply of a range of nutrients to maximise yield and quality. Most phosphorus (P) should be applied pre-plant but with nutrients such as N and K >50% will be applied in frequent, weekly to 3 weekly applications, depending on soil type, after planting to increase efficiency.

7.5.1 Phosphorus (P)

Use pre plant soil tests (0 – 15 cm) to assess P status of soil and apply P either in a single P (DSP, TSP) or compound (NPKS + trace elements) fertiliser according to the following table.

Table 7.2. P required (kg P/ha) according to pre plant Colwell P soil test for two sand categories in the MWA based on clay content.

Soil test	<5% clay	>5% clay
< 11	160	250
11 - 20	145	225
21 - 30	110	200
31 - 40	75	180
41 - 50	50	150
51 - 60	40	120
61 - 70	30	85
> 70	30	30

This shows that P fertiliser requirements decrease from high rates at low P soil test to a maintenance rate of about 30 kg P/ha at high or target P soil levels and rates are higher on soils with higher P (clay) fixing capacity. Use the kg P/ha values in the table to calculate the rate of fertiliser needed. For example if 160 kg P/ha is needed apply potato E plus at 1280 kg/ha (160/0.125 as potato E plus has 12.5%P). This rate of fertiliser also applies (kg/ha); 90 (N), 108 (K), 77 (S), 77 (Ca), 1.7 (Cu) and 2.6 (Zn). WA research showed it was best to broadcast and incorporate P prior to planting and not band P, to potatoes on coarse sands (< 5% clay). For heavier soils (> 5% clay) banding is likely to be the better option.

7.5.2 *K, N, Ca and Mg*

Pre plant soil tests can also be used as part of potassium management and, as a guide, if Colwell K is > 120 mg K/kg soil rates of K can be reduced to maintenance rates of about 50 kg K/ha before planting plus 100 kg/ha post plant or even less. Soil tests are not a reliable guide to fertiliser N requirements but generally sands have low N (< 0.05% total N) which means they are N infertile and require moderate to high amounts of applied N split between pre and post planting applications. Following a lush clover pasture soil N may be considerably higher in heavier soil (i.e. > 2% total N) and rates of applied N can be reduced.

Soil tests are not always an accurate guide to Ca and Mg needs. Liming to adjust soil pH usually corrects Ca deficiency but due to its low solubility, low tuber Ca can still occur even after high pre-plant applications. For this reason post plant applications of soluble forms of Ca are suggested (see later). Mg may not be low on heavy soils and even on sandy soils usually no more the 40 kg Mg/ha (400 kg magnesium sulphate/ha) is needed for maximum yield. Some limes (dolomite) provide Mg in pre plant applications which should provide adequate supplies of Mg for the crop.

7.5.3 *Trace elements*

Compound fertilisers such as the above may provide adequate amounts of some trace elements as well as NPK. On sandy soils Mn and B may need to be applied in addition to Cu, Zn and Mo. Mn is less available at low pH and increasing pH with liming may overcome low soil Mn. Mo is less available at low pH as well and low availability, if it occurs, maybe corrected with liming. However be sure Mo is low by plant testing first as only very low amounts of fertiliser Mo are required to be correct deficiency. If too much Mo is applied to soils it could cause problems in animals (molybdenosis) on pastures used for grazing after the potato crop. Similarly Cu and B are only required in low concentrations by the plant and care must be taken not to over apply. For example 500g/ha of borax (11% B) applied in 100 L of water to the foliage twice after emergence should correct low plant B.

7.5.4 *Post planting*

Apply post plant N and K to a total of 250 to 300 kg/ha if pre-plant soil K and N is low, depending on soil type, with higher rates for the more sandy soils. Also on the sandy soils divide the total amount into weekly applications and on the heavier soils into 3 weekly applications. Apply K as sulphate or nitrate to processing potatoes as KCl (muriate of potash) has been shown to lower the specific gravity (dry matter %) of tubers compared to other forms of potassium fertilisers. Apply some of the nitrogen as calcium nitrate to supply up to 75 kg Ca/ha post planting in addition to any calcium applied prior to or at planting. For example 394 kg Ca nitrate /ha (19% Ca and 15 % N) applies 75 kg Ca/ha and 60 kg N/ha.

Seed crops often require less fertiliser N, than non-seed crops, as they may grow for a shorter period especially if the plan is to maximise the yield of small round seed. The tuber size in some varieties such as Atlantic is very sensitive to applied N and high rates may result in low yields of small round seed and high yields of oversize tubers. Also excess rates of applied N may increase the incidence of tuber disorders such as hollow heart in sensitive varieties.

7.5.5 *Monitoring fertiliser programs with plant testing*

The effectiveness of fertiliser programs should be monitored using plant tissue (petiole testing). In the case of trace elements (Cu, Zn, Mo, Mn and B) petiole testing is much more accurate than soil testing as there are very few standards for deficiency or adequacy for WA soils. Collect adequate numbers of petioles from the crop, usually 20 to 30 per test area, and note the crop stage by measuring the length of the longest tuber in mm.

Table 7.3. Concentration of macro (%) and micro (mg/kg) nutrients at the S2 (10 mm (tuber stage considered adequate for maximum yield of potato crops grown on sands.

Nutrient & symbol	% or mg/kg	S2 (10 mm tuber stage)
Nitrogen (N)	%	4.5 - 5.5
Nitrate –N (NO_3-N)	%	2.6 - 3.5
Phosphorus (P)	%	0.8 - 1.0
Potassium (K)	%	10 - 16
Calcium (Ca)	%	0.5 - 1.5
Magnesium (Mg)	%	0.3 - 0.75
Sulphur (S)	%	0.2 - 0.35
Boron (B)	mg/kg	20 - 40
Copper (Cu)	mg/kg	5 - 16
Iron (Fe)	mg/kg	230
Manganese (Mn)	mg/kg	20 - 100
Molybdenum (Mo)	mg/kg	0.1 - 1.5
Zinc (Zn)	mg/kg	30 - 110

7.6 Irrigation

7.6.1 *Scheduling*

Schedule irrigation based on crop demand using the previous day's pan evaporation value (Epan) from the nearest weather station. To determine irrigation requirements in mm/day multiply the crop factors (%) for each crop stage (Table 7.4) by the daily Epan in mm (from the nearest weather station). Soil moisture monitoring can also be used to check the effectiveness of the program to ensure soil water depletion (% of AWC = available water content) doesn't exceed guidelines.

Table 7.4. Crop factor (CF% of Epan) with crop stage used for irrigation of potatoes on sands in WA.

