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Support for seed potatoes sales to Sri Lanka: determining constraints to production

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FINAL REPORT

HORTICULTURE AUSTRALIA LIMITED

PROJECT PT03064

SUPPORT FOR SEED POTATO SALES TO SRI LANKA: DETERMINING THE CONSTRAINTS TO PRODUCTION

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Purpose of this Report:	To identify agronomic practices that will maximise yield and quality of crops grown from Australian seed in Sri Lanka.
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Frontispiece. Terraced potato crop at Nuwara Eliya, Sri Lanka

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1. Media Summary

Key components of project

Potato yield in Sri Lanka is low compared with Australia. Poor quality seed has been identified as a major limit to yield. However it has been shown that even with good quality seed yield may not improve substantially unless optimum agronomic practices are adopted. Yields need to be increased substantially to cover the cost of seed, maximise profit and increase international competitiveness.

We surveyed agronomic conditions and practices in a number of crops to identify which factors could be used to maximise yield and quality of Sri Lankan potatoes.

Industry significance

If potato yields in Sri Lanka can be increased through better agronomy in combination with good seed, then this will lead to higher profits for farmers. This will convince the farmers of the value of high quality seed and better agronomy and improve the prospects for Australian seed potato exports. Higher yields and profits for Sri Lankan farmers are needed if the Sri Lankan potato industry is to become sustainable. Currently the Sri Lankan potato industry is protected by a tariff on imported table potatoes.

Key outcomes

Management of micronutrients such as copper, zinc and possibility iron and manganese, to avoid excess application, is needed to increase yields in Sri Lanka. We found that farmers' capacity to identify pest and disease may also be crucial to increasing yield. Time of planting in both Badulla and Nuwara Eliya is also important in maximising yield. Improved management of diseases such as late blight will also lead to improved yield.

The surveys showed that yield could be increased to at least twice the national average (26 versus 13 t/ha) by improved agronomic practices in each growing region. A longer-term goal would be to improve yields to 40 t/ha which is considered close to the potential for Sri Lanka.

Recommendations for future R&D

- Investigate methods to reduce excess use of trace elements such as copper and zinc in potatoes in Sri Lanka.
- Investigate the cost benefit of improved irrigation systems in potatoes in Sri Lanka.
- Develop training courses to enable farmers to improve their pest and disease identification skills.
- Time of planting should be investigated further.
- There is a need to introduce IPM systems to potato production in Sri Lanka to delay the onset of strains of late blight resistant to currently used fungicides.

Recommendations for practical application to industry

This project has identified various possible constraints to production in Sri Lanka. This shows the value of export market development work. The Australian potato industry is encouraged to support further seed development projects in Sri Lanka in support of developing further seed exports.

2. Technical Summary

Nature of problem

The wealth of the potato industry can be substantially increased by expanding export seed markets. WA seed potato exports have grown from 600 tonnes in 99/00 to 1,421 tonnes in 2003/04 and are increasing. Sri Lanka is a new market which produced > 89,000 t of potatoes in 2001/02. The average yield is just 12 t/ha compared with > 40 t/ha for Australia. Poor seed quality has been identified as the major reason for low yields. However a yield response to improved seed will only occur if there are no other major constraints. This project investigated factors limiting yield for Sri Lankan potato growers. This will eventually allow Australian seed imports to perform to their true potential.

Research undertaken

A literature review was conducted on current and historic crop management. A survey questionnaire was developed which enabled the research partners to identify sites to be surveyed and the format and extent of the survey. The survey concentrated on the variety Granola. 30 sites each in two cropping periods were surveyed. The locations were Nuwara Eliya and Badulla.

Major findings & industry outcomes

- Low yields were associated with high copper (and possibly zinc) concentrations in the plant in at least one planting in the highlands of Sri Lanka. This information alerts the Sri Lankan potato industry that the over use of copper and zinc in fertilisers and fungicides maybe an important issue. Testing soil amendments which may reduce the absorption of copper and disease control methods which require less copper could be investigated.
- The finding that sprinkler systems affect yield should be investigated further. Different systems could be compared and the benefit/cost for each system should be determined.
- Accurate pest and disease identification may be vital if farmers are to improve yields. Farmers require training to improve their pest and disease identification skills.
- Sowing date influence on yield should be investigated further to determine what factors are causing the yield decline. Planting all crops at the optimum time for yield may result in supply exceeding demand and the relationship between supply and demand and price needs to be investigated to determine how to tackle this issue.
- The frequent use of chemicals to control late blight will result in the development of resistant strains. There is a need to introduce IPM systems to potato production in Sri Lanka to delay the onset of strains of late blight resistant to currently used fungicides.
- We showed that surveys designed to identify yield constraints in new markets can provide helpful information in a relatively short period of time. The results can lead to research to overcome yield constraints and this information will help Australian seed potatoes perform to their potential in new export markets.

Recommendations & future work

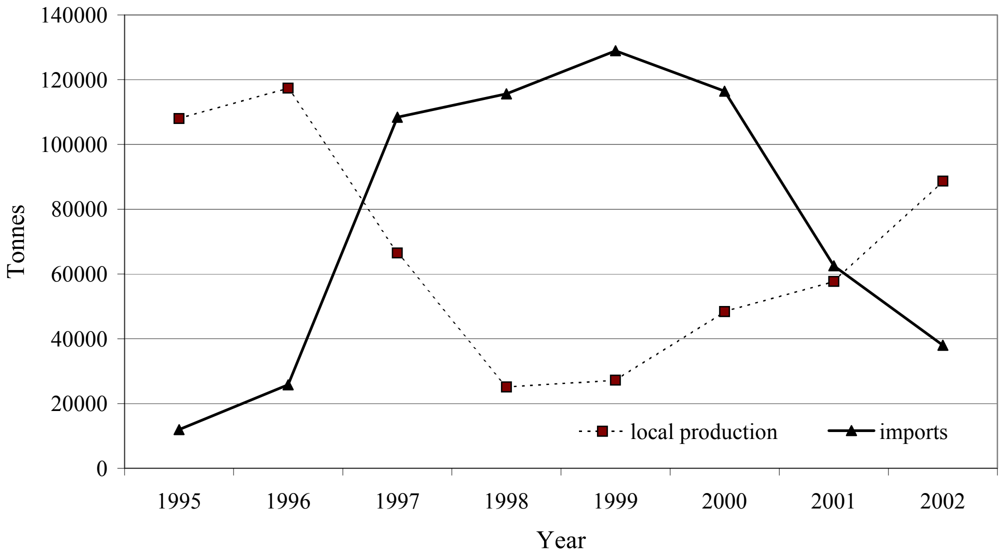
Phase 2 of the project will focus on trial work to further define the factors limiting potato crop management with Phase 3 being a series of Best Management Practice trials to demonstrate the potential of WA seed, grown as part of an integrated crop management program.

3. Introduction

3.1 Background

3.1.1. Production history

Potatoes have been grown in Sri Lanka since at least 1812 but it was not until 1967, when the government stopped the importation of table potatoes, that rapid expansion occurred (Sathiamoorthy *et al.* 1985). Since then potato production has fluctuated depending on growing conditions and competition from imports. In 1994 table potato imports were once again permitted which resulted in Sri Lankan production decreasing from *c.* 110,000 t in 1995 to 25,000 t in 1998 (Figure 1) in response to imports from India and Pakistan undercutting the local industry (Hatherley *et al.* 2003). A tariff of 20 Rs/kg on imported table potatoes was introduced in 1999 for food security and development of the rural economy. This resulted in the recovery of domestic potato production to *c.* 89,000 t in 2002 (Hatherley *et al.* 2003) with an average yield of 13 t/ha (FAOSTAT). Farm gate price for potatoes in 2003 was 40 – 45 Rs/kg (Hatherley *et al*. 2003). In Sri Lanka potatoes are produced mainly for the fresh market with Desiree and Granola the main (56%) varieties.



Tariff of 20 Rs/kg on imported table potatoes introduced in 1999

Figure 1. Sri Lankan potato production and potato imports from 1995 to 2002 (Hatherley *et al.* 2003).

Currently the import of table potatoes depends heavily on the production levels within Sri Lanka as shown in Figure 1. If the tariff were dropped then domestic production would be expected to fall while imports will increase.

Potato consumption is increasing in Sri Lanka: 9 kg of potatoes consumed per person in 2000 compared to 5 kg in 1990.

3.1.2. Production areas and seasons

The main cropping season is called the *Maha* (wet season) which lasts from October to January. This includes the highest rainfall period from October to December caused by the north-east monsoon from the Bay of Bengal. The minor cropping season is called the *Yala* (dry season) and lasts from March to July. This period contains the high rainfall period of April to June caused by the south-west monsoon from the Indian Ocean. During the monsoons the central highlands cause a rain shadow, so that while the windward slopes received plentiful rain, the lee slopes are subjected to drying winds. Between the monsoons conventional rainfall occurs. Rainfall is most consistent in the highland areas while the lower lands require irrigation for cropping in the *Yala* season.

Most (99%) potatoes are produced in the up country (highland) regions because of the milder climatic conditions compared with the lowlands. The two most important growing regions are Nuwara Eliya and Badulla.

Nuwara Eliya is in the up country wet zone at an altitude of 1,800 to 2,000 m with average temperatures between 15 to 20°C. The average annual rainfall is 2,250 mm falling mainly between April and November with December to March usually dry. About 20,000 t of potatoes (29% of the national crop) are grown on 1,500 ha by 10,000 farmers at an average yield of 13.4t/ha. *Maha* Crops are planted between August and September and harvested between November and December. *Yala* crops are planted between February and March and harvested between April and May. The hilly topography requires the use of terraces for cropping and limits the level of mechanisation that can be adopted. Most potatoes in Nuwara Eliya are grown either for the fresh market with high quality tubers kept as seed for the next planting. Growers sow imported seed at both planting seasons. Planting cannot be done in May, June and July because of the heavy winds and rain. Similarly production in December and January is restricted because of the night frost in these two months.

Badulla is in the up country intermediate zone at a lower altitude than Nuwara Eliya at 550 to 910 m with average temperatures between 18 and 25°C. The average annual rainfall is 1729 mm falling mainly between October and March. About 49,000t (70% of the national crop) of potatoes are grown on 4000 ha by 5,000 farmers at an average yield of 12.3t/ha. In Badulla there are two planting seasons, one in the uplands in November-December (*Maha* planting) and the other in June-July (*Yala* planting) in the paddy fields of lowlands after the rice harvest. Harvest is in March and April for the *Maha* planting and in October and November for the *Yala* planting. Most potatoes in Badulla are grown for the fresh market with growers using their own seed in June and July and imported seed for planting in November and December.

3.2.3. Seed supply

Sri Lanka has a long history of importing seed potatoes and even imported Delaware seed from WA in the 1960s under the Colombo Plan. In the last decade the seed has come from Europe. There is no tariff on imported seed as it is recognised as a valuable input. The high production in 1995 was associated with high quantities (14,000 t) of imported seed. Recent quality problems have meant that new seed sources have been sought and WA received orders of about 2,000 tonnes in 2002. About 500 tonnes was sent mainly by "Potato International" (Iwan Gunawan, personal communication). This seed sold in the Sri Lankan highlands for about 100 Rs/kg (AUD $2.00 kg). Farm-gate price in WA was probably 0.70/kg for small tubers. In 2003 Western Potatoes had orders for 800 tonnes and Potato International planned to export another 500 tonnes to Sri Lanka.

In Sri Lanka, imported seed is grown three times. The seed flow within Sri Lanka is shown in Figure 2. So total seed requirement can be estimated as ⅓ of their planting area multiplied by the seeding rate of 2.5 t/ha. In 2001 the area planted was 3,642 ha so seed requirement is $3{,}642/3 \times 2.5 \approx 3{,}000$ tonnes. Demand may reach 6,500 tonnes if production returns to former high levels. European seed exporters are still active in this market.

Most seed is imported by private companies (18 importers) with the government seed scheme only providing about 5% of requirements. Seed imports have fluctuated from 14,188 tonnes in 1995 to 7,029 tonnes in 2002 coming mainly from Germany, Holland, New Zealand and USA.

The Sri Lankan Department of Agriculture also has a program to develop a local seed scheme based on pathogen tested material. Such schemes require isolated, "disease free" bulking areas large enough to produce sufficient seed to have a commercial impact on the industry. Similar schemes have failed in Indonesia, the Philippines and Vietnam because suitable seed bulking areas do not exist. Jayasinghe (2003) reports that in Indonesia such schemes have not worked because basic seed husbandry is neglected, early generation material becomes contaminated, government certification is not adequate and the quality seed that leaves the system is too small in quantity to have a practical impact on industry. The Department of Agriculture in Sri Lanka is also working to strengthen the informal seed potato systems used by farmers (Nugaliyadde, 2003).

3.2. Limits to yield

Potatoes are an important crop in Sri Lanka but yields remain low: between 11-14 t/ha for the years 2000 to 2004 (FAOSTAT). Yield needs to be improved to increase production and profitability for the farmer. It is also imperative that Sri Lankan potato production becomes more competitive so that can become a sustainable industry, not dependent on tariff protection. Yields can reach 40 t/ha but unreliable rainfall, poor storage, variable seed quality, high incidence of bacterial and fungal diseases appear to be the major factors lowering yield (Sathiamoorthy *et al.* 1985). Considerable research has been undertaken in Sri Lanka to improve potato yield. Disease and pest research includes examining the incidence and control measures of late blight (Wimalajeewa and Thavam 1974), potato cyst nematode (*Globodera rostochiensis*) (Toida and Ekanayake 1992) and bacterial wilt (Kelaniyangoda *et al.* 2002, Velupillai 1985). Nutrition work includes the use of potassium (Wijewardena and Amarasiri 1997), nitrogen (Vaz and Gunasena 1974), and phosphorus (Wijewardena 1994) fertiliser in potato crops. Other agronomy research includes investigations of cultural methods, such as tuber size and spacing (Rajadurai 1994), inter-cropping (Kuruppuarachchi 1990), time of planting (Kuruppuarachchi 1987) and storage (Rhoades 1986).

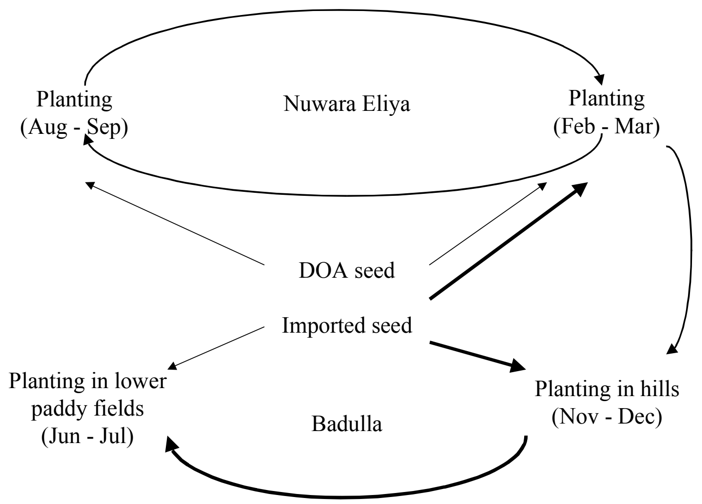


Figure 2. Seed flow for the Nuwara Eliya and Badulla districts in Sri Lanka (Nugaliyadde, personal communication).

Surveys of agronomic conditions and practices have been used to identify limits to potato yields in different countries. For example a survey of agronomy conditions and practices were related to yield and used to identify factors limiting or enhancing potato yield in the Red River Delta of Vietnam (McPharlin *et al*. 2003). Low yield was associated with low N, P and K concentration in the petioles, low plant density, multiple rather than single incidence of diseases (late blight, bacterial wilt, *Rhizoctonia*) and single rather than multiple break crops (i.e. rice) between potatoes in the rotation. The higher incidence of pests identified in the higher yielding crops in the Vietnam survey suggested that maybe these farmers were better 'educated' in pest management. Other surveys have concluded that farmer education level leads to higher technical efficiency. For example it was concluded that better educated farmers were more technically efficient in a survey of 55 potato farmers in Badulla, Sri Lanka, during the July to October crop of 1999 (Amarasinghe and Weerahewa 2001).

Either very low or very high plant density can reduce total yield (Struik and Weirsema 1999). In Vietnam low plant density, less than half the density used in Australian crops, was associated with low yield in flood-irrigated winter grown crops in the Red River Delta (McPharlin *et al.* 2003). In West Java total yield of Atlantic crops sown with whole seed was 29% higher at a 70 x 20 cm compared with a 70 x 30 cm spacing (Dawson *et al.* 2005).

Similarly yield of irrigated Desiree decreased as plant spacing increased from 60 x 20 cm to 60 x 50 cm in Kilinochchi, Sri Lanka (Rajadurai 1994). Increasing density usually leads to a higher yield of smaller tubers and the converse occurs as density is reduced (Travis 1987, Rajadurai 1994).