Crop stage	Name	CF (Epan)%*	AWC%**
1	Emergence	90	30
2	Vegetative	100 - 110	25
3	Tuber initiation	110 - 120	30
4	Tuber bulking	110 - 120	20
5	Maturation	90	40

*CF = crop factor value to be multiplied by previous day's pan evaporation (Epan)** AWC = % depletion in available water content (AWC = field capacity – wilting point).

Over watering at crucial growth stages such as tuber initiation can lead to an increase in powdery scab if present in the soil. Overwatering at planting can lead to seed piece breakdown or blackleg in the crop.

7.6.2 *Salinity*

Potatoes are not tolerant of salinity so high levels of salt in the soil or irrigation water will cause yield and quality decline. High levels of salt in the soil or irrigation water or in fertilisers have been shown to lower the dry matter (specific gravity) of potatoes. This is important in those varieties used for processing as SG value affects grower returns.

7.6.3 *Soil*

Most soils in the MW are sands and appear to have low salt levels {EC (1:5 H_2O) < 0.10 dS/m} prior to cropping so don't pose a risk for potato production. Potatoes can tolerate soil salt concentrations up to an EC (1:5 H2O) of 0.12 dS/m.

7.6.4 *Irrigation water*

Irrigation water quality in the area varies with TSS (total soluble salt) concentrations from < 480 to 640 mg/L (EC1:5 from 75 to 100 mS/m). Potato yields will be reduced if the salt in the irrigation water is above 650 mg/L (> 100 mS/m). Also there is a risk of salt build up in the soil even below these values especially during periods of low rainfall, which can occur in winter and spring in the MW. Rainfall is low in salt (30 mg/L) so it readily flushes salt down the soil profile out of the root zone. To manage salt extra irrigation water, above crop demand, needs to be applied to flush the salt down the soil profile out of the root zone in the absence of rainfall.

Table 7.5. Extra irrigation required (% flushing ratio) above crop demand according to the salt concentration (mg/L) in the irrigation water.

Salt (mg/L)	Flushing ratio (% extra irrigation)
500	7
750	11
1000	14

7.6.5 *Plant*

Chloride (Cl) concentration in petioles is usually 3 to 4% in years of normal rainfall in the MW which is not reported to cause yield and quality loss in WA potato crops. When rainfall is low, petiole Cl can increase to 8 to 10% with associated symptoms and yield loss. To avoid this follow the irrigation instructions in Table 7.4.

7.6.6 *Frost*

The MWA is not a high frost risk area for cereal production as this in based on the sensitivity of cereals to frost at anthesis (flowering) which usually occurs in the spring. However there are frosts in the area during winter (June to August) which can damage potato crops. It has been observed that during years with dry winter periods, with cloudless skies, such as in 2008, 2010 and 2012 there were a number of frosts in the area which required grower action to minimise crop damage. It is normal to apply irrigation water to minimise crop damage during frosts. With centre pivots if frost is likely it is difficult to cover the whole crop area in sufficient time to minimise frost damage unless watering is started the night before the predicted frost.

7.7 Insect pest control

To produce quality seed and consumer potato crops in the MWA, it is recommended that the principles of integrated pest management be followed – ability to recognize pests, beneficials and benign insects; conduct monitoring; base decisions on insecticide use on action thresholds for pest abundance; be aware of registered insecticides and their toxicity to beneficials. The threshold allowed under the WA seed scheme rules by inspectors is "A sample of 100 randomly selected leaves (a middle and lower leaf from 50 plants) will be examined for the presence of aphid colonies. A colony is defined as a leaf containing three or more aphids of which at least two are wingless".

A monitoring kit should be made up and include the identification guide references Emery *et al.* (2005) (see Table 7.6 for list of pests and page numbers in this guide) and the video *Managing Virus Diseases of Potato Crops Potato leafroll and tomato spotted wilt* (2003) – the insects potato tuber moth and leaf eating ladybird and associated damage which do not appear in these guides but which occur in the MWA have been included here as Fig. 7.1; "bum bag" to contain: 10x hand lens, collecting vials, note book (waterproof paper and 2B pencil, paper bags and self seal plastic bags). Monitoring information should be recorded electronically for comparisons to be made across seasons.

For seed potato crops planted in autumn (March to early April), it is recommended to apply systemic insecticide to the soil at planting. Applying insecticide at planting in winter planted crops appears to be unnecessary. Also for consumer potato crops, application of soil applied insecticide at planting for aphid control is not required

For both consumer and seed potato crops, from crop emergence to crop die off, a regular/weekly insect monitoring program should be followed. If centre pivots are planted, then two opposite quadrants should be checked. Follow a circular path through the crop quadrant to ensure a representative area is covered. Monitoring should include observation of 50 destructively sampled leaves in each quadrant up to canopy row closure then 25 leaves thereafter. Leaves checked should be lower healthy leaves. The undersides of the leaves are checked for aphids and aphid mummies (parasitised aphids) and thrips. Include notes on the occurrence of other insects on leaves and also make observations as the monitoring path is traversed through the crop. Record the presence of pests such as potato moth, tobacco looper, Rutherglen bug, *Heliothis* and beneficial insects such as ladybirds, lacewings, predatory bugs and beetles and hover fly larvae.

Table 7.6. Insects most likely to be seen in MWA potato crops are included in Fig. 7.1 – potato tuber moth and leaf eating ladybird - and in Emery *et al.* 2005 - “CROP INSECTS: THE UTE GUIDE”. Page numbers below refer to that guide.

Page Number	Agent
Natural enemies	
102 - 103	Aphid Parasites
106 - 107	Predatory Ladybird Beetles - Transverse Ladybird & Common Spotted Ladybird
113	Green Lacewings
114	Brown Lacewings
116	Hover Flies
117	Glossy Shield Bug
118	Spined Predatory Shield Bug
119	Damsel Bug
Pests	
17 - 19	Native Budworm or *Heliothis*
26	Diamondback Moth or Cabbage Moth – a look alike insect for potato moth
34	Looper Caterpillar
49	Rutherglen Bug
50	Brown Shield Bug or Brown Stink Bug
51	Green Mirid
54	Green Peach Aphid
63	Onion Thrips & Plague Thrips
66	Wingless Grasshopper

POTATO TUBER MOTH AND PUPAL CASE

POTATO TUBER MOTH LARVAE – TIP BORING AND LEAF MINING

ADULT

PUPA

LARVA

LEAFEATING LADYBIRD

Fig 7.1. Photos of potato moth and leaf eating ladybird and the damage they cause to potato crops.

For seed crops up to the start of crop senescence, apply aphicides if aphids are present at up to 5% leaves infested with winged and wingless aphids. Be aware of the different toxicity levels of registered insecticides and choose the least toxic (see Table 7.7). To avoid the development of resistance, alternation of insecticides is recommended. There have been reports of GPA developing resistance to pirimicarb.