Seed or seed piece size can influence potato yield either directly, as a source of energy for the growing plant, or indirectly through its influence on plant and stem density. The pattern of yield response to seed size is that yield can be reduced by small seed size but can also be reduced with large seeds because of very high stem density as there are more eyes on larger compared with smaller tubers (Struik and Weirsema 1999). The optimum size of seed to sow to obtain maximum yield can therefore vary with variety and a range of agronomic and environmental conditions but is usually between 30 and 80g. Yield of Desiree increased as seed size increased from 15-30 mm to 45-55 mm in Sri Lanka (Rajadurai 1994). However due to the high cost of seed, income was optimised if larger seed was sown at the highest (60 x 50 cm) spacing. Seed size doesn't always effect yield as it did not appear to influence yield of survey crops in Vietnam (McPharlin *et al.* 2003).

Measurements of soil structure, penetration resistance and fertiliser application were significantly correlated with potato yield in a survey of agronomic conditions on ferrosols and dermosols in Tasmania (Cotching *et al.* 2004).

The purpose of this project was to identify agronomic factors limiting potato yield in major production areas of Sri Lanka. This information would enable future projects to test ways to overcome the constraints and lead to the development of best management practices which will assist Sri Lankan farmers produce higher yields. The ability to produce higher yields will help make expensive imported seed more affordable for farmers.

4. Materials & Methods

Survey Design

Agronomic conditions and practices were examined over 2 crops by CIC field officers. The first crop (crop 1) was planted at Nuwara Eliya. Here 30 farmer sites were surveyed. These sites were sown from the 02/02/04 to the 24/04/04 and harvested from the 25/05/04 to the 24/07/04. The survey was repeated in Badulla (crop 2). Here 30 sites were surveyed with sites sown from the 28/06/04 to the10/08/04 and harvested from the 12/09/04 to the 27/10/04.

This survey used a "Stratified Cluster Sampling" design as the regions were not randomly selected, i.e. stratified, but chosen because they were important potato growing regions. The grower sites within each region were randomly selected from crops planted with the variety Granola.

The survey questionnaire is shown in Appendix 1.

Assessment of Agronomic practices and conditions

Practices

Agronomic practices such as sowing (rate, depth, date, method), rotation, tillage (method, frequency, depth), irrigation, fertiliser, weed, pest and disease management, selection and treatment of seed, date and method of harvest etc were determined mainly from grower responses to the questionnaire.

Conditions

Agronomic conditions such as soil and plant nutrient status, incidence of pests and diseases were determined from direct measurement or fortnightly monitoring before and/or after sowing. For example the soil samples were analysed for nutrients before sowing and plants for nutrients after sowing.

Sampling and analysis of soil for nutrients

Ten – 15 soil samples were collected from the topsoil (0-15 cm) at each site and dried at ambient temperature for 3-4 days prior to chemical analysis. Dried soil samples were submitted to the CIC Soil Laboratory and analysed for extractable or exchangeable nutrients using multinutrient extractants: $NaHCO_3$, NH_4F and EDTA for P, K, Mn, Cu, Zn, Fe; KCl for Ca, Mg and Na and Calcium phosphate for B and SO4-S (after Portch and Hunter 2002). All results were expressed as µg/g dry soil basis for nutrients and as 1:5 soil/water for pH.

Sampling and analysis of plants for nutrients

At each site the petiole of the 4^{th} or 5^{th} leaf from the growing point was sampled form 20 plants. In crop 1 these were sampled twice at 42 and 60 days after sowing. In crop 2 petioles were sampled 3 times, 21, 42 and 60 days after sowing. All samples were dried at 70°Cin a force draught oven for 48 h and submitted to the CIC laboratory for macro (N, P, K, Mg, Ca, S, Na) and micro (Fe, Mn, Cu, Zn) nutrient analysis. All results were expressed as % dry petiole basis for macro-nutrients and as µg/g for micro-nutrients.

Identification of pest type and assessment of incidence

Farmers recorded incidence of pests in the crop during growth as well as in the stored produce. Control measures, such as chemical application and cultural methods prior and during the crop was also recorded. Pests were identified by the farmer and confirmed by a CIC field officer.

Identification of disease type and assessment of incidence

Farmers were asked to record the incidence of diseases that were present during the crop as well as during seed storage. Again, disease control measures used by each farmer was recorded. Diseases were diagnosed by the farmer and confirmed by a pathologist from the Agricultural Research Station, Sita Eliya.

Yield

The total, marketable and reject yield of the crop at each site was determined at harvest from the total yield recorded by the farmer.

Data analysis

Simple linear regression were used to analyse the relationship between the continuous measures of agronomic conditions (i.e. soil and plant nutrient concentrations), practices (i.e. plant spacing) versus yield across the all the sites in both crops. A probability of <0.05 was used as the minimum level of significance. Concentrations of nutrients considered deficient, adequate or excessive (toxic) according to Huett *et al.* (1999) were shown as vertical lines on each regression.

Discrete data such as pest and disease presence was analysed by placing the 30 growers in quartiles according to yield. There were 9, 10 and 11 growers in the first, second and third quartiles respectively (for the first planting). The data was then tabulated according to quartile and a logistic regression (binomial function) or Poisson logarithmic linear regression (multinomial function), based on average yield, was then performed to determine significance. The Binomial function was performed when there were only two factors to choose from or when growers answered a question multiple times and a P value provided for each factor tested. The multinomial function was chosen when there were multiple options but growers only answered once and a single P value is provided for all factors tested. These functions are referred to in the results text as the logistic regression and the log linear regression respectively. Due to the small sample size (30 growers) a significance level of 0.1 (10%) was used. Data was converted to percentages of grower responses for the Highest Yielding Quartile (HYQ) and the Lowest Yielding Quartile (LYQ) by dividing the number of responses for each individual option by the number in each quartile, i.e 9 and 11. As there were growers who gave multiple responses for questions 7, 12, 18, 20, 38 and 40 the percentages in each quartile do not add to 100 percent in these questions. Each answer given in these questions were considered independent of one another and therefore each individual response in these questions was still converted to percentage by dividing by the numbers in its corresponding quartile.

5. Results

Yield

Yield varied 6 fold from 4 to 26 t/ha (mean 13.9 t/ha) over 30 grower sites in crop 1 and 2.4 fold from 10 to 24 t/ha (mean 17.4 t/ha) over 30 grower sites in crop 2. The mean yield of crop 1 was significantly (P<0.001) lower than crop 2 (17.9 t/ha). The higher yield in crop 2 was associated with a higher mean plant density (6.2 v 8.7 plants/m^2) and a shorter cropping history. Potatoes were grown for an average of 17 years in crop 2 compared with 22 years for crop 1.

Training

The number of years experience farmers had in growing potatoes ranged from 1 to 44 (mean 21.6) years for crop1 and from 4 to 36 (mean 16.9) years for crop 2. Years of experience in growing potatoes had no significant relationship (linear regression) to yield in either crop 1 (y = 12.74 + 0.055x, *P*<0.48) or crop 2 (y = 17.51 - 0.066x, *P*<0.94).

Source of knowledge of potato growing, either self or family taught, had no significant impact on yield in either crop (Table 1). There was insufficient data for other sources of learning to draw any conclusions on the value of formal training in crop 1. For example only one grower had attended formal training and this grower was in the highest yield quartile. In crop 2 formal training was not associated with higher yield.

Table 1. Source of knowledge/skill (% of growers) of potato growing with yield quartile.

Source	Crop 1			Crop 2		
	LYQ*	HYQ*	P value **	LYQ*	HYQ*	*P* value **
Father or family	67	45	0.33	27	2	0.67
Self taught	56	45	0.64	27	47	0.25
Formal training	0	9	--	47	33	0.46
Other	0	0	--	0	0	-

*Lowest and highest yield quartile
**From the logistic regression for each factor

Seed selection and supply

Country of origin

The country of origin of the seed used by the % of growers in the lowest and highest yield quartiles in crops 1 and 2 is shown (Table 2). Higher yield is associated with the use of imported rather than local seed in crop 1. For example local seed made up 22% of the seed used in the lowest yielding crops compared with none used in the highest yielding crops. In crop 2 however, local seed represented 53% of the HYQ. Country of origin of seed had no significant effect on yield in both crop 1 and 2 (from the log linear regression).

Table 2. The % of growers using seed of different origin with yield quartile.

Origin	Crop 1			Crop 2		
	LYQ*	HYQ*	P value **	LYQ*	HYQ*	*P* value **
Holland	67	73	0.28	20	33	0.25
Germany	11	18		-	7	
U.S.A	0	0		-	-	
Australia	0	9		-	-	
India	0	0		-	7	
Sri Lanka	22	0		80	53	
Other	0	0		-	-	

*Lowest and highest yield quartile
**From the log linear regression for all factors

Local source of seed

The local source of the seed used by the % of growers in the lowest and highest yield quartiles is shown (Table 3). A greater proportion of growers (78% of LYQ and 91% of HYQ in crop 1, 60% of LYQ and 73% of HYQ in crop 2) used seed that wasn't their own. However, using their own seed or other sources had no significant effect on yield in crop 1 and 2 (from the logistic regression).

Table 3. The % of growers using different methods of seed supply with yield quartile.

Source	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Own seed	22	9	0.32	40	27	0.44
Other	78	91	0.32	60	73	0.44

*Lowest and highest yield quartile
**From the logistic regression for each factor

Number of seasons that seed was retained

The number of seasons for which growers retained and re-used seed by the % of growers in the lowest and highest yield quartiles is shown (Table 4). Of the thirty growers in crop 1, 89% and 91% of the LYQ and HYQ, respectively, used seed that they had retained for 2 seasons. The number of seasons that the seed had been retained had no significant effect on yield (from the logistic regression) in crop 1 and 2 (Table 4).

Table 4. The % of growers retaining seed for different times by yield quartile.

Number of season seed kept	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Previous season	11	9	0.43	60	30	0.29
2 seasons	89	91	0.43	40	70	0.29
>2 seasons	0	0	-	0	0	-

*Lowest and highest yield quartile
**From the logistic regression for each factor

Reasons for buying seed

The reason for buying of seed by the % of growers in the lowest and highest yield quartiles is shown (Table 5). Buying seed based on variety was significantly (P<0.024, logistic regression) related to yield in crop 1 (Table 5). No other reasons for buying seed had any significant impact on yield in crops 1 and 2.

Table 5. The % of growers buying seed for different reasons with yield quartile.

Reason for seed purchase	CROP 1			CROP 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Price	0	0	-	0	0	-
Country of origin	22	27	0.80	20	27	0.67
Variety	67	100	0.02	80	67	0.40
Availability	11	0	-	0	0	-
Previous experience	22	36	0.48	47	47	0.87
Other	11	0	-	0	7	0.23

*Lowest and highest yield quartile
**From the logistic regression for each factor

Price of seed

The price growers paid for seed ranged from 100 to 125 Rs/kg (mean 120) in crop 1 to 100 to 135 Rs/kg (mean 109) in crop 2. There was no significant relationship (linear regression) between the price paid for seed and yield ($y = 2.5 + 0.098x, P<0.56$) in crop 1 whilst in crop 2 yield increased significantly ($y = 60.5 + 0.104x, P<0.05$) with seed price.

Grading seed

Grading seed (or not) by the % of growers in the lowest and highest yield quartiles is shown (Table 6). Of the thirty growers in the first crop, only 44 and 36% of the LYQ and HYQ, respectively, graded their seed before planting. In crop 2, 67% of the LYQ and 87% of the HYQ graded their crop. There was no significant effect of grading seed before planting and yield in both crops (from the logistic regression).

Table 6. The % of growers who graded seed with yield quartile.

Grading	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Yes	44	36	0.71	67	87	0.19
No	56	64	0.71	33	13	0.19

*Lowest and highest yield quartile
**From the logistic regression for each factor

Seed quality

Generation number

The generation number of seed purchased by the % of growers in the lowest and highest yield quartiles is shown (Table 7). There was no significant effect (P<0.42) of seed generation on yield (log linear regression) in either crop. However lowest yield was associated with higher use of seed of unknown generation and there was more use of seed of known generation in the highest yield quartile.

Table 7. The % of growers using seed of different generation with yield quartile.

Generation number	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
G2	0	0		0	7	
G4	0	9		0	0	
G5	0	0		0	0	
G6	0	18	<0.42	0	0	0.23
G7	11	9		0	0	
G7	11	9		0	0	
Unknown	89	63		100	93	

*Lowest and highest yield quartile
**From the log linear regression for all factors

Seed Selection

External factors

The reasons for selecting seed by % of growers in the lowest and highest yield quartile is shown (Table 8). Selecting seed based on size or appearance had no significant effect on yield in both crop 1 and crop 2 (log linear regression). However most (72% of the HYQ and 78% of the LYQ) of the growers in crop 1 selected seed based on appearance. The majority of LYQ and HYQ growers (both 86%) in crop 2 selected their seed based on both size and appearance.

Table 8. The% of growers using different criterion for selecting seed with yield quartile.

Selection	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Size	0	9	0.24	7	7	1.00
Appearance	78	72		7	7	
Size & appearance	22	18		86	86	

*Lowest and highest yield quartile
**From the log linear regression for all factors

Pest and diseases of seed

The pests and or diseases on seed by % of growers in the lowest and highest yield quartiles are shown (Table 9). Higher rodent numbers on seed were associated with higher yield (logistic regression). The absence of pests or diseases on seed during storage had no significant effect on yield on both crop 1 and crop 2.

Table 9. The % of grower seed lots with different pests and diseases and yield quartile.

Pest or disease	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
None	44	18	0.16	7	13	0.54
Soft Rot	0	0	-	7	0	0.23
Dry Rot/*Fusarium*	0	0	-	20	7	0.27
Bacterial Wilt	0	0	-	0	7	0.23
Mealy Bug	0	0	-	0	0	-
Tuber moth	56	27	0.21	47	67	0.27
Aphids on sprout	67	72	0.79	47	67	0.27
Rodents	0	36	0.02	13	13	-
Shrinkage	0	0	-	0	0	

*Lowest and highest yield quartile
**From the logistic regression for each factor

Seed sprout number length and yield

There was slightly lower number of sprouts/seed in the HYQ (4.8) compared with LYQ (5.3) in crop 1 but this was not significantly different ($P<0.22$, t test). $Y = 21.0 - 1.39X$ ($R2=0.06$, $P<0.11$).

Sprout length of seed from LYQ (2.7 mm) was not significantly different ($P<0.88$) to seed from the HYQ (2.6 mm) in crop 1.

Seed Storage

The method of seed storage by % of growers in the lowest and highest yield quartiles is shown (Table 10). All thirty growers in crop 1 bought seed in boxes while 22% and 18% of the LYQ and HYQ, respectively, bought further seed in net bags. Buying seed in net bags had no significant effect on yield in crop 1 (logistic regression). In crop 2 there was a significant relationship between yields and storing seed in boxes.

The mean length of seed storage was the same for both LYQ and HYQ in crop 1 (15.8 weeks) and 2 (15.3 weeks) and therefore had no significant effect on yield (t test).

Table 10. The% of growers using different storage methods and yield quartile.

Source	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Boxes	100	100	0.86	87	80	0.001
Net bags	22	18	0.86	13	20	0.001
Other	0	0	-	0	0	-

*Lowest and highest yield quartile
**From the logistic regression for each factor

Seed preparation and treatment

The method of seed preparation by % of growers in the lowest and highest yield quartiles is shown (Table 11). A greater proportion of the HYQ (63%) planted small tubers at high densities while a greater proportion of the LYQ (56%) used cut large tubers in crop 1. A greater proportion of the HYQ (66%) used cut large tubers in crop 2. The method of grading seed had no significant effect on yield in crop 1 and crop 2 (log linear regression).

Table 11. The % of growers using various grading techniques prior to planting and yield quartile.

Source	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Cut large tubers	56	18		46	66	
Plant small tubers at higher density	33	63	0.44	27	7	0.29
Discard bad seed	11	18		27	27	

*Lowest and highest yield quartile
**From the log linear regression for all factors

The pesticide seed treatment by % of growers in the lowest and highest yield quartiles is shown (Table 12). All thirty growers in the first crop bought seed that was treated with phenthoate in storage. The majority of growers in crop 2 also used phenthoate. There was no significant difference in yield between using phenthoate and pyrimiphos methane in crop 2.

Table 12. The % of growers who had seed that was treated with a chemical in storage.

Seed treatment	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
None	0	0	-	0	0	-
Phenthoate	100	100	-	93	100	0.23
Pyrimiphos methane	0	0	-	7	0	0.23
Other	0	0	-	0	0	-

*Lowest and highest yield quartile
**From the logistic regression for each factor

The chemical treatment of seed by % of growers in the lowest and highest yield quartiles is shown (Table 13). Chemical seed treatments had no effect on yield in either crop 1 or 2 (log linear regression).

Table 13. The% of growers using various chemical seed treatments at planting and yield quartile.

Chemicals	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
None	56	55		47	67	
Carbendazim	33	18		27	13	
Thiram	0	0	0.67	6	0	0.38
Captan	0	0		20	13	
Other	11	27		0	7	

*Lowest and highest yield quartile
**From the log linear regression for all factors

Roguing crops

Whether crops were rogued or not by % of growers in the lowest and highest yield quartiles is shown (Table 14). The majority of growers in the survey (78 to 91% in the LYQ and HYQ, respectively) for crop 1 did not rogue during the growing season. Roguing had no significant effect on the yield of crop 1 (Table 14). All 30 growers in crop 2 rogued their crop.

Table 14. The % of growers roguing with yield quartile

Rogued	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Yes	22	9	0.44	100	100	-
No	78	91	0.44			

*Lowest and highest yield quartile
**From the logistic regression for each factor

Pest and Diseases during planting

The type of pests in crops by % of growers in the lowest and highest yield quartiles is shown (Table 15). The relationship between the presence of cutworm in crops and yield was significant (logistic regression) with a higher % of growers reporting cutworm at higher yields in crop 1. A higher incidence of mites during crop 2 was associated with higher yields. A higher incidence of white grubs during crop 2 was significantly related to lower yields. The presence of other pests had no significant effect on the yield on both crop 1 and crop 2.

Table 15. The % of grower crops with different pests and yield quartile.

Pest	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Don't know	11	0	-	7	0	0.23
Aphids	22	0	0.19	13	33	0.19
Cutworm	67	100	0.04	80	87	0.62
Thrips	11	0	-	7	7	-
Leaf miner	78	45	0.14	60	33	0.14
Mites	22	0	0.25	0	27	0.01
White grubs	33	27	0.78	40	7	0.03
Other	0	0	-	0	0	-

*Lowest and highest yield quartile
**From the logistic regression for each factor

The type of diseases in crops by % of growers in the lowest and highest yield quartiles is shown (Table 16). The presence of *Fusarium* dry rot in the potato crops of crop 1 had a significant effect on yield (logistic regression). A higher percentage (67%) of the LYQ reported having *Fusarium* than the HYQ (27%) in crop 1. There was a significant relationship between those growers in crop 2 that did not know what disease was present in their crop and low yields. Higher yields were associated with early blight incidence in crop 2 but other diseases did not have a significant effect on the yield in both crops 1 and crop 2.

Table 16. The % of grower crops with different diseases and yield quartile.

Disease	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Don't Know	0	9	0.48	20	0	0.03
Bacterial wilt	11	18	0.67	13	20	0.62
Late blight	89	72	0.40	67	80	0.41
Rhizoctonia	22	27	0.79	13	27	0.36
Soft Rot	0	0	-	0	0	-
Fusarium	67	27	0.06	27	40	0.44
Viruses	0	9	-	7	0	0.23
Early blight	67	82	0.45	60	87	0.09
Black leg	33	18	0.47	33	27	0.69
Scab	0	0	-	0	0	-
Other	0	0	-	0	0	-

*Lowest and highest yield quartile
**From the logistic regression for each factor

Pest and Disease relationships

The relationship between leaf miner and late blight was not significant in both crops with a P-value of 0.67 crop1 and a P-value of 0.44 in crop 2.

Soil treatments for disease and pest control

The type of soil chemical treatment for disease control by % of growers in the lowest and highest yield quartiles is shown (Table 17). A majority of growers did not use any soil treatment to control pest and disease in either crop. There was no significant effect of soil treatment on yield (logistic regression) in either crop.

Table 17. The% of growers using different soil treatments for disease control and yield quartile.

Treatment	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
None	78	45	0.13	93	93	-
Bleaching powder	22	55	0.13	-	-	-
Formalin	0	0	-	-	-	-
Other	0	0	-	7	7	-

*Lowest and highest yield quartile
**From the logistic regression for each factor

The type of chemical treatment of soil for nematode control by % of growers in the lowest and highest yield quartiles is shown (Table 18). The majority of growers, 89% (LYQ) and 81% (HYQ), used carbofuran to control nematodes before planting their potato crop in crop 1. Again the majority, 87% (LYQ) and 86% (HYQ), used carbofuran to control nematodes in crop 2. The use of nematicides to control nematodes prior to planting had no significant effect on yield in both crops (log linear regression).

Table 18. The % of growers using a nematicide before planting and yield quartile.

Nematicide	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
None	11	9	0.72	13	7	0.42
Carbofuran	89	82		87	86	
Unknown	0	9		0	7	

*Lowest and highest yield quartile
**From the log linear regression for all factors

The type of soil treatment for insect control by % of growers in the lowest and highest yield quartiles is shown (Table 19). Fifty-six percent and 82% of growers in the LYQ and HYQ respectively in crop1 and 100% and 93% in crop 2 used chemicals to control insects prior to planting their potato crop. The different techniques used to control insects prior planting had no significant on yield (log linear regression).

Table 19. The % of growers using different pre-plant insect control and yield quartile.

Treatment	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Neem	33	18	0.74	0	0	0.7
Tea waste	11	0		0	7	
Tobacco waste	0	0		0	0	
Chemical	56	82		100	93	

*Lowest and highest yield quartile
**From the log linear regression for all factors

Irrigation practices

The different irrigation practices used by % of growers in the lowest and highest yield quartiles are shown (Table 20). The majority of growers, 88% and 81% of LYQ and HYQ, irrigated their crops using a hose and nozzle, while 11% and 18% of LYQ and HYQ used a sprinkler system in crop 1. The use of a hose and nozzle to irrigate had no significant effect on yield (logistic regression) in crop 1 nor furrow and watering can in crop 2. In crop 2 the use of sprinklers was significantly related to higher yield and the use of watering cans with lower yield. There was a trend for yield to increase with number of irrigations in crop 1 ($y = 4.96 + 0.53x, P<0.09$) but not in crop 2 ($y = 15.13 + 0.14x, P<0.6$).

Table 20. The % of growers that used different methods to irrigate their crops and yield quartile.

Method	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Sprinkler	11	18	0.64	0	13	0.09
Hose & nozzle	89	82	0.64	13	13	-
Furrow	0	0	-	7	7	-
Watering can	0	0	-	13	0	0.09
Furrow & watering can	0	0	-	60	67	0.71

*Lowest and highest yield quartile
**From the logistic regression for each factor

Rotation

There were twenty different cropping sequences (rotations) practised in crop1 and six in crop 2 (Appendix 4). The most common rotation used by farmers in crop 1 was two plantings of leek followed by potatoes which was practised by 6 growers, whereas in crop 2 the most common rotation used was paddy (rice) followed by potatoes which was practised by 19 growers. Crop rotation had no significant effect on yield in either crop 1 ($P<0.38$) or crop 2 ($P< 0.52$) from the logistic regression for each factor. There was no significant relationship (linear regression) between total crop or potato crop number/year and yield in either crop (Table 21).

Table 21. Linear regression between yield and total or potato crop number per year for both crops.

Independent variable (x)	Market yield (y) (t/ha)	Comments
	Crop 1	
Crop number/year	$y = 21.40 - 2.8x$	ns ($P = 0.14$)
Potato crops/year	$y = 16.70 - 2.13x$	ns ($P = 0.28$)
	Crop 2	
Crop number/year	$y = 11.93 + 2.69x$	ns ($P < 0.84$)
Potato crops/year	-	-

Agronomic factors at planting

Tillage method and depth

The method of tillage by % of growers in the lowest and highest yield quartiles is shown (Table 22). The method of tillage used prior to planting had no significant effect on yield from crop 1 but did in crop 2. Tilling with hand or tractor and hand was associated with significantly higher yield than tillage by tractor alone in crop 2.

Table 22. The % of growers using different tillage techniques and yield quartile.

Method	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
Tractor plough & till	33	45	0.92	73	33	0.039
Tractor plough, hand till	22	10		27	53	
Entirely by hand	45	45		0	14	

*Lowest and highest yield quartile
**From the log linear regression for all factors

The depth of tillage by % of growers in the lowest and highest yield quartiles is shown (Table 23). The depth of tillage had no significant effect on yield (Table 23).

Table 23. The % of growers that tilled their soil at different depths and yield quartiles.

Depth	Crop 1			Crop 2		
	LYQ*	HYQ*	*P* value **	LYQ*	HYQ*	*P* value **
20 cm with machine	44	36	0.82	13	27	0.35
12-15 cm by hand	56	55		80	73	
Other	0	9		7	0	

*Lowest and highest yield quartile
**From the log linear regression for all factors

Number of times the ground was tilled had no significant effect on yield in crop 1 ($y = 18.93 - 2.5x$, $P<0.31$) or crop 2 ($y = 15.57 + 0.89x$, $P<0.58$).

Linear regressions were fitted to market yield to examine whether agronomic factors at planting such as spacing (in row, between row and density), sowing date, crop growth period (sowing –harvest date), sowing depth, seed size and eye number per seed/seed piece were correlated with yield (Table 24). There was a significant ($P<0.05$) linear reduction in yield with a delay in sowing after the 1/02/05 (Figure 3) in crop 1. There was no significant relationship between other agronomic factors at sowing such as sowing density, depth, seed weight and rotation and yield in crop 1.

Table 24. Linear regressions between agronomic factors at planting and yield.

Independent variable (x)	Market yield (y) (t/ha)	Comments
	Crop 1	
Between row spacing (cm)	y =31.3 - 0.296x	ns (*P* = 0.36)
Within row spacing (cm)	y = 18.6 - 0.17x	ns (*P* = 0.67)
Density (plants/ha)	y = 7.84 + 0.98x	ns (*P* = 0.50)
Sowing depth (cm)	y = 11.24 + 0.635x	ns (*P* = 0.42)
Seed weight (g)	y = 16.97 - 0.14x	ns (*P* = 0.45)
Crop number/year	y = 21.40 - 2.8x	ns *P* = 0.14)
Potato crops/year	y = 16.70 - 2.13x	ns (*P* = 0.28)
Sowing date (days after 01/02/04)	y = 17.40 - 0.12x	significant (*P* < 0.05)
Crop growth period*	y = 24.24 - 0.95x	ns (*P* < 0.18)
	Crop 2	
Between row spacing (cm)	y = 13.9 + 0.067x	ns (*P* < 0.84)
Within row spacing (cm)	y = 14.3 + 0.14x	ns (*P* < 0.59)
Density(plants/ha)	y = 19.68 - 0.26x	ns (*P* < 0.63)
Sowing depth (cm)	y = 15.37 + 0.41x	ns (*P* < 0.37)
Seed weight (g)	y = 36.23 - 0.34x	significant (*P* < 0.03)
Sowing date(days after 15/06/04)	y = 19.07 - 0.078x	ns (*P* < 0.38)
Crop growth period**	y = 14.87 + 0.032x	ns (*P* < 0.54)

*Period between the date of sowing and harvest.

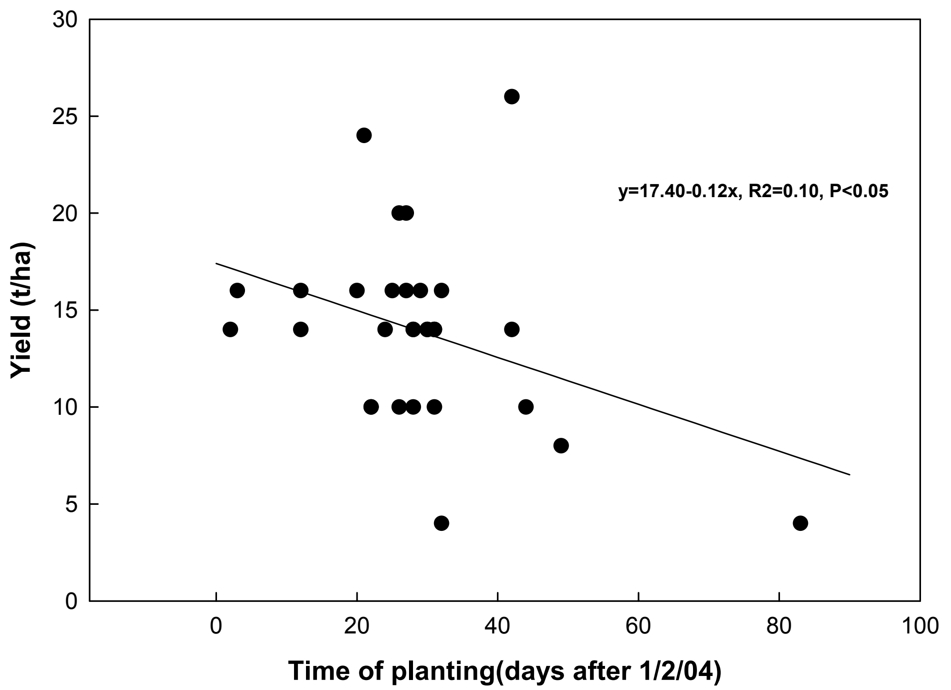


Figure 3. Relationship between time of planting (days after 01/02/04) and yield.

Nutrients in Soil and Plant

Relationship between soil nutrients, pH and nutrients in petioles and yield

The concentration (mean, range) of extractable or exchangeable nutrients in topsoil and their relationship to concentrations in petioles at the first sampling from crop 1 and crop 2 is shown (Table 25). Mean concentrations ranged from 0.08mg/kg B dry soil for extractable B to 1277mg/kg for exchangeable Ca in crop1 (Table 25) and from 0.72mg/kg B dry soil for extractable B to 761mg/kg for exchangeable Ca in crop2 (Table 25). There was no significant correlation (from the linear regression) between concentrations of soil nutrients and petiole nutrient concentrations in either crop. However there was a trend towards increasing petiole Mg with increasing soil exchangeable Mg ($P<0.09$) in crop 1 only.

Table 25: Concentration (mean +/- SE, range in mg/kg dry soil) of nutrients in topsoil (0-15 cm) prior to planting and results of linear regression of soil versus petiole concentrations at first sampling.

Nutrient	Mean +/- SE (mg/kg dry wt)	Range (mg/kg dry wt)	Linear Regression of soil nutrient concentration and petiole nutrient concentration
		Crop 1	
B*	0.08 +/- 0.02	0.01 - 0.31	-
Ca**	1277 +/- 68	559 - 2098	y = 1.215-0.00173*x (*P*<0.43, ns)
Cu***	4.9 +/- 0.44	1.8 - 13.2	y = 9.21+0.338x (*P*<0.64, ns)
Fe***	358 +/- 15	154 - 587	y = 52+0.51x (*P*<0.08, ns)
K***	240 +/- 18	13 - 463	y = 12+0.004x (*P*<0.59, ns)
Mg**	112 +/- 6	48 - 190	y = 0.19+0.0006x (*P*<0.09, ns)
Mn***	18 +/-1 .4	8 - 35	y = 504+6.5x (*P*<0.17, ns)
NH_4-N**	4.3 +/- .65	1 - 15	-
P***	92 +/- 7	21 - 184	y = 0.45+0.0008x (*P*<0.32, ns)
Zn***	8.5 +/-	3 - 18	y = 90.2+0.45x (*P*<0.75, ns)
pH (1:5H_2O)	5.3 +/- 0.09	4.5 - 6.6	-
		Crop 2	
B*	0.72 +/- 0.11	0.01 - 2.38	-
Ca**	761 +/- 39	364 - 1150	y = 1.62-0.0008x (*P*<0.36,ns)
Cu***	7.64 +/- 0.47	3.16 - 11.6	y = 16.33-0.48x (*P*<0.13,ns)
Fe***	440 +/- 39	91 - 1046	y = 224+0.6x (*P*<0.99,ns)
K***	132 +/- 16	42 - 460	y = 16.36-0.007x (*P*<0.08,)
Mg**	8.64 +/- 0.59	4 - 16	y = 0.23+0.0009x (*P*<0.3,ns)
Mn***	26 +/- 4	4 - 90	y = 199+2.36x (*P*<0.003, R^2=0.3)
NH_4-N**	18 +/- 9	1 - 279	y = 2.67-0.002x (*P*<0.34,ns)
P***	37 +/- 6	9 - 126	y = 0.24+0.0008x (*P*<0.12,ns)
Zn***	5.84 +/- 1.42	1.2 - 40.6	y = 40.5+0.47x (*P*<0.15,ns)
pH (H_2O)	5.41 +/- 0.09	4.6 - 6.4	-

*Extractable in calcium phosphate **Exchangeable in KCl and *** Extractable in $NaHCO_3$, NH_4F and EDTA for P, K, Mn, Cu, Zn, Fe (after Portch and Hunter 2002).