Table 7.7. Insecticides registered for use in potato crops in Western Australia and their toxicity to natural control agents (beneficial insects).

Active ingredient and group	Product (™)	Toxicity
acetamiprid 4A	Intruder, Supreme	Toxic to beneficial
alpha-cypermethrin 3A	Dominex, Dominex Duo, plus others	Toxic to beneficial
imidacloprid 4A	Confidor Guard	Soil application less toxic than foliar
	Confidor	Toxic to beneficial
dimethoate 1B	Rogor plus others	Toxic to beneficial
phorate, 1B	Thimet, Umet, Zeemet	Soil application
pirimicarb 1A	Aphidex, Pirimor	Low toxicity to beneficial
pymetrozine 9B	Chess	Low to moderate toxicity to beneficial
spirotetramat 23	Movento	Low to moderate toxicity to beneficial

7.8 Roguing (Seed crops only)

Before seed potato crops reach the stage of row closure, undesirable plants should be removed. This involves the procedure of rouging. Tips on how best to rogue crops can be seen on a video (*Managing Virus Diseases of Potato Crops Potato leafroll and tomato spotted wilt* 2003).

7.9 Disease control

Skin blemish diseases are seen at the time of harvest or post harvest and downgrade the pack outs of ware potatoes while some are known to reduce yield. Black dot and silver scurf can be particularly prominent in certain crops in certain years. Scab diseases can also occasional occur in sandy soils. Control of these diseases generally begins at planting. There are some in-furrow or seed piece chemical applications registered for the control or suppression of these diseases. Care should be taken if applying liquid fungicides to furrows on days where the seed potato will sweat in the furrow, leading to potential seed piece breakdown. As some of these chemicals are registered for in crop use, resistance management should be considered when deciding on the chemical to use (details below).

Depending on weather conditions the crop may be susceptible to a number of foliar diseases that could potentially reduce the overall yield. Frosts or other forms or damage (mechanical) can cause entry points for diseases such as *Botrytis* or early blight (Target spot). Overwatering can also be conducive to Black leg and *Sclerotinia* (White mould) diseases as it increases humidity and stresses the plant, reducing its ability to naturally defend against infection. Over applications of nitrogen fertilisers can lead to excess plant growth and weaker plant cells that can also make crops more susceptible to disease.

Early blight is the most common foliar disease present in WA and the first signs of disease infection are small circular spots that expand in concentric rings. It is usually the older leaves that are infected first but the disease, if left unmanaged, can lead to severe infection that reduces the crops lifespan and subsequent yield.

There are numerous chemicals registered for control of foliar diseases with several modes of action. Of these some work as contact fungicides, providing a barrier from infection, whereas others have translaminar activity where they penetrate the leaf and travel a small distance beyond the point of spray. Foliar diseases of potatoes have the ability to develop resistance to the chemicals that are used to control them. The resistance management guidelines for potatoes should be followed to prevent this from occurring. The guidelines are published by Croplife Australia and can be found on their website www.croplifeaustralia.org.au.

7.10 Harvest

Temperature, tuber condition (hydration, temperature, specific gravity) and harvester operation must be considered if potatoes are to be harvested with minimal damage.

When the skin of a potato is broken and bruised the cells below are damaged and the tubers deteriorate because entry of pathogens becomes easier and water loss from the tuber increases. This damage can have severe consequences.

7.10.1 *Machinery maintenance and operation*

The most important factor influencing bruising of tubers is the ratio of ground speed to conveyor speed. Bruising is minimised when conveyors are kept full of potatoes. Increasing ground speed by shifting the tractor transmission to a higher gear can speed up harvest, increase and smooth out the flow of tubers, and reduce damage. Individual conveyors are often at the wrong speed relative to the preceding or following conveyor. Harvester operators should manage equipment properly to reduce bruising.

7.10.2 *Level of tuber impact*

The greater the drop height, the more bruising that occurs. This also leads to a shift in damage from blackspot to shatter bruise. Long impact durations and low velocities result in blackspot bruising and internal crushing (for example, small bumps along the conveyor) while short impacts and high velocities result in internal shattering (for example, drops from the elevator to the bunker).

An integrated approach is required to maximise the percentage of bruise-free potatoes. This involves harvesting as close to ideal temperature and soil moisture conditions as possible, while matching the volume of material flowing through the harvester to its capacity.

7.11 Soil and tuber conditions

Soil moisture, temperature and soil type influence the severity of bruising, as does tuber hydration, temperature and specific gravity.

7.11.1 *Soil type*

Soil condition at harvest determines how easily potatoes are separated from the soil. Medium to light, loose, moist soils separate easily while heavy, compact, wet soils are difficult to separate from tubers. Dry sandy soil will separate too rapidly from tubers on the primary conveyor, reducing the total load of soil and tubers on the conveyor, which can increase tuber damage. Rocky soils will also cause damage to potatoes at harvest.

7.11.2 *Soil temperatures*

Optimum soil temperature for harvest is 12–18 ºC. Harvest temperatures greater than 25 ºC or lower than 5 ºC can lead to bruising.

Soil temperature is primarily controlled by air temperature and solar radiation but can be reduced by more frequent irrigation. Evaporative cooling is an important factor, so the drier the soil, the closer the soil temperature will be to air temperature.

Soil temperature and moisture can be managed by applying irrigation before harvest if soil is too dry or tuber temperature is above 18 ºC. Enough water should be applied to cool the soil sufficiently but not saturate it as this leads to increased risk of bacterial rots. During summer, harvest at night or when soil temperatures are lower.

7.11.3 *Soil moisture*

Irrigation prior to harvesting is very important in increasing the soil moisture content in clay soils. This reduces the number of clods and provides a layer of wet soil between the tubers and machine components, reducing the impacts and consequent damage. On sandy soils manage moisture so soil will not separate from the conveyor thereby increasing tuber damage. If soil is too wet then delay harvesting. Soil moisture for harvest should be between 60 and 80 per cent of field capacity.

7.11.4 *Skin maturity*

Plan to allow 2 to 4 weeks after top removal for skins to harden. Maintain soil moisture so tubers do not dehydrate underground while the skin is hardening.

7.11.5 *Tuber temperature*

Tuber temperatures between 12 and 18 ºC are considered ideal for harvesting as this is when less bruising occurs and microbial growth is not too fast. Tubers warmer than 18–20 °C and under drought stress are susceptible to blackspot bruising. Harvesting when tuber pulp temperature exceeds 18 °C or soil temperature is greater than 25 °C increases the risk of microbial rots, especially in damaged tubers. Tuber temperatures should also be kept within the optimum range during washpacking.