The linear regressions between concentrations of nutrients in petioles at the first sampling of both crops and topsoil pH are shown (Table 26a). In crop 1 concentrations of Mg in the petiole increased significantly *(P*<0.023) and Mn decreased *(P*<0.027) with soil pH but pH was not correlated with the concentrations of other nutrients (Table 26a). In crop 2 concentrations of Zn in the petiole increased significantly *(P*<0.03) with soil pH but pH was not correlated with the concentrations of other nutrients (Table 26a).

Table 26a. Linear regressions of soil pH versus petiole nutrient concentrations at first sampling for Crop 1 & Crop 2.

Nutrient in petiole	Linear regression of petiole nutrient levels and soil pH	Significance
	Crop 1	
Ca	y = 2.17 - 0.22x *(P*<0.16)	ns
Cu	y = 22.3 - 2.14x *(P*<0.48)	ns
Fe	y = 285 - 9.5x *(P*<0.89)	ns
Mn	y = 1414 - 149x *(P*<0.027)	*
Mg	y = - 0.028 + 0.054x *(P*<0.023)	*
Zn	y = 165 - 13.3x *(P*<0.20)	ns
	Crop 2	
Ca	y = 2.12 - 0.21x (*P*<0.60)	ns
Cu	y = 5.96 + 1.23x (*P*<0.44)	ns
Fe	y = 70 + 28.6x (*P*<0.57)	ns
Mn	y = 116 + 27x (*P*<0.52)	ns
Mg	y = 0.63 - 0.06x (*P*<0.33)	ns
Zn	y = - 17 + 11.19x (*P*<0.03, R^2=0.17)	**

Significance at *(P<0.05) or **(P<0.01) respectively

The linear regressions between concentrations of nutrients in the soil prior to planting and yield are shown in Table 26b. Concentrations of Ca and Mg in the soil were significantly correlated with higher yield in crop 1 but not 2. The was no significant correlation between the concentrations of other nutrient in the soil and yield in either crop.

Table 26b. Linear regressions between soil nutrient concentrations and yield.

Nutrient in soil	Linear regression between yield and soil nutrient concentration	Significance
	Crop 1	
B	y =15.46 -1.1x *(P*<0.91)	ns
Ca	y = 7.56 + 0.005x *(P*<0.04, R^2=0.12)	*
Cu	y = 16.24- 0.47x *(P*<0.22)	ns
Fe	y = 17.55 – 0.01x *(P*<0.37)	ns
K	y = 9.98 - 01x *(P*<0.08)	ns
Mg	y = 8.2 + 0.05x *(P*<0.05, R^2=0.10)	*
Mn	y = 13.10+0.05x (*P*<0.7)	ns
NH_4-N	y = 12.41+0.36x (*P*<0.16)	ns
P	y = 10.27+0.04x (*P*<0.08)	ns
Zn	y = 11.36+0.30x (*P*<0.2)	ns
pH	y = 2.89-1.46x (*P*<0.10, R^2=0.06)	ns
	Crop 2	
B	y = 16.72+0.63x (*P*<0.66)	ns
Ca	y = 14.41 +0.0035x (*P*<0.38)	ns
Cu	y = 17.12 +0.004x (*P*<0.99)	ns
Fe	y = 15.77+ 0.003x (*P*<0.44)	ns
K	y = 17.14+0.00013x (*P*<0.98)	ns
Mg	y = 17.45 -0.0033x (*P*<0.89)	ns
Mn	y = 16.65+0.02x (*P*<0.60)	ns
NH_4-N	y = 16.8 + 0.02x (*P*<0.2)	ns
P	y = 15.39+0.05x (*P*<0.06)	ns
Zn	y = 17.27-0.02x (*P*<0.86)	ns
pH	y =15.88+0.24x (*P*<0.90)	

Concentration of nutrients in petioles and yield

Micronutrients

The concentration (mean, range) of micronutrients in petioles for two sampling times (crop 1) and for three sampling times (crop2) and their relationship to yield is shown Table 27.

Mean Cu concentrations in petioles decreased from 10.9 mg/kg dry weight in sample 1 to 5.4 mg/kg in sample 2 in crop 1 and from 14.8 mg/kg in sample 3 to 8.46 mg/kg in sample 2 in crop 2. There was a significant negative correlation (P<0.01 sampling time 1, *P*<0.05 sampling time 2, from the linear regression) between yield and mg/kg Cu in the petioles at both sampling times in crop 1 (Figure 4) but not in crop 2 (Appendix 3, Figure 1). Although yields were reduced at high mg/kg Cu they were not significantly lower at Cu concentrations considered deficient (i.e., 3 to 5 mg/kg) at either sampling time in crop 1.

Mean Fe concentrations in petioles decreased from 234 mg/kg dry weight in sample 1 to 151 in sample 2 in crop 1 and from 221 at sample 1 to 77 at sample 3 in crop 2. There was no significant correlation (from the linear regression) between mg/kg Fe in the petioles and yield at either sampling time or crop (Appendix 2, Figure 1 and Appendix 3, Figure 2). Also there was no evidence of either Fe deficiency or toxicity at either sampling time. However there were some very low yields (<10 t/ha) at Fe concentrations considered excessive (i.e. > 150 mg/kg, Huett *et al*. 1997) at the first but not the second sampling.

Table 27. Concentration (mean +/- SE and range in mg/kg dry basis) of micro-nutrients in petioles at 2 or 3 samples times and linear regression of petiole concentrations versus yield for Crop 1 & Crop 2.

Nutrient	Sampling time	Mean +/- SE (mg/kg)	Range (mg/kg)	Regression
			Crop 1	
Cu	1	10.9 +/- 1.4	0.5 - 23	y = 18.30 - 0.38x (*P*<0.01, R^2=0.30)
	2	5.4 +/- 0.44	2.2 - 11	y = 19.92 - 1.01x (*P*<0.05, R^2=0.17)
Fe	1	234 +/- 23	84 - 556	y = 16.69 - 0.012x (*P*<0.09, R^2=0.06)
	2	151 +/- 20	70 - 460	y = 14.35 - 0.001x (ns)
Mn	1	618 +/- 34	166 - 933	y = 17.7 - 0.005x (ns)
	2	812 +/- 71	337 - 1840	y = 15.2 - 0.0013x (ns)
Zn	1	94 +/- 5.2	50 - 140	y = 18.39 - 0.047x (ns)
	2	136 +/- 17	38 - 432	y = 15.52 - 0.008x (ns)
Cu & Fe	1	-	-	y = 17.9 - 0.4Cu + 0.003Fe (*P*<0.014, R^2=0.27)
	2	-	-	y = 19.7 - 1.04Cu + 0.002Fe (*P*<0.09, R^2=0.13)
Cu & Zn	1	-	-	y = 23.2 - 0.4Cu - 0.05Zn (*P*<0.004R^2=0.35)
	2	-	-	y = 19.7 - 1.09Cu + 0.005Zn (*P*<0.08, R^2=0.13)
Cu	1	12.35 +/- 0.72	8 - 22	y = 18.15 - 0.075x (ns)
	2	8.46 +/- 0.51	6 - 15	y = 18.73 - 0.154x (ns)
	3	14.8 +/- 1.5	6 - 24	y = 17.20 + 0.054x (ns)
Fe	1	221 +/- 22	95 - 650	y = 17.63 - 0.0018x (ns)
	2	206 +/- 31	75 - 760	y = 17.65 - 0.00106x (ns)
	3	77 +/- 6	55 - 125	y = 24.92 - 0.0895x (ns)
Mn	1	260 +/- 19	80 - 460	y = 17.22 + 0.00005x (ns)
	2	496 +/- 35	260 - 950	y = 16.15 + 0.00258x (ns)
	3	772 +/- 67	380 - 1240	y = 19.92 - 0.00248x (ns)
Zn	1	44 +/- 2.4	26 - 80	y = 21.92 - 19.1x (ns)
	2	76 +/- 5	43 - 137	y = 18.93 - 0.0197x (ns)
	3	76 +/- 5	55 - 110	y = 22.93 - 0.065x (ns)
Cu & Fe	1	-	-	y = 18.3 - 0.06Cu - 0.0001Fe (ns)
	2	-	-	y = 18.8 - 0.02Cu + 0.0007Fe (ns)
	3	-	-	y = 23.2 + 0.2Cu + 0.11Fe (*P*<0.03, R^2=0.30)
Cu & Zn	1	-	-	y = 21.2 + 0.08Cu - 0.1Zn (ns)
	2	-	-	y = 21.2 - 0.12Cu - 0.02Zn (ns)
	3	-	-	y = 22.7 + 0.2Cu - 0.1Zn (ns)

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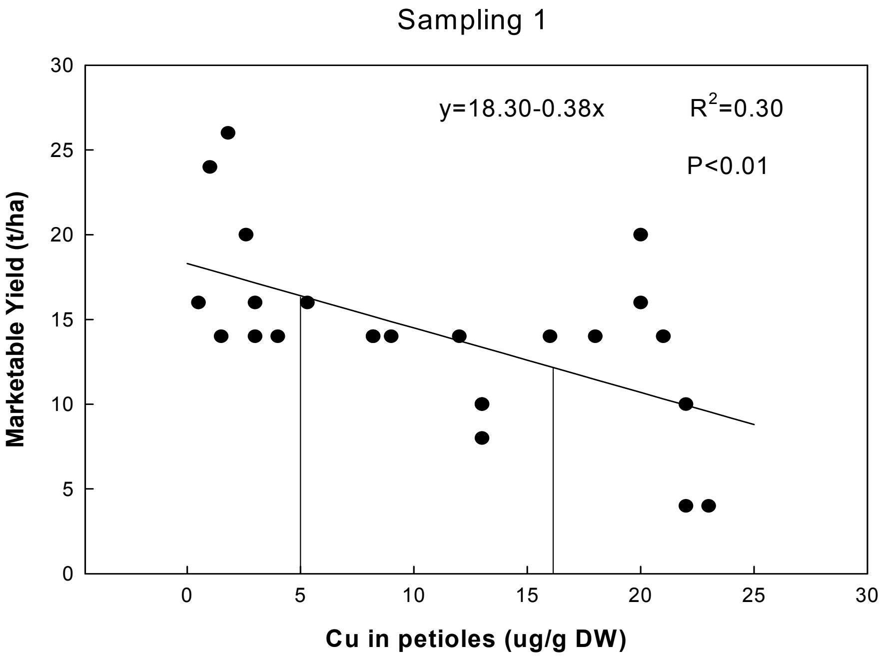

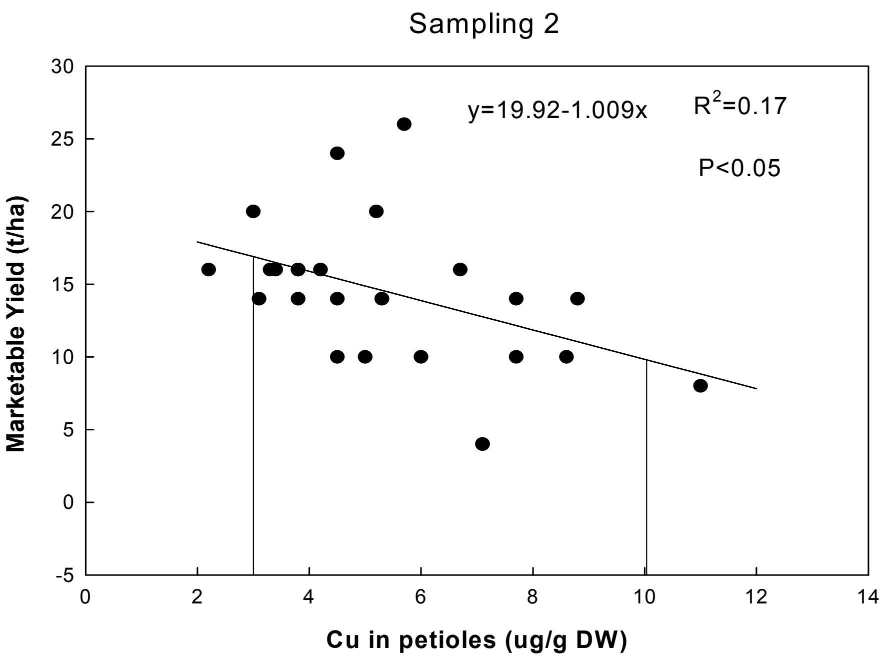

Figure 4. Cu in petioles (mg/kg DW) with yield at 2 sampling times. Vertical, lines correspond to range of concentrations from minimum (< is deficient), left line, to maximum (> is toxic), right line, at each time.

Mean Mn concentrations in petioles increased from 618 mg/kg dry weight in sample 1 to 812 mg/kg in sample 2 in crop 1 and from 260 mg/kg in sample 1 to 772 mg/kg in sample 3 in crop 2. There was no significant correlation (from the linear regression) between Mn concentration in the petioles and yield at either sampling time or crop (Appendix 2, Figure 2 and Appendix 3, Figure 3). Also there was no evidence of either Mn deficiency or toxicity at either sampling time. However there were some very low yields (<10 t/ha) at Mn concentrations considered excessive (i.e. > 300mg/kg, Walworth and Muniiz 1993) at both sampling times.

Mean Zn concentrations in petioles increased from 94mg/kg dry weight in sample 1 to 136 mg/kg in sample 2 in crop 1 and from 44 in sample 1 to 76 in samples 2 and 3 in crop 2. There was no significant correlation (from the linear regression) between mg/kg Zn in the petioles and yield at either sampling time or crop (Appendix 2, Figure 3 and Appendix 3, Figure 4). However one third of the sites at sampling one and two thirds at sampling two recorded Zn concentrations in petioles that maybe excessive (i.e. >110-180 mg/kg, Huett *et al*. 1997).

Effects of more than one nutrient

The yield reduction in crop 1 with increasing Cu concentrations in the petioles was better explained when Zn concentration was included (R^2 higher) in the regression than by Cu alone at least in sample 2 (Table 27). Yield reduction was not better explained with the addition of any other micronutrient concentration in the regression with Cu. In crop 2 yield reduction was best explained by concentrations of both Cu and Fe in the regression, for sample 3 only, compared to other nutrients alone or in combinations with others.

Macronutrients

Crop 1

The concentration (mean and range) of macro nutrients in petioles and their relationship to yield at 2 sample times for crop 1 is shown in Table 28 and 3 sample times for crop 2 is shown in Table 28. Mean Ca concentrations in petioles were 0.99% and 0.82% dry basis in sample 1 and 2 respectively in crop 1 and increased from 0.55% in sample 3 to 1.38% in sample 2 in crop 2. There was no significant correlation (from the linear regression) between %Ca in the petioles and yield at either sampling time or crop (Appendix 2, Figure 4 and Appendix 3, Figure 5). Also there was no evidence of either Ca deficiency or excess at either sampling time. However there were some very low yields (<12 t/ha) at Ca concentrations considered excessive (i.e. > 1.5%, Huett *et al*. 1997) in sample 1 but not sample 2.

Mean K concentrations in petioles increased from 12.91% dry weight in sample 1 to 15.86 in sample 2 in crop 1 and decreased from 15.3% in sample 1 to 13.51% in sample 3 in crop 2. There was no significant correlation (from the linear regression) between %K in the petioles and yield at either sampling time or crop (Appendix 2, Figure 5 and Appendix 3, Figure 6). Also there was no evidence of either K deficiency or excess at either sampling time in crop 1. However at the second sampling in crop 1 most sites recorded %K in petioles that maybe excessive (i.e. >14%, Huett *et al*. 1997).

Mean Mg concentrations in petioles were 0.26 and 0.27% dry weight in samples 1 and 2 respectively in crop 1 and from 0.31% in sample 1 and 2 to 0.18% in sample 3 in crop 2. There was no significant correlation (from the linear regression) between %Mg in the petioles and yield at either sampling time or crop (Appendix 2, Figure 6 and Appendix 3, Figure 7). Also there was no evidence of either Mg deficiency or excess at either sampling time. However there were some very low yields (<10t/ha) at Mg concentrations considered deficient (i.e. <0.3%, Huett *et al*. 1997) at both sampling times.

Nitrogen

Mean N concentration in petioles was 1.82% dry weight in sample 2 in crop 1 and from 2.08 to 2.63% in crop 2. There was no significant correlation (from the linear regression) between %N in the petioles and yield in either crop at any sampling time (Appendix 2, Figure 7a, Appendix 3, Figure 8). Also there was no evidence of either N deficiency or excess although crops with <1.5% N in either crop maybe deficient (Maier *et al*. 1994).

Phosphorus

Mean P concentrations in petioles decreased from 0.53% dry weight in sample 1 to 0.24 in sample 2. There was no significant correlation (from the linear regression) between %P in the petioles and yield at either sampling time (Appendix 2, Figure 8 and Appendix 3, Figure 9). Also there was no evidence of either P deficiency or excess at either sampling time. However at the second sampling most sites recorded %P in petioles that maybe inadequate (i.e. <0.3%, Huett *et al*. 1999).

Sulphur

Mean S concentration in petioles in crop 1 was 0.28% dry weight in sample 2. There was no significant correlation (from the linear regression) between %S in the petioles and yield at sampling time two (Appendix 2, Figure 7b). Also there was no evidence of either S deficiency or excess.

Table 28. Concentration (mean +/- SE and range in % or mg/kg dry basis) of macro-nutrients in petioles at 2 (crop 1) or 3 (crop 2) sample times and linear regression of petiole concentrations versus yield.

Nutrient	Samp-ling	Mean+/- SE	Range	Regression
			Crop 1	
Ca	1	0.99 +/- 0.08	0.44 - 1.93	y = 17.66 - 3.74x (R^2=0.08, *P*<0.08)
	2	0.82 +/- 0.07	0.2 - 1.81	y = 13.8 + 0.9x (ns)
K	1	12.91 +/- 0.65	4.1 - 18.8	y = 14.71 - 0.06x (ns)
	2	15.86 +/- 0.42	11.8 - 20.0	y = 16.50 - 0.14x (ns)
Mg	1	0.26 +/- 0.01	0.15 - 0.42	y = 17.77 - 12.9x (ns)
	2	0.27 +/- 0.02	0.14 - 0.47	y = 17.78 - 12.2x (ns)
N	2	1.82 +/- 0.05	1.4 - 2.3	y = 18.15 - 2.01x (ns)
P	1	0.53 +/- 0.03	0.03 - 0.84	y = 12.17 + 3.34x (ns)
	2	0.24 +/- 0.03	0.12 - 0.75	y = 15.72 - 5.08x (ns)
S	2	0.28 +/- 0.015	0.16 - 0.44	y = 17.70 - 0.0016x (ns)
			Crop 2	
Ca	1	0.8 +/- 0.16	0.3 - 3.00	y = 17.16 + 0.073x (ns)
	2	1.38 +/- 0.23	0.3 - 4.2	y = 16.73 + 0.506x (ns)
	3	0.55 +/- 0.03	0.4 - 0.7	y = 17.31 + 1.3x (ns)
K	1	15.3 +/- 0.32	12.6 - 19.60	y = 14.4 + 0.185x (ns)
	2	14.13 +/- 0.49	8.6 - 18.0	y = 23.29 - 0.415x (ns)
	3	13.51 +/- 0.33	11.4 - 16.0	y = 19.9 - 0.144x (ns)
Mg	1	0.31 +/- 0.03	0.11 - 0.65	y = 15.73 + 4.9x (ns)
	2	0.31 +/- 0.003	0.11 - 0.66	y = 16.17 + 4.07x (ns)
	3	0.18 +/- 0.02	0.07 - 0.34	y = 18.61 - 3.5x (ns)
N	1	2.63 +/- 0.12	1.7 - 3.7	y = 19.24 - 0.76x (ns)
	2	2.35 +/- 0.10	1.3 - 3.2	y = 20.25 - 1.20x (ns)
	3	2.08 +/- 0.07	1.7 - 2.6	y = 15.16 + 1.37x (ns)
P	1	0.28 +/- 0.02	0.17 - 0.46	y = 15.78 + 5.24x (ns)
	2	0.23 +/- 0.02	0.08 - 0.35	y = 20.57 - 13.4x (ns)
	3	0.16 +/- 0.01	0.10 - 0.22	y = 21.83 - 24.4x (ns)
S	1	0.19 +/- 0.01	0.11 - 0.26	y = 20.79 - 19.1x (ns)
	2	0.21 +/- 0.01	0.13 - 0.28	y = 21.62 - 19.6x (ns)
	3	0.16 +/- 0.001	0.14 - 0.19	y = 42.85 - 152.1x (ns)

Nutrient Interactions

The linear regression between the concentrations of 2 selected nutrients in the petioles for both crops is given in Table 29. No regression was significant in either crops or any sampling time.

Table 29. Linear regressions of the relationship between the petiole concentrations of two selected nutrients at 2 (Crop 1) or 3 (Crop 2) sampling times.

Interaction	Sampling	Regression	R^2	*P* value
		Crop 1		
Cu & Fe	1	Cu = 0.72 + 0.04Fe	0.46	<0.001
	2	Cu = 5.3 + 0.006Fe	0.02	ns (<0.89)
Cu & Mn	1	Cu = 4.13 + 0.01Mn	0.04	ns(<0.19)
	2	Cu = 5.08 + 0.0004Mn	0.02	ns(<0.78)
Cu & N	1	-	-	-
	2	Cu = 9.36 – 2.2N	0.03	ns(<0.21)
Cu & Zn	1	Cu13.97 - 0.03Zn	0	ns (<0.58)
	2	Cu = 3.8 + 0.011Zn	0.16	<0.03
Mn & Zn	1	Mn = 449 + 1.81Zn	0.04	ns(<0.15)
	2	Mn = 745 + 0.49Zn	0	ns(<0.6)
		Crop 2		
Cu & Fe	1	Cu = 10.74 + 0.007Fe	0.09	ns (<0.3)
	2	Cu = 6.42 + 0.009Fe	0.34	*** (<0.001)
	3	Cu = 7.57 + 0.094Fe	0.08	ns (<0.16)
Cu & Mn	1	Cu = 12.9 - 0.002Mn	0	0.79
	2	Cu = 8.38 - 0.002Mn	0	0.94
	3	Cu = 26.75 - 0.015Mn	0.43	**(<0.005)
Cu & N	1	Cu = 18.37 -2.29N	0.11	*(<0.05)
	2	Cu = 12.39 -1.67N	0.06	ns(<0.10)
	3	Cu = -16.97 + 15.27N	0.46	**(<0.003)
Cu & Zn	1	Cu = 11.8 + 0.005Zn	0.04	ns(<0.17)
	2	Cu = 10.5 – 0.026Zn	0.03	ns(<0.19)
	3	Cu = -1.19 + 0.18Zn	0.12	ns(<0.1)
Mn & Zn	1	Mn = 218 + 0.09Zn	0	ns(<0.6)
	2	Mn = 150 + 4.6Zn	0.39	***(<0.001)
	3	Mn = 1176 – 5.34Zn	0.06	ns(<0.19)

6. DISCUSSION

Seed

The farmer's decisions on seed selection and the resultant impact on yield were variable. Whilst the country of origin of seed had no impact on yield overall, where Australian seed was used (crop 1) yields were in the higher quartile and there was a higher use of local seed in the lower compared with higher yield quartiles in both crops. The dominance of the use of Dutch seed made it difficult to assess the impact of seed from other countries. Other results that suggest farmers make careful decisions in the selection of seed is the positive correlation between price paid for seed and yield in crop 2 and the trend for greater use of seed of known generation in the higher yielding quartiles of each crop (Table 7). This is encouraging as it shows farmers know the value of good quality seed and are prepared to pay for it.

The use of round seed rather than cut seed was not consistently associated with higher yield between crops. Whilst there was a trend to higher use of cut seed in lower yields in crop 1 this was not the case in crop 2. This supports work in both Vietnam (McPharlin *et al*. 2003) and Indonesia (Dawson *et al*. 2005) that crops grown from cut seed can yield as well or better than crops grown from round seed in tropical conditions. It appears that the use of cut seed in the tropics can be successful if the seed is high quality and good management practices (adequate curing, good storage conditions and hygienic cutting) are followed (McPharlin *et al.* 2003). Following simple good management practices with seed appears to be more important than applying expensive chemicals to seed by farmers who can least afford it. In Vietnam the highest yields were often achieved with cut and cured seed with no additional chemical seed treatments (McPharlin *et al*. 2003). These results are important as it means there may be the potential for Australian farmers to export larger seed tubers to Sri Lanka. This will enable them to become more price competitive in the export market as they could sell a larger fraction of their crop for seed.

There is some indication from the results that seed age maybe important in yield. Sprout number and length have been used to as criteria for seed physiological age in Sri Lanka (Carls and Caesar 1979) with older seed having more and longer sprouts. There was a trend towards higher yield being associated with fewer sprouts/seed in crop 1 (page 19). This suggests that younger seed may yield better than older seed in Sri Lanka. Crops grown from older seed (12 months) yielded less than from younger seed (8 months) in Atlantic crops in West Java (Dawson *et al*. 2005). It may therefore be important for both exporters and growers to supply seed of an appropriate age to maximise yield. This will take careful planning because of the different planting times in Sri Lanka and the likelihood that planting times may be delayed for months because of seasonal conditions. Such delays can easily lead to seed being too old when planted which may result in a decrease in yield compared to that of younger seed. Australian seed exporters experienced these problems in West Java because of quarantine delays.

The effect on yield by grading seed based on size/appearance and/or the presence of pests and diseases was inconclusive. However there was some evidence that storage in net bags was better than in boxes (crop 2) probably because of better ventilation in net bags.

There was no evidence that using larger seed increased yield in either crop. By contrast in crop 1 reduction in yield was associated with increasing seed size whilst seed size did not appear to influence yield in crop 2. These findings contrast with work that shows yield increases with seed size to an optimum usually between 40 and 80g per seed or seed piece (Struik and Wiersema 1999). Reductions in yield with seed size are usually associated with inadequate (small seed) or excess crop density (large seed) as determined by plant and stem density. There was no evidence in this work that lower yield associated with larger seed size was related to density in either crop.

Agronomic factors

The higher mean yield of crops in Badulla (crop 2) than in Nuwara Eliya (crop 1) was most likely related to better climatic conditions in Badulla. The higher rainfall, number of rain days, cloud cover and lower temperature and solar radiation in Nuwara Eliya (Sathiamoorthy *et al.* 1985) would lead to lower yield compared with Badulla. Also crops in Nuwara Eliya are closer together in the narrow valleys compared with the more widely separated plantings in Badulla. The reduced isolation may result in higher pests and disease incidence.

Planting date

Delaying sowing of cv.Granola in Nuwara Eliya (crop 1) after 01/02/04 resulted in a significant reduction in yield (Figure 3). There was also a trend, though not significant, to reduced yield of Granola yield with planting after 15/06/04 in Badulla (crop 2). Other work in Sri Lanka has shown time of sowing influences potato yield. For example the total yield of cvs Arka and Desiree declined, and yield of small tubers (<25 mm), increased, when sown after November from 1983-87 in Kalitiya in the North West of Sri Lanka (Kuruppuarachchi 1987). The reduction in yield in Nuwara Eliya was not related to crop longevity (i.e. period between sowing and harvest date). This was shown by the highest yielding site (26 t/ha) which grew for the shortest period (80 days) while the longest growing site (139 days) only yielded (14 t/ha). Similarly there was no relationship between crop longevity and yield in Badulla. By contrast the length of the crop growth period was positively correlated with yield of Atlantic in West Java where the highest yielding crops grew the longest (Dawson *et al*. 2005). The severity of late blight was thought to be a key determinant of the length of time the crop grew in West Java. Given the similar importance of late blight as a limit to production in Sri Lanka it is surprising crop growth period was not related to yield.

Irrigation systems

Trends for improved yield with different irrigation and cultivation practices were also shown. For example there appeared to be higher yield with the use of sprinklers compared with other irrigation methods in crop 2 (Table 20). This table also showed lower yield s were associated with the use of watering cans. There was also a trend towards higher yield with more frequent irrigation in crop 1 (page 22). This suggests that improvements in methods and amount of irrigation may increase yield. The use of sprinklers may indicate the adoption of improved irrigation technology compared with watering cans. Certainly it would be easier to apply irrigation more frequently with a sprinkler system than with watering cans.

Planting density

Planting density, as determined by in-row and between-row spacing, had no significant influence on yield within each crop. However the mean density was 39% higher in crop 2 compared with crop 1 and this may have contributed, along with climatic factors, to the higher yield in crop 2. Planting density has been reported to influence yield of potatoes in tropical potato growing regions such as in Sri Lanka, West Java and Vietnam. For example total yield declined as planting density decreased from 8.3 to 3.3 plants/m^2 in the north of Sri Lanka (Rajadurai 1994). The range of planting densities reported in this study (4.8 to 7.8 m^2 and 6.9 to 11.5 m^2) may have been too narrow, or the minimum densities too high, to influence yield. The association of higher yield with higher density in crop 2 versus crop 1 suggests increasing density may be important in raising yields. This was shown in Indonesia where yield of Atlantic sown from whole seed increased significantly from 24.8 to 32.1 t/ha as density increased from 4.6 to 6.9 plants/m^2 (Dawson *et al.* 2005). Yields of potatoes of a number of varieties, including TPS, Dutch and Chinese varieties, increased from 10 to 35 t/ha as planting density increased from 3.5 to 7.5 plants /m^2 in Vietnam (McPharlin *et al*. 2003). However even though this effect was shown over a wider range of densities the correlation between density and yield was highly significant ($P<0.001$) so significant effects of density on yield could be discerned with smaller changes in density.

Cultivation

There was no evidence that mechanical cultivation was better than manual methods in either crop. Given the steep topography of Nuwara Eliya, the use of mechanical cultivation must proceed carefully so as not to increase soil erosion. A combination of mechanical and manual methods of cultivation appears the most appropriate in these regions at present.

Nutrients

Low yields of crops in Nuwara Eliya, but not Badulla, were significantly correlated with high concentrations of copper in the plant petioles at both samplings. Yields were low at petiole Cu concentrations considered to be excessive i.e. >10 to 16 µg/g (Huett *et al.* 1999) in the 2 samplings. The high plant Cu concentrations could be explained by the high concentrations of extractable Cu in the top soil before sowing which ranged from 1.8 to 13.2 µg/g with a mean of 4.9 µg/g (Table 25). These concentrations could have contributed to high plant concentrations as soil concentrations from 0.5 to 5.0 µg/g (DTPA extractable) is considered adequate (Jones 1981) or high (Rayment 1993) for vegetable crops. Our Cu extraction method did not used DTPA but instead used $NaHCO_3$, NH_4F and EDTA (Portch and Hunter 2002) which would most likely have extracted more Cu from the soil than DTPA alone (Brennan and Best 1999), but how much more is unknown. However if we had used the DTPA extraction, assuming that it only extracted 50% of our soil Cu values, then the levels we found would be equivalent to 2.0 µg/g to 6.0 µg/g DTPA which would still be high enough to cause plant growth problems.

These high concentrations of Cu in the soil would have arisen from application of Cu in trace elements and fungicides ($CuSO_4$, Cu $(OH)_2$ and CuO) over a long time i.e. residual copper. Cu in the plant could have originated from this residual copper as well as from current applications of Cu fertilisers and or fungicides. Copper phyto-toxicity has been reported in other crops from long term use of copper fungicides. For example replanted vines exhibited symptoms of copper phyto-toxicity in vineyards in Brazil (Giovanni 1997). Long term use of copper fungicides and fertilisers were shown to contribute to reduced growth of citrus trees in sandy soils in Florida (Reuther and Smith 1952). For example the dry weight of 'Citrange' seedlings was significantly reduced when extractable Cu in the soil exceeded 19 µg/g (Graham *et al.* 1986). The soil Cu concentrations are higher than that determined in this study but Graham *et al.* (1986) used a double acid extraction (Mehlich 1953) which is now known to extract much higher amounts of Cu than DTPA or ETDA alone or in combination with non acid extractants (Brennan and Best 1999). Making conclusions about soil Cu by comparing different soil tests is problematic.

Plant concentrations of Cu are a more direct measure of Cu status of the crop than soil measures and this study shows high plant concentrations of Cu may have reduced yield. The lack of a significant correlation between soil Cu versus petiole Cu or yield means soil Cu data from this survey cannot predict petiole Cu or yield accurately as is possible with properly calibrated soil tests. Some improvements in this prediction in surveys can be made by accounting for differences in bulk density, pH, cation exchange capacity, organic matter or silt and clay % across sites (Dolar and Kenney 1971 and Osiname *et al.* 1973) which was not possible here apart from using pH. Consequently data from controlled experiments which calibrate soil Cu with plant Cu and yield are preferred for determining soil tests which provide target levels for deficiency and toxicity in the plant (Brennan and Best 1999).

It appears that the concentrations of other micronutrients such as Zn may contribute to reduced yield in combination with Cu at least in crop 1. Zn is also a component of fungicides (mancozeb) and it is possible overuse could occur similar to Cu.

There was a trend towards lower yields with increasing Zn rather than Cu concentrations in crop 2. However low yield could be explained by high Cu concentrations decreasing Fe concentrations in petioles at least in sample 3. This negative interaction between Cu and Fe has been reported before in potatoes (Gupta *et al.* 1995). Thus visual symptoms of Fe deficiency in leaves induced by high Cu are sometimes evident on crops. A negative interaction between Cu and Zn concentrations in petioles which was expected was not found in either crop. By contrast the reduced yield with increasing Cu concentrations in crop 1 was associated with increasing Zn concentrations.

The association of higher yield with higher soil Ca and Mg concentrations in crop 1 may suggest higher soil pH decreases Cu and Zn concentrations in the plant and improves yield. However there was no significant correlation between high yield and high pH in either crop although there was a non-significant trend towards higher yield with higher pH in crop 1. Amendments to increase soil pH maybe useful in lowering copper and zinc levels in crops and should be examined further.