7.11.6 *Reducing drops and adding cushioning*

Modifications to equipment and decreasing harvesting can minimise damage. Reducing drop heights from conveyors will improve potato quality.

Considerable bruising can occur where drops are greater than 40 cm, particularly when the drop area is on belting supported by a hard metal roller or plate.

The impact surface affects the amount of damage caused to a potato. Cushioning materials considerably reduce impact. Tubers are less likely to get damaged if mechanical components are covered in rubber.

7.12 Further Information

Western Australian Certified Seed Potato Scheme Production Rules.

Western Australian Registered Seed Potato Scheme Production Rules

Available at http://www.agric.wa.gov.au/PC_90017.html?s=1403679556

Managing Virus Diseases of Potato Crops Potato leafroll and tomato spotted wilt 2003, DVD, Department of Agriculture and Food, Western Australia South Perth.

Available from Entomologist, Manjimup Horticultural Research Institute, Department of Agriculture and Food, Western Australia, phone 08 9777 0000.

Emery, R., P Mangano, P &., P Michael, P. (2005,). *Crop insects: the Ute Guide Western Grain Belt Edition*. . Department of Agriculture and Food, Western Australia. 157 pp.

8 Modelling Potato Crop Growth

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8.1 Introduction

The WA mainland spans 22 degrees of latitude from 13°34’ S at Cape Londonderry to 35°08’ S at West Cape Howe, a distance of 2,600 km.

Horticulturists have taken advantage of this geographic range to produce annual crops year round. The potato industry traditionally produced winter potatoes near Perth while summer crops were grown in the SW and Great Southern regions.

Winter potato crops at Perth produce comparatively low yield and growers have moved further north looking for more favourable winter growing conditions. New areas like Gingin and then Dandaragan have been developed through trial and error of pioneer growers.

There is potential to identify suitable areas through the use of a potato growth model using climate data. If model predictions are combined with soil suitability, water availability and an analysis of crop production and transport costs, areas with the best potential for potato production can be identified.

8.2 Aim

To assist the WA potato industry capture winter production potential by using a potato growth model to identify potential higher yielding winter potato production areas.

8.3 Methods

8.3.1 *Model*

A short version of the LINTUL-POTATO model, the Meijer Potato Model May 2011, supplied by Prof Paul Struik of Wageningen University was used. The LINTUL-POTATO model was developed to simulate potential dry matter production through the relative effect of temperature on rates of emergence, light use efficiency, tuber initiation and tuber growth (Kooman & Haverkort, 1995). LINTUL-POTATO is a development of the Light INTerception and UtiLization simulator known by the acronym LINTUL (Register of Ecological Models, 2007). This model overcomes the shortcomings of temperate long day condition potato models and models developed for tropical conditions (Kooman & Haverkort, 1995). LINTUL-POTATO model was validated for temperatures from 2 to 28 °C which encompassed most reported optimal temperatures for potato growth (Kooman & Haverkort, 1995).

8.3.2 *Sites*

Two potato production sites were used to run model alongside a growing crop; the DAFWA Research Support Unit at Kununurra and grower’s crops near Dandaragan.

8.3.3 *Climate data*

Climate data from the Australian Government, Bureau of Meteorology (2013) was used. On the webpage http://www.bom.gov.au/climate/data/ choices selected to download climate data were:

Data about "Weather & climate"

Type of data "Statistics monthly"

For Dandaragan data from the weather station 009037 Badgingarra Research Station was used as this was the closest weather station to Dandaragan that was a similar distance from the coast. For Kununurra the weather station used was 002014 Kimberley Research Station.

Photosynthesis measurements

The temperatures during crop growth at Kununurra were in excess of maximum temperature for photosynthesis of 33 °C in LINTUL-POTATO. For example the mean maximum temperature for the month of September was 36.5 °C (Bureau of Meteorology 2013). Therefore photosynthesis was measured at Kununurra to determine a maximum temperature for photosynthesis value more appropriate for Kununurra.

A commercial crop of potatoes (cv. Atlantic) grown on 'Tropical Sands' Farm, Mulligans Road, Kununurra was used for the photosynthesis measurements. Planting date was 10 July 2012 and spray-off was on 19 September 2012.

Measurements were made between 4 and 6th September 2012, 56 days after sowing and just prior to full row closure. Measurements were carried out on the youngest full expanded leaflet of a youngest expanded leaf (5th from growing point) on 5 plants equidistant apart (16 rows part) selected in a zigzag pattern in the eastern third of the crop. The leaflet was enclosed in the chamber and the net exchange of CO_2 between the leaf and the atmosphere was measured with the PAR in set at 1500 µmol m^{-2} s^{-1}. Measurements were made at 5 times through the day from 0930 to 1600 h when the photosynthetically active radiation (PAR) ranged between 1400 and 1650 µmol m^{-2} s^{-1} to cover a range of temperatures. The rate of photosynthesis was then calculated using this rate of CO_2 exchange and other factors such as the leaf area enclosed, the volume of enclosure and temperature by the inbuilt microcomputer of the IRGA and expressed as µmol CO_2 m^{-2} s^{-1}.

8.4 Results

8.4.1 *Actual yield versus LINTUL-POTATO output.*

Kununurra

An Atlantic potato seed crop trial was planted on 27 June 2011. First emergence was on 11 July 2011, 14 days after planting (dap) and most plots had 50% emergence 20 dap (7 July 2011). 100% canopy cover occurred on 15 August 2011, 49 dap.

The seed plots (four of the five replicates) were sprayed-off on 30 August 2011 as sampling showed the largest tubers had reached the maximum seed size of 75 mm diameter. The seed plots were harvested 9 days later on 8 September 2011.

The grow-out plot (one replicate) had tops removed on 4 October 2011 and was harvested on 7 October 2011.

Harvest Index (HI) was measured from the four seed plots where average fresh weight of shoots was 444 g and tuber weight was 562 g giving a HI of 55%.

Actual yield of the seed plots of Atlantic, harvested 64 dap when tubers had reached 75 mm diameter, was 21.0 t/ha (Table 8.1, merged columns 1 & 2). The LINTUL-POTATO estimate used a HI of 60 with photosynthesis maximum temperature of 33 °C and yield output was 2.5 t/ha (Table 8.1, column 1), about 10% of actual yield.

Photosynthesis measurements versus air temperature taken at Kununurra in 2012 are shown in Figure 8.1. Extrapolation of these data estimates maximum photosynthesis of potatoes at Kununurra occurred at 43 °C. When this higher photosynthesis maximum temperature is used in the LINTUL-POTATO model the predicted yield for Kununurra increases to 20.9 t/ha (Table 8.1, column 2).

Actual yield of the grow-out plot of Atlantic at Kununurra was 36.4 t/ha 99 days after planting (Table 8.1, column 3). With a maximum photosynthetic temperature of 43 °C LINTUL-POTATO estimated the yield of the grow-out plot which matured 99 dap to be very similar at 34.6 t/ha (Table 8. 1, column 3).

Table 8.1. Actual yields and LINTUL-POTATO predictions for Kununurra and Dandaragan.

Item	Kununurra				Dandaragan
Column number	1	2	3	4	5
Latitude (°S)	15.7				30.3
Crop type	Seed (Atlantic)		Grow-out (Atlantic)	Coolest time	Seed (Nadine)
Planting date	27-Jun		27-Jun	15-Jun	13-Jul
Maturity date	30-Aug		04-Oct	22-Sep	15-Oct
Days from planting	64		99	99	94
Actual yield					
Fresh weight (t/ha)	21.0		36.4	-	63.5
LINTUL assumptions					
Photosynthesis min T	8	8	8	8	8
Photosynthesis min opt T	20	20	20	20	20
Photosynthesis max opt T	25	25	25	25	25
Photosynthesis max T	33	43	43	43	33
Harvest Index (%)	60	60	60	60	75
Dry matter (%)	17	17	17	17	15
LINTUL yield output					
Dry matter (t/ha)	0.4	3.6	5.9	7.0	8.4
Fresh weight (t/ha)	2.5	20.9	34.6	41.0	55.8

The LINTUL-POTATO was run to indicate potential yield at Kununurra for a crop growing over the coolest time of year using the crop duration of 99 days observed in the grow-out plot (Table 8.1, column 4). Here the LINTUL-POTATO yield output was 41.0 t/ha from 15 June planting date. This yield was 13% higher than the observed yield of 36.4 t/ha from the 27 June planting. This indicates that a time of planting investigation may be worthwhile at Kununurra should potatoes become a commercial crop at this location.

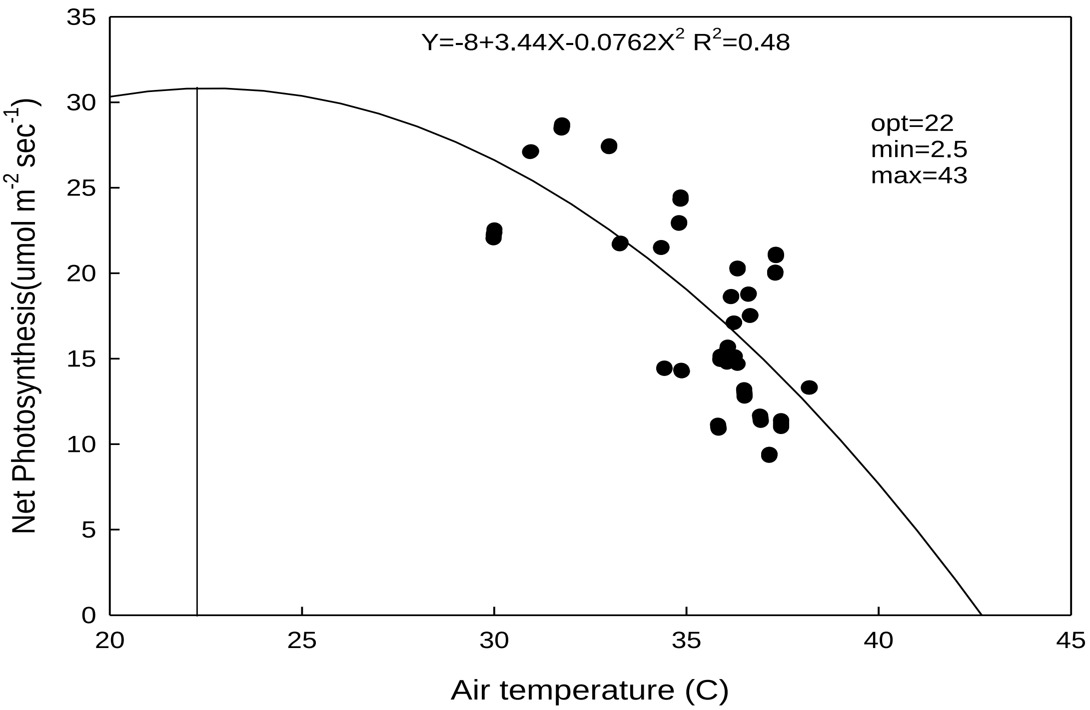

Figure 8.1. Air temperature (°C) and net photosynthesis of Atlantic potatoes at Kununurra from 4 to 6 September 2012.

Dandaragan

At Dandaragan a Nadine seed potato crop trial was planted on 13 July 2011. The crop matured after 94 days on 15 October 2011 and measured yield was 63.5 t/ha (Table 8.1, column 5).

LINTUL-POTATO was run for this site to compare model yield with observed. Some input data was changed from that used for the tropical Kununurra site. HI was 75% and maximum temperature of photosynthesis of 33 °C. Also Nadine is a very low dry matter potato so the previously used dry matter input of 17% was reduced to 15%. LINTUL-POTATO produced an output of 55.8 t/ha, within 12% of observed yield (Table 8.1, column 5).

8.4.2 *LINTUL-POTATO potential yield estimates for other locations*

LINTUL-POTATO was also used to assess the possible yields for other sites between Kununurra and Dandaragan for the cropping period of 15 June planting with 22 September maturity. Inputs used to run the model as well as output yields are shown in Table 8.2. The latitudes for the sites are also shown Table 8 2.

Table 8.2. LINTUL-POTATO output yield for potato crops at various sites in WA. Planting date was 15 June and maturity was 22 September giving a growing period of 99 days. The planting date means the crops are grown over the coolest time of year. LINTUL-POTATO inputs: for columns 1 - 3 photosynthesis max was 43 °C with Harvest Index of 60%. LINTUL-POTATO inputs: for columns 4 - 8 photosynthesis max was 33 °C with Harvest Index of 75%. Tropic of Capricorn latitude = 23.26.