Diseases

Several diseases affected the potato crops during each crop and these are discussed separately below. First though, the significant effect in crop 2 where an inability to identify disease was related to low yield is discussed.

Inability to identify disease may be related to low yield

Table 16 shows that for crop 2 there was a significant relationship between low yield and inability to identify disease. 20% of crop 2 LYQ growers couldn't identify the disease affecting their crop while no growers in the HYQ had this problem. The converse is easier to discuss. On several occasions, especially from crop 2, the HYQ reported higher disease incidences than those of the LYQ (Table 16). Although this appears contradictory it can be explained by the higher yielding growers being better at disease identification than the LYQ growers. With greater disease identification skills it is possible that the HYQ farmers will be able to control the diseases more efficiently and effectively than the LYQ growers and thus achieve higher yields. A similar result was found in Vietnam where the higher yielding growers reported more disease incidents than the lower yielding growers (McPharlin *et al*. 2003).

Fusarium

The presence of *Fusarium* spp. was associated with lower potato yields in crop 1, with the LYQ reporting a higher (67%) incidence of *Fusarium* spp. than the HYQ (27%) (Table 16). *Fusarium* spp. are known to cause dry rot and wilt of potatoes. *Fusarium* dry rot affects tubers in storage and seed tubers at planting, while the less common *Fusarium* wilt reduces the tuber yield and quality by affecting the plants vascular tissues (Stevenson *et al*. 2001). The sources of inoculum that cause *Fusarium* dry rot or wilt includes infected soil and contaminated seed tubers (Stevenson *et al*. 2001). There are several species of *Fusarium* that affect potatoes but the specific species or species that caused the yield loss in this study was not identified. However, previous studies by Velupillai and French (1983) found *Fusarium oxysporum* and *F. solani* associated with dry rot and wilt of potatoes in plantings at Kalpitiya and Jaffna, Sri Lanka. In addition *F. avenaceum* has been reported on medicinal plant species used in Sri Lanka (Fernando and Abeywickrama 1996).

A larger proportion of the LYQ (56%) used cut seed compared to the HYQ (18%) at planting (Table 11). Stevenson *et al*. (2001) indicate that infection of seed tubers occurs when *Fusarium* spores or propagules enter wounds made during seed handling and cutting. Therefore by cutting the seed without proper curing conditions, an entry wound for the *Fusarium* dry rot is provided which could affect crop yield. This is supported by Leach (1985) who found that daughter tuber contamination was greatest when non-treated cut tubers were used, whilst the lowest contamination occurred from whole non-treated seed.

Interestingly both the lower and higher yielding quartiles in crop 1 did not record any *Fusarium* dry rot in their seed (Table 9). It is known that *Fusarium* spp. infection of tubers can either develop rapidly or remain latent and therefore it is possible that the tubers did not begin to break down until after planting, especially if conditions during storage did not promote disease expression. Stevenson *et al*. (2001) indicate that some level of *Fusarium* dry rot is always present in commercially available seed. Furthermore, only 44% of the LYQ and 36% of the HYQ graded their seed before planting in crop 1 (Table 6). Hence, either the potato growers in crop 1 couldn't distinguish between *Fusarium* dry rot symptoms and other rots or the *Fusarium* dry rot began after planting from latent infections.

The presence of *Fusarium* dry rot was not significant in crop 2 but it was the HYQ (40%) that recorded a higher incidence than the LYQ (27%) (Table 16). Also in crop 2 a larger proportion of the HYQ (66%) used cut seed than the LYQ (46%) (Table 11). However, both the seed storage and seed preparation, were not significant in crop 2.

Early blight (Alternaria solani)

Early blight caused by *Alternaria solani* was another disease that was present in high numbers in the LYQ (67% and 60%, crops 1 & 2) and the HYQ (82% & 87% crops 1 & 2) of both crops (Table 16). Early blight is present in potato growing areas worldwide and has the potential to reduce yield by decreasing the leaf surface of the plant (Stevenson *et al*. 2001). The HYQ in both crops recorded more early blight than the LYQ and this difference was significant in the crop 2. We think this is an indication that the higher yielding growers are better at disease diagnosis, and therefore disease control, than the lower yielding growers. The possibility of fungicide resistance must also be considered. Farmers in Sri Lanka spray fungicides often, every 3 days in some incidences, for the control of diseases including early blight. Products such as mancozeb, Anthracol WP 70%™ (propineb), Previcur™ (propamocarb) and Trimiltox Forte™ (copper and mancozeb) are used for early blight control in Sri Lanka on both potatoes and rotation crops. Studies by Holm *et al.* (2003) and Pasche *et al*. (2002) found that continual use of chlorothalonil and azoxystrobin, respectively, on potato fields in the USA meant that isolates of *A. solani* were developing resistance over the growing season and over the longer term. This could be occurring in Sri Lanka with certain fungicides and hence it is possible that this is why the incidence of early blight was the second highest recorded, behind late blight, in both crops. Further work on the resistance of chemicals in Sri Lanka is required.

Late blight

Although the effect late blight (*Phytophthora infestans*) had on yield was not significant in both crops, based on numbers of growers that reported the disease and observations of the crops, late blight was the most damaging of potato diseases present in Sri Lanka. 89% of the LYQ and 72% of the HYQ reporting the disease in crop 1, compared with 67% of the LYQ and 80% of the HYQ reporting the disease in crop 2 (Table 16).

Experiments on the mating type of *P. infestans* in Sri Lanka revealed that although not common, the A2 mating type was present in two imported potato varieties at the Regional Agricultural Research and Development Centre, Bandarawela (Kelaniyangoda and Somachandra 2001). It was also determined that several pathotypes of late blight exist in the up country of Sri Lanka, including Bandarawela and Sita Eliya, and that these pathotypes are different from location to location and have changed over time (Kelaniyangoda and Somachandra 2001).

Fungicides have been screened in Sri Lanka for their effectiveness against *P. infestans* for several years and a spraying schedule was developed based on seasonal reports (Kelaniyangoda and Somachandra 2001). In late blight favourable conditions during the *Maha* season (Feb-Mar) in Badulla, two sprays of systemic fungicides and three contact/protective fungicides have been encouraged. In Nuwara Eliya, growers are encouraged to spray a minimum of two systemic sprays and three or more protective sprays. Although this was encouraged, during field visits to growers it was observed that growers were spraying more regularly with products such as mancozeb and metalaxyl, due to the severity of the late blight, which was seen to infect crops within a month of emergence. A recent trial has now found that spraying with mancozeb three times a week is providing better protection than previous schedules (George Babu, personal communication).

By spraying so often in the presence of both A1 and A2 mating types there is a strong possibility that the late blight strains present in Sri Lanka are becoming resistant to certain chemicals. With the A1 and A2 mating types, sexual reproduction can occur which would enable a greater genetic variability of *P. infestans* in Sri Lanka and a greater chance of fungicide resistance developing. Metalaxyl resistant isolates of *P. infestans* have been found in many places around the world, including Nepal (Ghimire *et al*. 2001), Scotland (Cooke *et al*. 2003) and Brazil (Reis *et al*. 2003). The development of resistance limits fungicide options and may even result in farmers wasting money through the application of expensive but ineffective fungicides. Studies on the resistance of late blight to fungicides are required in Sri Lanka. To initiate this work a set of agar plates containing various concentrations of metalaxyl was given to Agricultural Research Station, Sita Eliya researchers. This will allow them to perform preliminary tests to determine the metalaxyl resistance of *P. infestans* isolates found on potatoes in Sri Lanka.

The most common potato varieties grown in Sri Lanka are of European origin with Desiree accounting for 70% of plantings in the Badulla region and Desiree, Lyra, Granola and Escort being the most common in Nuwara Eliya (Kelaniyangoda and Somachandra 2001). With several pathotypes of late blight existing in Sri Lanka it is no surprise that the varieties most commonly grown in Sri Lanka are highly susceptible to late blight infection. Several varieties have been developed in Sri Lanka to be resistant to the late blight races that exist there, including Sita and Krushi, but these varieties are not popular with the farmers as they have a long growing period (Kelaniyangoda and Somachandra 2001). There is ongoing evaluation/screening of new potato clones obtained from CIP to the late blight races present in Sri Lanka. Recently a variety known as Hillstar was released which had moderate resistance to late blight (George Babu, personal communication).

Kelaniyangoda and Somachandra (2001) indicate that the destruction of infected crop residues, crop rotation and the avoidance of staggered cultivation are all commonly used cultural practices that are used in Sri Lanka to control late blight. However, although the main rotation crop in crop 1 was leeks and the main rotation crop in crop 2 was paddy (rice), we observed in the field that other solanaceous crops such as tomato (*Lycopersicon esculentum*) were often planted close to mature and emerging potato crops. This means that in Sri Lanka there is a large amount of late blight inoculum present all year round. This inoculum infects newly planted crops very early in the season and makes control difficult. Minimising the amount of initial inoculum is critical for late blight control (Stevenson *et al*. 2001). The ever-present inoculum also means that growers who do rotate their potato crops with non host crops are still likely to suffer infections even if the inoculum source is quite some distance away. In a study on the dispersal and release of late blight sporangia, Aylor *et al*. (2001) found that wind speeds of 1 to 2 m s^{-1} (3.6 - 7.2 km h^{-1}) are sufficient for a sizeable proportion of late blight sporangia to leave the potato canopy and be dispersed 10 to 20 km within 3 hours.

Weather conditions are a very important factor in the dispersal and severity of late blight. Sporangial germination occurs at temperatures of 18-24^{o}C, while production of zoospores occurs at 8-18^{o}C (Stevenson *et al*. 2001). Infections at optimal temperatures (18-22^{o}C) can became visible within 3 days and temperatures of 10-25^{o}C with wet conditions (prolonged surface wetness or 100% relative humidity) induce sporulation. As mentioned previously, the average weather conditions in both the Nuwara Eliya (crop 1) and Badulla (crop 2) are suitable for these events to occur. This means that in Sri Lanka repeated cycles of infection can occur rapidly. Hence controlling late blight is difficult in Sri Lanka with weather conditions so conducive for disease development.

Surface water is another condition that is conducive to the development of late blight epidemics. Porter and Johnson (2004) found that spores of *P. infestans* could survive in surface water for between 14 and 21 days and stated that avoidance of conditions that promote surface water would aid in the management of late blight. Potato growers in Sri Lanka often create fields that pool water as a result of the rotation of potatoes with paddy and other crops. Areas under potato cultivation also experience substantial soil erosion, with estimates of 15 tonnes/ha during the *Maha* and 9 tonnes/ha during the *Yala* seasons (Samarakoon and Abeygunawardena 1995), which would also lead to greater surface water in and around potato crops. Hence these condition in Sri Lanka are likely to promote the spread of *P. infestans* in the potato crop.

The presence of other pest and diseases in the potato crop also influences the effect late blight has on the crop and visa versa. Stevenson *et al*. (2001) mentions that late blight lesions in tubers allow soft rot bacteria, *Fusarium* spp. and *Phytophthora erythroseptica* to gain access to the tubers. This may explain why the LYQ, who reported higher late blight incidence, also reported higher *Fusarium* dry rot in crop 1 (Table 16). Leaf miner which has been a problem in potato crops in Sri Lanka (Table 15) is also known to provide an entry point for the infection of late blight (George Babu, personal communication). Furthermore, rodent damage to the HYQ in crop 1 was significant, and was present in crop 2 (Table 9). This damage could provide suitable wounds for late blight infections. Other diseases, be they bacterial or fungal, and pests may also be providing entry wounds on plants and tubers for late blight. Therefore controlling these diseases and pests may also aid late blight control in Sri Lanka. So to improve yields there is a need to train growers in integrated pest management (IPM) techniques to reducing pest and disease impacts.

Black leg

Similar levels of black leg were reported in both crops, none of which had any significant affect on yield (Table 16). Interestingly no grower in each crop reported any soft rot decay of tubers during the planting (Table 16) and very little was recorded in the seed (Table 9). Black leg and soft rot are both caused by *Erwinia* spp. which are known to remain symptomless (latent) until the conditions favour disease expression. Therefore this may explain why only very little soft rot was recorded in the seed. Also it is known that the presence of other tuber diseases such as *Fusarium* dry rot and late blight often increases the incidence of bacterial pathogens by providing wounds through which they can invade (Stevenson *et al*. 2001). Both crops 1 and 2 recorded high levels of late blight and recorded *Fusarium* dry rot. Furthermore it is probable that in Sri Lanka with continual cropping and high rainfall there is an inherent level of bacteria in the soil. Pérombelon and Hyman (1989) found low levels of *Erwinia* spp. in Scottish soils that had not been cropped for 16 months and found that populations increased after cropping with brassicas. Pérombelon (2002) also indicated that prolonged periods of irrigation/rainfall that lead to high soil water levels also promotes black leg in potato crops.

Rhizoctonia

Rhizoctonia solani was present in similar numbers in the LYQ and HYQ of both crops (Table 16). Based on the proportion of growers that recorded *Rhizoctonia* in both crops it does not appear that *Rhizoctonia* causes large yield losses of potatoes in Sri Lanka. It was however expected that the growers in Nuwara Eliya (crop 1) would experience more *Rhizoctonia* than the growers in Badulla (crop 2) as a result of cooler temperatures. The average temperature in the Nuwara Eliya potato growing region of Sri Lanka is 15-20°C with an annual rainfall of 2,250 mm. The Badulla region, at lower altitude, experiences warmer temperatures of 18-25°C with an annual rainfall of 1,729 mm. Stevenson *et al*. (2001) indicate that soil temperatures above 21°C will minimise the damage caused by *R. solani,* even when high levels of inoculum are present. They report that low temperatures maximise *Rhizoctonia* damage, even where low fungal populations exist. However, it is possible that the growers in crop 1 controlled the disease through the use of bleaching powder as a soil additive (Table 17). Virk *et al*. (1979) found that the use of bleaching powder on cut potato seed gave some control of *Rhizoctonia* in India.

Bacterial wilt

The incidence of bacterial wilt (*Ralstonia solanacearum*) was low for both the LYQ and the HYQ in both crops 1 and 2 (Table 16). However, the HYQ in crop 1 did record a greater incidence of bacterial wilt than the LYQ, which was not expected, as a higher proportion of the HYQ used bleaching powder (Table 17) and the effect was nearly significant (P=0.13). Studies in India by Kishore *et al*. (1996) and De & Sengupta (1992) found that the use of disease free seed and the application of bleaching powder during planting reduced the inoculum of bacterial wilt. Both the LYQ and the HYQ in both crops did not record any or very little bacterial wilt in their seed prior to planting (Table 9) and therefore the infection source of bacterial wilt in Sri Lanka comes from the soil. It is possible that the HYQ in crop 1 recorded more bacterial wilt than the LYQ because the HYQ are more accurate in diagnosing between *Fusarium* wilt and bacterial wilt. Bacterial wilt could therefore be greater in the LYQ but the growers are confusing this wilt with that of *Fusarium* wilt, which the LYQ of crop 1 found in high proportions (Table 16). Furthermore, Velupillai and French (1983) state that bacterial wilt is constantly present in the paddy lands of the Badulla region and this explains the presence of bacterial wilt in crop 2.

The low levels of bacterial wilt found in this study could also result through the control of nematodes. Root knot nematodes are known to have a synergistic relationship with bacterial wilt and therefore increases its severity on potato crops (Stevenson *et al*. 2001). Managing the populations of nematodes will hence reduce the incidence and severity of bacterial wilt. With similar proportions of growers in each crop using chemicals to control nematodes (Table 18) it is not surprising therefore that the levels of bacterial wilt is also similar between the crops.

Pests

Insects

Cutworm

The presence of cutworm had a significant negative correlation with yield, with 100% of the HYQ recording cutworm compared to 67% of the LYQ in crop 1. Although not significant, a high proportion of the LYQ (80%) and the HYQ (87%) in crop 2 also reported cutworms (Table 15). The reason the HYQ reported more cutworms than the LYQ may be because the HYQ could be better at identifying the symptoms of cutworm, both foliage and stem, than the LYQ. This idea is supported by the finding that 11% of the LYQ in crop 1 and 7% of the LYQ in crop 2 reported that they did not know what insect caused the damage to their potato crop, whereas all of the HYQ knew the insect that caused the damage in their crops (Table

15). Cutworms are also major pests of rotation crops such as cabbage, so it is likely that there is a high level present year round in Sri Lankan agricultural fields.

Mites

The presence of mites was significantly associated with higher yields in crop 2 (Table 15). Mites are not considered to be a serious pest of potatoes in Sri Lanka, but they are considered a serious perennial pest of tea plantations. Danthanarayana and Ranaweera (1970) indicated that the control of mites in tea crops in Sri Lanka was economically worthwhile. Hence as potatoes are grown close to tea crops in Sri Lanka it is likely that the mites found on the potatoes in crop 2 moved from the surrounding tea plantations. It appears that the mites are not yield limiting because more were reported by the higher yielding growers. Alternatively the identification of this small, cryptic pest could be an indication of farmers with superior pest identification skills. These farmers are then able to apply better pest management, as discussed under cutworm and the inverse relationship between disease prevalence and yield.

White grubs

In both crops, white grubs were associated with lower yields, significantly in crop 2 (Table 15). White grubs are the larvae of scarab beetles, which are very destructive on a wide variety of hosts, including potatoes. White grubs are known to eat the roots of potato plants and damage the tubers, which leads to a reduction in quality and yield. Interestingly, both the HYQ and the LYQ in crop 2 used carbofuran (Table 18) and other chemical seed treatments (Table 13) before planting. Also, the majority of growers in crop 2 rotated their potato crops with paddy, which would reduce the level of soil insects, including white grubs, prior to the potato crop being planted. Hence although the LYQ are using similar control measures as the HYQ it is possible that the LYQ are not applying the insecticides at the correct rates or time to ensure adequate control.

Leaf miner

Leaf miner was another pest that was recorded in high proportions in both the LYQ (78% and 60%) and the HYQ (45% and 33%) but this was not significant in both crops (Table 15). The leaf miner, *Liriomyza huidobrensis*, was recorded in Sri Lanka for the first time in 1997 and has been associated with potato crop losses of 100% in some areas (Nugakiyada 2000). When first accounted in Sri Lanka, farmers sprayed their potato crops with insecticides and other chemicals such as chlorine, lime and kerosene oil in an attempt to control it (Nugakiyada 2000). However, Braun and Shepard (1997) indicate that *Liriomyza* species tend to be resistant to commonly used pesticides and fungicide use can lead to heavier infestations in subsequent seasons. Adding to the difficulty in controlling leaf miner is the fact that it is a polyphagous insect that attacks several crops including tomatoes, crucifers, carrots, beans and several commonly occurring weeds (Braun and Shepard 1997). Furthermore, it is known that damaged potato crops from leaf miner infection are more susceptible to late blight, including late blight resistant varieties (Nugakiyada 2000). Hence, controlling leaf miner is not only difficult in Sri Lanka but can also play an important role in increasing the impact of other pests and diseases.

Aphids

A large proportion of growers in both crops indicated that aphids were present on the sprouts during storage (Table 9). A lower proportion of growers in both crops reported aphids on their crops during planting (Table 15). As the majority of growers used phenthoate when the seed was in storage, it is likely that this reduced the numbers of aphids present prior to planting. Plus with the continual use of other chemical insecticides during the crops, including neem (Table 19), the levels of aphids were kept minimal during this study. With only a small proportion of growers indicating that they had aphids on their crops it was also expected that the proportion of growers reporting viruses would be low (Table 16). Although the levels of viruses were low it was interesting to note that the majority of growers in crop 1 did not rogue their crops for viruses, whereas the majority of growers in crop 2 did (Table 14). Encouraging growers in Sri Lanka to rogue potato crops for diseased plants will help increase yields.

Does neem use increase insect damage compared with synthetic chemical use?

Apart from cutworm, a greater proportion of the LYQ reported problems with every insect than the HYQ in crop 1 (Table 15). An explanation might be that although similar proportions of the LYQ and HYQ used phenthoate (Table 12) and other chemicals (Table 13) prior to planting for insect control, only 56% of the LYQ used chemicals at the time of planting, compared to 82% of the HYQ (Table 19). The differences in insecticides used at planting is most likely a result of costs with the cheaper, more environmentally friendly, neem being preferred by the LYQ over the more expensive synthetic chemicals. Neem however is not an as efficient insecticide as other insecticides on the market. Viji and Bhagat (2001) compared neem products with synthetic insecticides on black cutworm (*Agrotis ipsilon*) in India, and found that although neem provided good protection and higher yields than the control, the synthetic insecticides resulted in higher yields and less plant mortality. Only a small percentage of growers in crop 2 used tea waste as an insecticide, the remainder used chemicals (Table 19), and they achieved significant higher yields than crop 1.

Nematodes

The majority of growers in both the LYQ and HYQ of the surveys used carbofuran as a nematicide but this did not have a significant effect on yield (Table 18). Carbofuran is a non-fumigant nematicide from the carbamate group and is known to control several genera of nematodes, including cyst nematodes (Whitehead 1998). A previous study by Hirata *et al.* (2000) found 15 genera and nine species of plant parasitic nematodes associated with vegetables, fruit trees and ornamental plants in Sri Lanka. In trials by Lamberti *et al.* (1993) and Ekanayake and Jayasundara (1994) it was found that the use of carbofuran, as a soil applied nematicide, controlled root-knot nematodes *Meloidogyne javanica* and *M. incognita* and increased yields of tomatoes in Sri Lanka.

Potato cyst nematode (*Globodera rostochiensis*) was first discovered in Sri Lanka in 1990 from soil samples taken from Nuwara Eliya (Ekanayake 1990). A survey of the major potato production areas of Sri Lanka in 1991 by Toida and Ekanayake (1992) revealed that *G. rostochiensis* was restricted to the Nuwara Eliya region after presumably being introduced from imported seed potatoes around 1984. Further studies have identified the pathotype of *G. rostochiensis* in Sri Lanka to be that of Ro1 (Mangalika Nugaliyadde, personal communication). Monitoring and sampling of PCN is conducted at the Agricultural Research

Station, Sita Eliya on a regular basis. Seed potato farms in Nuwara Eliya are taking biosecurity precautions to exclude PCN.

7. Technology Transfer

This project was planned as a first stage in the development of best management practices for Australian seed potatoes in Sri Lanka. If the project continues the next stage would involve experimental work and later a technology transfer stage would demonstration the best management practices that had been developed. Nevertheless this project did involve technology transfer related to the participation of the farmers in the survey in both crops. This involved regular visits of CIC staff to each site before planting to take measurements and collate answers to survey questions on agronomic practices and on a weekly basis after planting to take measurements. DAWA staff visited prior to commencement of the project to plan the surveys and during each of the cropping cycles. In addition DAWA staff visited after the surveys were completed to get feedback from growers particularly on major limits to yield. Staff of Agricultural Research Station, Sita Eliya were involved in disease and pest identification.

Feedback from growers included:

- Information that yield had declined markedly since the 1970s in both cropping regions.
- Good quality seed was critical in producing high yields.
- Imported seed was an important source of high quality seed.
- Control of diseases and pests especially late blight and leaf miner was fundamental to successful potato production.
- The information that, on the sites identified with high copper levels, poor emergence was a noticeable problem.

Information from this project that is of importance to Sri Lankan farmers includes:

- Different agronomic practices in the survey crops meant yield varied from 2.4 to 6.0 times. This indicates that there is potential for the lower yielding sites to improve productivity through sharing information with the better performing farmers. The CIC file officers will be in a good position to identify high yielding and influential farmers.
- Even the best yields in each region (26 t/ha) were below 'potential' of at least 40 t/ha. This indicates that further research on constraints to production may have the potential to increase yields of even the high yielding farms.
- Overuse of micronutrients appears to have contributed to yield decline and this is now an important sustainability issue for the potato growers. A combination of high quality seed and good agronomic practices will be essential if yields close to their maximum potential are to be realised.

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8. Recommendations

This project aimed to determine the constraints to potato production in Sri Lanka. We were able to identify by a survey of 2 cropping periods several factors that had a significant effect on yield. Future work should test these findings experimentally to determine whether best management practices can be developed to overcome these constraints.

The finding that copper and possibly zinc concentrations may reduce potato yield requires experimentation to determine methods to reduce copper and zinc uptake by the potato crop. Also there is a need to determine the sources that have lead to the high copper and zinc concentrations in the soil. Soil amendments such as lime could be tested. At the same time disease control methods which deliver less copper to the crops could be investigated.

The finding that sprinkler systems affect yield should be investigated further. Different systems could be compared and the benefit/cost for each system could be determined.

We found that accurate pest and disease identification may be vital if farmers are to improve the yield of their crops. Appropriate training courses should be developed to enable farmers to improve their identification skills.

Sowing date appeared to influence yield. This should be investigated further to determine what factors are causing the yield decline. Planting all crops at the optimum time for yield may result in supply exceeding demand and the relationship between supply and demand and price needs to be investigated to determine how to tackle this issue.

The frequent use of chemicals to control late blight will result in resistant strains developing. There is a need to introduce IPM systems to potato production in Sri Lanka to delay the onset of strains of late blight resistant to currently used fungicides.

The survey to identify yield constraints in new markets has been successful. This shows that our methodology has merit and is a sound way to identify which agronomic areas require improvement if Australian seed potatoes are to perform to their potential in new export markets. We have found that survey work was strongly supported by our in-country partners in Sri Lanka and Vietnam (McPharlin *et al*. 2003). This leads to the development of mutually beneficial partnerships.

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Abbreviations

°	degrees
B	boron
C	Celsius
Ca	calcium
CIC	Chemical Industries Colombo
Cl	chloride
Cu	copper
cv.	cultivar
DW	dry weight
Fe	iron
G	generation
h	hour
ha	hectare
HAL	Horticultural Australia Ltd
HYQ	highest yielding quartile
K	potassium
LYQ	lowest yielding quartile
m	metres
Mg	magnesium
mg	milligram
Mn	manganese
N	nitrogen
Na	sodium
NH_4-N	ammonium nitrogen
ns	not significant
P	phosphorus
P	probability
pH (H_20)	acidity (measured in a solution of water)
R^2	regression coefficient
Rs	Sri Lankan rupee
S	sulphur
t	tonne(s)
t/ha	tonnes per hectare
WA	Western Australia
µ	micro
wt	Weight
Zn	zinc

Appendix 1. Survey questionnaire

SURVEY QUESTIONAIRE

Formatted: Bullets and Numbering

Soil

1) Site Number?
2) Date when soil sampled?
3) What is the slope of the land? …………………. (Gradient)

4) What is the soil depth? ………….. (Measure)
   3 sites to 40 cm

5) Soil Analysis

Collect 20 sub-samples of soil 0-15 cm from each site. Bulk together to give a single sample for analysis for each site.

5.1 Soil structure analysis

5.2 Nutrient analysis

Formatted: Bullets and Numbering

NUTRIENT	VALUE	UNITS
pH		
N-total		
NO_3-extractable		
NH_4-extractable		
P		
K		
Mg		
Ca		
S		
Na		
Fe		
Mn		
Ca		
Zn		

AGRONOMIC PRACTICES

6) How many years have you grown potatoes?

7) Where did you learn to grow potatoes?

   1. Father or family
   2. Self taught
   3. Formal training

4. Other (specify)

8) From which country did your Seed come?
   1. Holland
   2. Germany
   3. United Kingdom
   4. U.S.A.
   5. Australia
   6. India
   7. Sri Lanka (local)
   8. Other

9) Who was the supplier?
   1. Own Seed
   2. Other (specify)

10) If own Seed, how many season have you kept the Seed?
   1. Previous season
   2. 2 seasons
   3. >2 seasons

11) What was the generation of the seed? Give number

12) Why did you buy this seed?
   1.Price
   2. Country of origin
   3. Variety
   4. Availability
   5. Previous experience
   6. Other (specify)

13) What was the price of the seed? …………... Rs/kg

14) Did you grade the Seed before planting?
   1. Yes
   2. No

15) If yes, what did you do?
   1. Cut large tubers
   2. Plant small tubers at higher density

3. Discard bad Seed. % discarded …………%?

16) Will you rogue the crop during the growing season?

1. Yes
1. No

17) What criteria will you use to select tubers to retain for seed?

1. Size
2. Appearance (Disease/Damage)
3. Size & Appearance

18) How was the Seed stored?

1. Boxes in store
2. Net bags in store
3. Other (specify)

19) How long was the Seed stored before planting? ………… weeks

20) Was the Seed damaged by pests and disease in storage? If so, name them

1. No
2. Soft Rot
3. Dry Rot/*Fusarium*
4. Bacterial Wilt
5. Mealy Bug
6. Tuber Moth
7. Aphids on Sprouts
8. Rodents
9. Shrinkage

21) Was the Seed treated with fungicide, insecticide or rodenticide in storage? If so, name them

1. No
2. Phenthoate
3. Pyrimiphos Methane
4. Other (specify)

22) Estimate number of sprouts per tuber

23) How long were the sprouts? ………….. cm

Appendix 1. Survey questionnaire

PLANTING

24) Was the Seed treated with a chemical at planting? If so, name them

1. No
2. Carbendazim
3. Thiram
4. Captan
5. Other (specify)

25) What depth was the Seed planted? ………… cm

26) What was the spacing?

Within the row? …………. cm

Between rows? …………. cm

27) What Seed size was planted?

…………. number per kg

28) What was the date of planting?

CROP ROTATION

29) How many crops were grown a year on this site ?

30) How many potato crops were grown a year on this site ?

31) What crops other than potatoes were grown on this site?

32) How far is the nearest crop of potatoes?

TILLAGE

33) What method of tillage was used prior to planting?

1. Plough and till by small tractor
2. Plough by small tractor and till by hand
3. Entirely by hand

34) How many times was the ground tilled?

35) How deep was the tillage?

1. 20 cm with machine
2. 12-15 cm by hand
3. Other

PEST & DISEASE CONTROL

36) What soil treatments were used for pest and disease control ?

1. None
2. Bleaching Powder
3. Formalin
4. Other (specify)

37) Were nematicides used to control nematodes before planting? If so, give names

1. None
2. Carbofuran
3. Other (specify)

38) What insects were problems in your potato crop?

1. Don’t know
2. Aphids
3. Cutworm
4. Thrips
5. Leaf Miner
6. Mites
7. White Grubs
8. Other (specify)

39) How were insects controlled prior to planting?

1. Neem
2. Tea waste
3. Tobacco waste
4. Chemical (specify)

40) What diseases were problems in your potato crop?

1. Don't know
2. Bacterial Wilt
3. Late Blight
4. Rhizoctonia
5. Soft Rot
6. *Fusarium*
7. Viruses
8. Early Blight
9. Black Leg
10. Scab
11. Other (specify)

41) Were weeds a problem in your crop?

42) How were weeds controlled before planting?

1. Round up (Glyphosate): Rate …………..
2. Gramoxone (Paraquat): Rate …………..
3. Other (specify)

43) How were weeds controlled after planting ? Specify

44) List names of fertilizers (e.g. Urea) and amendments (e.g. Dolomite, manure) applied both pre and post planting

DATE	NAME	RATE	UNITS	COMMENTS

45) What method was used to irrigate the crop ?

Appendix 1. Survey questionnaire

1. Furrow
2. Watering can
3. Furrow & Watering can
4. Sprinkler
5. Hose & Nozzle

46 How many times was the crop irrigated?

MONITORING CROP

To be done fortnightly until four sets of data have been collected.

3 single row plots, each 3 metres long are to be assessed. Plots to be chosen at random at each visit. Leaf analysis - Collect a total of 10 leaves at each visit. Tear off leaflets to leave petiole and rachis for analysis.