Item	Kununurra	Broome	Newman	Carnarvon	Murchison	Mullewa	Dandaragan	Medina
Column #	1	2	3	4	5	6	7	8
Latitude (°S)	15.7	18.0	23.4	24.9	26.9	28.5	30.3	32.2
LINTUL yield output								
Dry matter (t/ha)	7.0	8.1	7.7	11.4	9.4	8.6	7.0	7.0
Fresh weight (t/ha)	41.0	47.4	45.4	66.9	55.3	50.4	41.1	41.0
% of Dandaragan	100%	115%	110%	163%	135%	123%	100%	100%
Budget info (/ha)								
seed price				550				
seed %				88%				
oversize price				240				
oversize %				8%				
Income ($ ’000)	20.6	23.9	22.8	33.7	27.8	25.4	20.7	20.7
costs less freight*				11,500				
freight to buyer ($/t)	200	139	74	113	82	56	33	33
freight*	7,872	6,330	3,225	7,244	4,332	2,729	1282	1,279
Gross margin ($‘000/ha)	1.3	6.0	8.1	14.9	12.0	11.1	7.9	7.9

* freight of produce to buyer (estimated).

LINTUL-POTATO yield output increased from the 41.1 t/ha for the 22 June planting time at Dandaragan as latitude decreased until the highest yield of 66.9 t/ha under a Carnarvon climate (Table 8.2, column 4). Dandaragan is at latitude 30 degrees south while Carnarvon is at 25 degrees south latitude. Carnarvon yield output was 63% higher than Dandaragan. Further north of Carnarvon the LINTUL-POTATO yield output decreased markedly.

Budget estimates were applied to the LINTUL-POTATO yield outputs with price and cost assumptions shown in Table 8.2. Cost of production was set at $11,500/ha which were close to budget information supplied by growers at Kununurra and Dandaragan (Paul Mattingley, personal communication). Freight costs for transporting produce to market varied with distance from Perth where the potatoes were assumed to be sold. The derived gross margins produced from climate data of Mullewa, Murchison, and Carnarvon were much higher than that of Dandaragan with the Carnarvon gross margin twice that of Dandaragan (Table 8.2, columns 4 – 7). Newman had a similar gross margin to Dandaragan; $8,100/ha and $7,900/ha respectively. The gross margins from Broome and Kununurra were less than Dandaragan (Table 8.2, columns 1, 2 & 7).

8.5 Discussion

The potato photosynthetic response to temperature at Kununurra showed that the maximum temperature for photosynthesis was higher than the 33 °C default of LINTUL-POTATO. This is probably due to the plants acclimatising to the warm conditions. Havaux (1993) showed that the limiting temperature of 38 °C for photosystem II of photosynthesis could be overcome in plants that had been acclimated at 30 to 35 °C. The acclimatised plants were able to maintain photosynthesis without appreciable loss even at 40 °C (Havaux 1993).

LINTUL-POTATO yield output was similar to a limited set of observed WA yields at both 16 and 30° latitude south. For tropical sites the maximum temperature of photosynthesis was increased to 43 °C due to the poor LINTUL-POTATO prediction using a maximum temperature of photosynthesis of 33 °C.

When climate data from sites between Dandaragan and Kununurra were run through LINTUL-POTATO potential yields were shown to increase from latitude 30 degrees south to 25 degrees south. At latitudes lower than 25 degrees potential yield declined. Rough budget figures applied to these yield estimates showed that increased freight costs to 25 degrees south were more than compensated by additional income due to improved yield.

These findings must be regarded as preliminary as potato production depends upon suitable soils, an irrigation supply of appropriate quality and quantity as well as low frost risk. However LINTUL-POTATO yield outputs indicate that it is worthwhile for the WA potato industry to consider winter production in areas with climate similar to Mullewa, Murchison and Carnarvon as such areas are likely to provide increased yields compared to Dandaragan.

LINTUL-POTATO model can be a valuable tool for the WA potato industry and a more rigorous validation of this model under WA conditions will be beneficial to the industry.

9 Technology Transfer

Monitoring of insect infestation of selected ware/crisp crops as well as all seed crops on the 3 farms was carried weekly to fortnightly Monitoring data was used to provide feedback to growers on management of the crops with management advice tailored to whether the crop was for seed, ware or crisp processing. Leaf and tuber (2012 only) testing for viruses (PLRV, PVY, PVS, PVX and TSWV) was carried out systematically on all seed crops on the 3 farms and in response to need for other crops. The feedback on aphid numbers was particularly useful as it enables growers to respond quickly to the threat of the possible spread of viruses within and between crops. Virus results were used by the grower to assess the effectives of their crop programs and the decision of target markets their seed crops. Where crops showed high levels of virus but good aphid control growers realised selection of source seed was needed to be improved and better quality seed (i.e. rating 1 certified seed) should be used. Virus results of seed crops were compared with WA seed scheme stands to see if these crops met the standards and should be used or sold as seed or for other uses.

Soil moisture monitoring at 3 depths over 0 – 60 cm was carried out on selected crops each year. There were at least 2 crops being monitored on each farm at any time from March to October in both 2011 and 2012. This enabled project staff to provided regular data (at least 3 times/week) to assist with irrigation management in this case as a secondary check on irrigation scheduling based primarily on crop factors per crop stage using previous days Epan. Growers were therefore aware of the performance of their irrigation program with respect to relevant soil moisture parameters such as field capacity (FC), refill (RP) and wilting point (WP) at each site and in particular if soil moisture was between FC and RP. Grower ability to adjust irrigation management to correct either over or under irrigation was sometimes limited by other factors such as the need to apply additional water to minimise frost damage, flush salts out of the soil, apply fertiliser or chemicals, or by the capacity of the irrigation system to deliver the required water.

Growers obtained their own nutritional analysis of petioles as a standard procedure for monitoring the effectiveness of fertiliser programs. This data was sometimes interpreted for the grower as to nutrient adequacy or otherwise by project staff using the ‘Croptest’ Model. If needed, additional petiole analyses were carried out ,via the project, to assist in resolving the cause of growth problems i.e. due to nutritional or due to other factors. For examples petiole analysis was used in combination with virus testing to show viruses to be a likely cause of growth problems rather than fertilisation. Petiole analysis was also useful in confirming whether reduced rainfall was causing an increase in plant salt (Na and Cl) concentration that would limit growth and whether additional irrigation, above crop demand, was needed to flush excess salt out of the soil.

Annual meetings were held in November 2011 and February 2013 to review the progress of the project for feedback and improvements. A ‘Seed Health’ field walk was held in July 2012 to reinforce the message arising for the results of the project.

The ‘Best Management Practices’ for potato production in the MWA arising from the project were documented and converted into a ‘stand alone’ document. This is being used to disseminate project findings to farmers.

10 Recommendations

10.1 Crop health

1. For all crops but especially those for producing seed potatoes the seed source (G4) should be from the WA Seed Potato Production Schemes. As well growers should purchase rating 1 certified seed as this has the lowest level of disease infection (0.01% for virus but with a nil tolerance for PVY and 0.10% for other diseases).

2. Compared to the main seed producing region of WA on the south coast, MWA seed potato crops planted in winter are more at risk of aphid invasion. Therefore growers need to monitor crops at least weekly for insect pests, with an emphasis on aphids in seed crops. Such monitoring will allow for timely intervention to protect crops from aphid build up and other pests such as tobacco looper.

3. Seed crops planted in autumn when aphids are more consistently present would need prophylactic application of systemic insecticide (i.e. Confidor Guard™) at planting but would be of little or no benefit at other times of planting.

4. Growers need to develop a plan for monitoring insects in their crops. This needs to include who is responsible with appropriate time set aside to undertake the monitoring, training to ensure they can recognise; pests, beneficial and neutral insects and know how to undertake monitoring to ensure infestations are detected and decide on pest abundance thresholds for intervention.

5. From this study, it is unlikely that the application of insecticides at planting would control the usual spring time invasion of aphids, in the winter sown seed crops. These spring (September) infestations are best dealt with by foliage applications of insecticides at or above threshold levels (2 or more wingless aphids on at least 5 % of leaves). A summary of recommendations for insect management of seed and non seed crops in the MWA is provided in Table 10.1.

Table.10.1. Summary of recommendations for insect management in MWA seed and non-seed potato crops.

Activity	Autumn planted crops		Winter planted crops	
	Ware processing	Ware processing seed	Ware processing	Ware processing seed
Monitoring	✗	✓	✓	✓
Insecticides dressing of setts	✗	✓	✗	✗
Natural insect control	✓	✓ ✗	✓	✓ ✗
Foliar insecticide application when threshold breeched	✗	✓	✗	✓

10.2 Irrigation

Irrigation management (scheduling) decisions should be based primarily on previous days pan evaporation from the nearest weather station and monitored using soil moisture measurements. Frequency and quantity of irrigation water application will vary as soil texture and associate water holding capacity, field capacity, refill and wilting points of the soil will vary between sites. Growers need to note that although soils in the area are mainly sands there are better quality sands with higher fine sand and clay content that result in different irrigation scheduling to sites with a higher coarse sands content. Application of irrigation water above crop demand will be required to address soil and plant salinity peaks during dry periods(salt flushing), frost mitigation and for post planting application of fertilisers (fertigation).

10.3 Fertilisation

Fertiliser programs should be designed as for sands with a portion of the total applied fertiliser applied after emergence. On coarse sands (<5% clay at least half the N and K should be applied post plant in frequent, weekly to fortnightly applications up to 12 weeks post emergence. On finer soils (>5% clay) post plant applications can be less than half of total applied fertiliser and applications can be less frequent. Broadcasting, rather than banding, P is recommended for coarse sands but it is not expected to be needed on heavier soils. Pre plant soil testing is recommended for P, K and lime decisions. Petiole analysis is recommended for monitoring the effectiveness of fertiliser programs as it is more reliable for most of nutrients, especially micro nutrients, than soil testing. Petiole results will also measure salt build up (Cl and Na) in the plant during dry periods, to aid in appropriate irrigation decisions. Petiole analysis also aids in diagnosing poor crop growth which may be due to nutritional or non-nutritional causes.

10.4 Future work

Following the predictions of the LINTUL model more work is needed to investigate the yield and quality performance of potato crops grown in winter in the middle latitudes of WA between Dandaragan and Broome.

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13 Appendices

Table 1. Yield of crops (mean of 5 replicates) grown with local (Dandaragan, Jameson) or SW (Busselton, Pemberton) seed.

(A) Fox Arden Fleets (Nadine)

Size	Seed source			Statistical summary	
grade	Dandaragan(d)	Pemberton(p)	d/p	t value	P
(g)	Yield (t/ha +/- (SE))				
0 - 30	0.88 (0.18)	1.29 (0.18)	0.68	-2.24	0.075
31 - 120	14.45 (1.96)	10.25 (1.96)	1.41	2.15	0.084
121 - 320	29.12 (2.02)	26.85 (2.02)	1.08	1.12	0.313
321 - 450	0.32 (0.72)	2.24 (0.72)	0.14	-2.65	0.045*
Marketable	43.89	38.4	1.14	5.63	0.002**
Total	45.25	41.1	1.10	4.08	0.01**

(B) Campbell Jameson Farm (Nadine)

Size	Seed source			Statistical summary	
grade	Jameson(j)	Busselton(b)	j/b	t value	P
(g)	Yield (t/ha +/- (SE))				
0 - 30	1.94	1.84	1.05	-0.19	0.86
31 - 120	11.60	18.83	0.62	2.99	0.040*
121 - 320	12.06	12.81	0.94	0.25	0.82
Marketable	24.02	31.71	0.76	1.85	0.14
Total	25.96	33.54	0.77	1.85	0.14

(C) Campbell Jameson Farm (FL1867)

Size	Seed source + yield (t/ha)			Statistical summary	
grade	Jameson(j)	Busselton(b)	j/b	t value	P
(g)	Yield (t/ha +/- (SE))				
0 - 50	1.14	3.11	0.37	7.48	0.001***
50 - 80	15.44	5.60	2.76	13.99	0.001***
80 - 300	12.30	6.30	1.95	2.71	0.042*
Marketable	27.74	11.86	2.34	5.50	0.003**
Total	29.54	15.48	1.91	4.50	0.006**
SG	1.091	1.085	1.005	4.57	0.01**

Table 2. Plant, stem and tuber numbers (mean of 5 replicates) of 4 metre long single row plots grown with local or SW seed.

(A) Fox Arden Fleets (Nadine)

Factor	Measurement by seed source			Statistical summary	
	Dandaragan(d)	Pemberton(p)	d/p	t value	P
Plant no.	16.75	17.00	0.99	-0.67	0.54
Stem no.	49.50	28.50	1.74	9.49	0.001
Stems/plant	2.96	1.67	1.77	12.65	0.001
Emergence (%)	98.82	97.65	1.01	1.00	0.37
Tuber no.	188	177	1.06	0.66	0.54
Tubers/plant	11.21	10.43	1.07	1.27	0.26
Tubers/stem	3.80	6.25	0.61	-6.05	0.002
Tuber weight (g)	109	107	1.02	0.26	0.80

(B) Campbell Jameson Farm (Nadine)

Factor	Measurement by seed source			Statistical summary	
	Jameson(j)	Busselton(b)	j/b	t value	P
Plant no.	17.0	15.5	1.10	-1.46	0.22
Stem no.	30.5	29.5	1.03	-0.51	0.64
Stems/plant	1.78	1.91	0.93	1.13	0.32
Emergence (%)	83.33	72.22	1.15	-1.46	0.22
Tuber no.	134	151	0.89	1.01	0.37
Tubers/plant	7.86	9.80	0.80	3.04	0.039
Tubers/stem	4.48	5.14	0.87	2.19	0.093
Tuber weight (g)	72	84	0.86	1.47	0.20

(C) Campbell Jameson Farm (FL1867)

Factor	Measurement by seed source			Statistical summary	
	Jameson(j)	Busselton(b)	j/b	t value	P
Plant no.	16.8	15.2	1.11	-1.55	0.19
Stem no.	39.4	38.2	1.03	-0.47	0.67
Stems/plant	2.34	2.51	0.93	1.83	0.14
Emergence (%)	100	84.21	1.19	-1.55	0.19
Tuber no.	205.2	159.8	1.28	3.04	0.039
Tubers/plant	9.6	13.53	0.71	3.55	0.016
Tubers/stem	4.12	5.42	0.76	3.09	0.027
Tuber weight (g)	83	34	2.44	5.4	0.005

Table 3. Water applied (mm)to potato crops in Dandaragan in 2011 and 2012 crop as irrigation (I) or rainfall (R) from emergence to senescence(spray off), I + R as % of Epan and yield (t/ha).

F1, F2 and F3 refers to 'Arden Fleets', 'Lightning Ridge' and 'Jameson Farm' properties respectively, P and F to pivot ant fixed sprinkler sites respectively.

Site/yr	Location	Variety	Plant dates	Harvest	Irrig. (I) mm	I + Rain	Epan (%)	Yield (t/ha)
2011								
1	F1P1a	Nadine	29/3	15/8	200	409	110	35
2	F1P1b	W star	20/4	15/9	152	454	106	38
3	F1P2a	Atlantic	1/7	30/10	48	105	56	30
4	F1P2b	FL1867	1/7	30/10	48	105	56	30
5	F2P1a	Nadine	10/3	15/7	160	299	72	40
6	F2P1b	Nadine	15/3	15/7	142	373	90	40
7	F2P2a	Nadine	1/6	20/10	78	274	96	39.5
8	F2P2b	Mondial	1/6	20/10	78	274	96	43.6
9	F2FSa	Nadine	13/7	31/10	63	224	56	63.5
10	F2FSb	Mondial	13/7	31/10	63	224	56	40.4
11	F3P1a	Mondial	20/3	15/8	279	524	131	28
12	F3P1b	Mondial	5/5	20/10	84	428	80	26
13	F3P1c	Nadine	5/5	20/10	84	428	80	31
2012								
14	F1P1	Nadine	3/4	30/8	247	494	110	42
15	F1P2	Nadine	20/5	30/9	244	552	132	30
16	F2P1a	Nadine	23/3	15/8	213	416	119	33
17	F2P1b	R' Lou	23/3	15/8	213	416	119	50
18	F2P1c	R'Rascal	23/3	15/8	213	416	119	52.5
19	F2P2	Nadine	12/6	30/10	220	378	109	43
20	F3P1	FL1867	3/4	6/10	221	503	110	29
21	F3P2a	Nadine	26/3	15/8	221	421	110	33
22	F3P2b	W'Star	4/6	31/10	111	247	86	23

Table 4. Volumetric soil water (mean and range in % v/v) for 3 depths, refill points (RP) and field capacity (FC) of each site and proportion of irrigation period (%) soil water was < RP, between RF and FC or > FC for each monitoring site.
F1, F2 and F3 refers to Arden Fleets, Lightning Ridge and Jameson Farm properties respectively, P and F to pivot ant fixed sprinkler sites respectively.

Year & site	Location	Variety*	Volumetric soil water (means & range (% v/v)) Soil depth (cm)			RP	FC	Proportion in soil water category (% time)		
			0 - 15	15 - 30	30 - 60	(%)		< RP	RP–FC	> FC
2011										
1	F1P1a	N	8 (5-14)	13 (8-22)	8 (6-13)	9	12	14	27	59
2	F1P1b	WS	8 (5-16)	14 (8-30)	8 (7-11)	15	20	66	26	8
3	F1P2	A	9 (7-17)	9 (7-16)	10 (9-15)	7	9.5	0	78	22
4	F2P1a	N	9 (6-17)	10 (7-30)	10 (7-20)	6	8	0	24	76
5	F2P1b	N	6.5 (4-11)	10 (6-20)	8 (5-14)	9	11	25	56	19
6	F2P2	N	6 (3-12)	8 (5-13)	7 (5-13)	8	10	63	34	3
7	F2FS	LC	7 (4-14)	7 (5-11)	7 (5-17)	8	10	63	34	3
8	F3P1a	M	6 (5-11)	7 (5-9)	10 (6-22)	6	7	23	40	37
9	F3P1b	M	6 (3-12)	7 (4-12)	7 (5-10)	7	9.5	37	57	6
2012										
10	F1P1	N	10 (6-24)	10 (6-32)	8 (6-14)	9	11.5	45	12	43
11	F1P2	N	8 (5-15)	8 (6-17)	7 (2-10)	7	9	13	66	2
12	F2P1	N	8 (5-15)	9 (3-20)	8 (6-12)		9	24	28	48
13	F2P2	N	8 (5-20)	8 (5-16)	8 (6-12)	7	9	22	64	14
14	F3P1a	N	11 (8-19)	11 (10-17)	11 (8-15)	8	11	2	47	51
15	F3P1b	WS	6 (3-13)	7 (5-11)	7 (6- 9)	6	7.5	12	45	43
16	F3P2	FL	10 (6-15)	9 (6-16)	10 (9-11)	7	9	21	39	40

* A = Atlantic, FL = FL1867, LC = Lady Crystal, M = Mondial, N = Nadine, WS = White Star

Table 5. Estimation of day degrees > 4 °C experienced by seed sources used for planting experiment 1. The local seed experienced almost twice the heat units of the SW seed due to earlier harvest and longer shed storage period.

Seed treatment	Date	Days	Day degrees > 4 °C
Local seed			
Spray-off	05-Oct-11		
Harvest	26-Oct-11		
Shed storage ends	11-Jan-12		1,668
Shed storage duration		98	
Into cool storage	12-Jan-12		
Base temperature reached	20-Feb-12		380
Out of cool store	20-Mar-12		0
Planting	03-Apr-12		271
Total day degrees			2,319
SW seed			
Spray-off	17-Dec-11		
Harvest	07-Jan-12		
Shed storage ends	04-Feb-12		763
Shed storage duration		49	
Into cool storage	05-Feb-12		
Base temperature reached	08-Mar-12		259
Out of cool store	20-Mar-12		0
Planting	03-Apr-12		270
Total day degrees			1,292