Monitoring growth & soil moisture

		PLOT 1	PLOT 2	PLOT 3
47)	Date of first visit :			
48)	Rainfall since planting (mm)			
49)	Number of plants			
50)	Number of stems			
51)	Canopy height (cm)			
52)	Is canopy cover 100% (Yes/No)			
53)	Length of longest tuber (mm)			
54)	Soil moisture (dry, wet, too wet)			
55)	Date of second visit :			
56)	Rainfall since planting (mm)			
57)	Number of plants			
58)	Number of stems			
59)	Canopy height (cm)			
60)	Is canopy cover 100% (Yes/No)			
61)	Length of longest tuber (mm)			
62)	Soil moisture (dry, wet, too wet)			
63)	Date of third visit :			
64)	Rainfall since planting (mm)			
65)	Number of plants			
66)	Number of stems			
67)	Canopy height (cm)			
68)	Is canopy cover 100% (Yes/No)			
69)	Length of longest tuber (mm)			

70)	Soil moisture (dry, wet, too wet)			
71)	Date of fourth visit :			
72)	Rainfall since planting (mm)			
73)	Number of plants			
74)	Number of stems			
75)	Canopy height (cm)			
76)	Is canopy cover 100% (Yes/No)			
77)	Length of longest tuber (mm)			
78)	Soil moisture (dry, wet, too wet)			

Appendix 1. Survey questionnaire

Insect Monitoring & Control

79) Insect Monitoring & Control

	PLOT 1	PLOT 2	PLOT 3
Date			
Insect			
Number per plant			
Severity (Light/Medium/Heavy)[1]			
Control applied by Farmer[2]:			
Date			
Insect			
Number per plant			
Severity (Light/Medium/Heavy)			
Control applied by Farmer:			
Date			
Insect			
Number per plant			
Severity (Light/Medium/Heavy)			
Control applied by Farmer:			
Date			
Insect			
Number per plant			
Severity (Light/Medium/Heavy)			
Control applied by Farmer:			

[1]For aphids > 20 per plant = Heavy, for leaf miner use published scale
[2]Describe chemical, number of applications and rate

Appendix 1. Survey questionnaire

	PLOT 1	PLOT 2	PLOT 3
Date			
Insect			
Number per plant			
Severity (Light/Medium/Heavy)[1.]			
Control applied by Farmer [2]:			
Date			
Insect			
Number per plant			
Severity (Light/Medium/Heavy)			
Control applied by Farmer :			
Date			
Insect			
Number per plant			
Severity (Light/Medium/Heavy)			
Control applied by Farmer :			
Date			
Insect			
Number per plant			
Severity (Light/Medium/Heavy)			
Control applied by Farmer :			

[1]For aphids > 20 per plant = Heavy, for leaf miner use published scale
[2]Describe chemical, number of applications and rate

80) Disease Monitoring & Control

	PLOT 1	PLOT 2	PLOT 3
Date			
Disease			
Number of plants affected			
Severity (Light/Medium/Heavy)			
Control applied by Farmer[1]:			
Date			
Disease			
Number of plants affected			
Severity (Light/Medium/Heavy)			
Control applied by Farmer:			
Date			
Disease			
Number of plants affected			
Severity (Light/Medium/Heavy)			
Control applied by Farmer:			
Date			
Disease			
Number of plants affected			
Severity (Light/Medium/Heavy)			
Control applied by Farmer:			

[1]Describe chemical, number of applications and rate

Appendix 1. Survey questionnaire

	PLOT 1	PLOT 2	PLOT 3
Date			
Disease			
Number of plants affected			
Severity (Light/Medium/Heavy)			
Control applied by Farmer[1]:			
Date			
Disease			
Number of plants affected			
Severity (Light/Medium/Heavy)			
Control applied by Farmer:			
Date			
Disease			
Number of plants affected			
Severity (Light/Medium/Heavy)			
Control applied by Farmer:			
Date			
Disease			
Number of plants affected			
Severity (Light/Medium/Heavy)			
Control applied by Farmer:			

[1]Describe chemical, number of applications and rate

Appendix 1. Survey questionnaire

81) Other Damage Monitoring & Control

	PLOT 1	PLOT 2	PLOT 3
Date			
Describe Damage			
Number of plants affected			
Severity of Damage (Light/Medium/Heavy)[1.]			
Control used by Farmer[2]:			
Date			
Describe Damage			
Number of plants affected			
Severity of Damage (Light/Medium/Heavy)			
Control used by Farmer:			
Date			
Describe Damage			
Number of plants affected			
Severity of Damage (Light/Medium/Heavy)[1.]			
Control used by Farmer [2.] :			
Date			
Describe Damage			
Number of plants affected			
Severity of Damage (Light/Medium/Heavy)[1.]			
Control used by Farmer [2.] :			

[1]Describe what was done

Appendix 1. Survey questionnaire

82) Harvest Date:

83) Why was this date chosen?

84) Weeks of growth left if crop harvested early:

85) Yield: weigh and record 5 single row plots, each 3 metres long

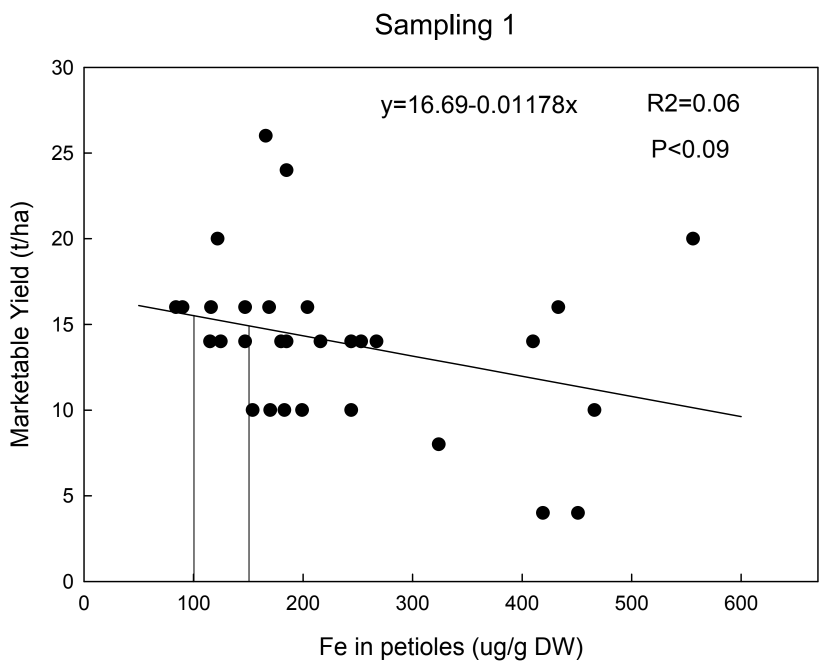
PLOT 1	TUBER GRADE	WEIGHT (g)	NO. OF TUBERS
1	< 30 mm		
	30-50 mm		
	>50 mm		
	Reject		
	Reason for most rejects *		
2	< 30 mm		
	30-50 mm		
	>50 mm		
	Reject		
	Reason for most rejects *		
3	< 30 mm		
	30-50 mm		
	>50 mm		
	Reject		
	Reason for most rejects *		
4	< 30 mm		
	30-50 mm		
	>50 mm		
	Reject		
	Reason for most rejects *		
5	< 30 mm		
	30-50 mm		
	>50 mm		
	Reject		
	Reason for most rejects *		

* Choose From: Diseased, Pest Damage, Mechanical Damage, Oversize, Other

Name of Evaluator:

…………………………………………………………….

Appendix 2. Additional Crop 1 data



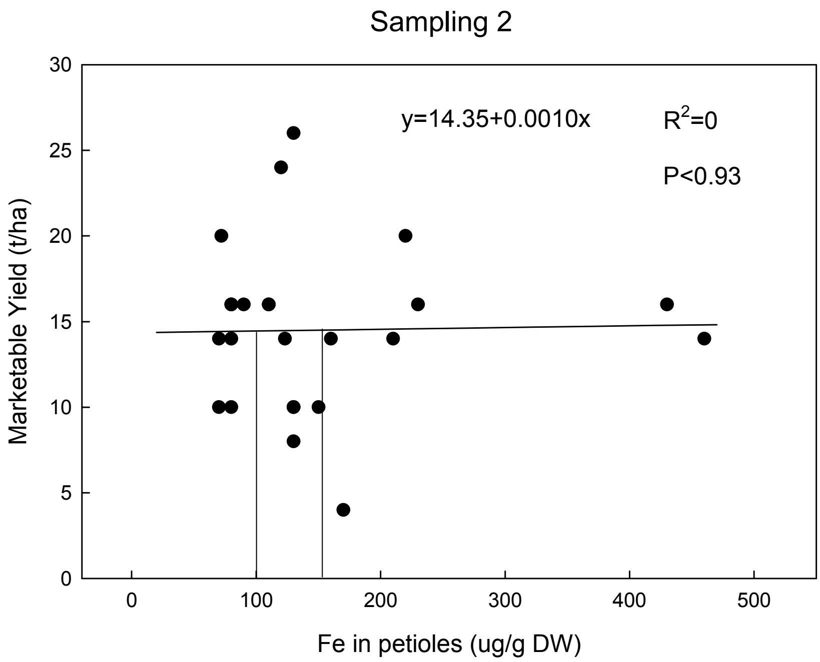
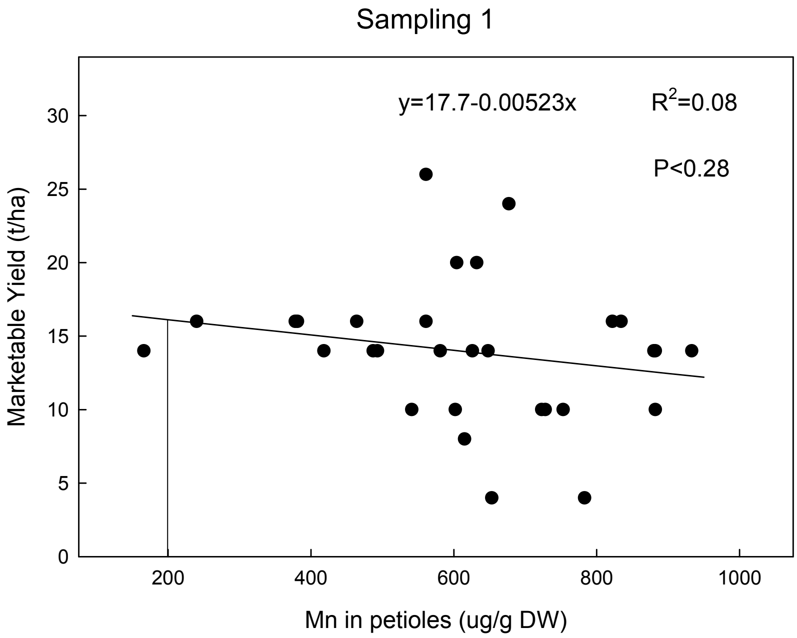


Figure 1. Fe in petioles (mg/kg DW) with yield at 2 sampling times. Vertical lines correspond to range of concentrations from minimum (< is deficient), left line, to maximum (> is toxic), right line at each time.

Appendix 2. Additional Crop 1 data



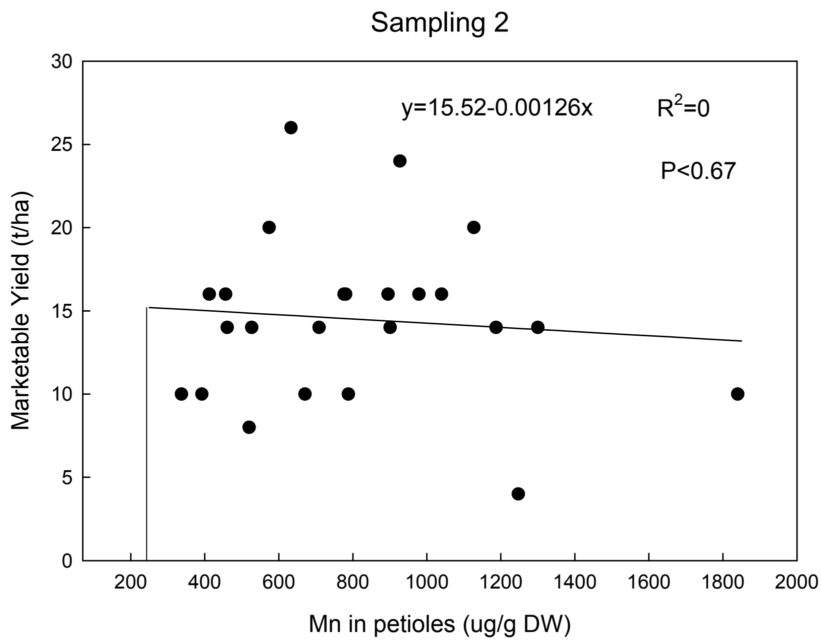
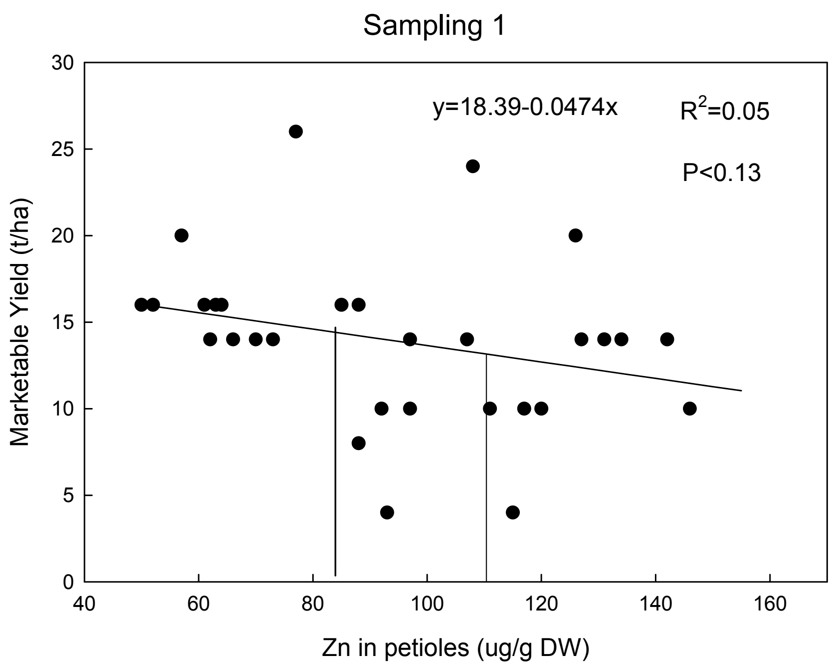


Figure 2. Mn in petioles (mg/kg DW) with yield at 2 sampling times. Vertical line corresponds to concentration above which toxicity may occur.

Appendix 2. Additional Crop 1 data



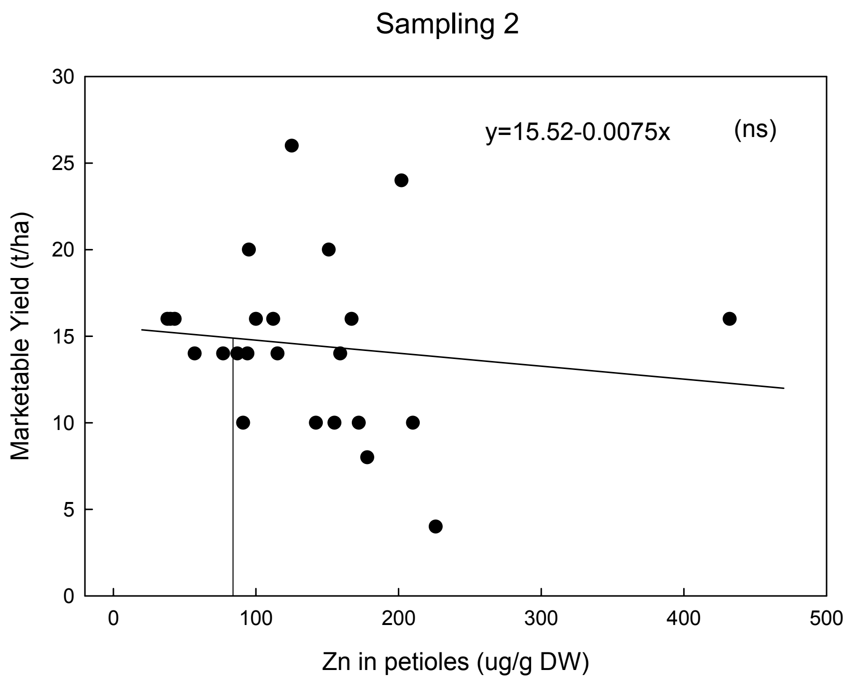
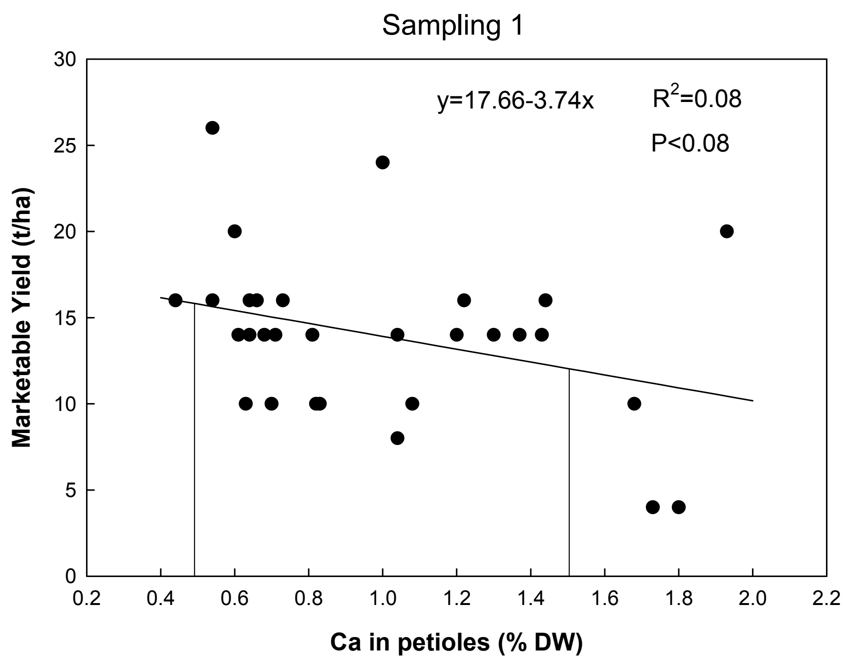


Figure 3. Zn in petioles (mg/kg DW) with yield at two samples time. Vertical line corresponds to concentration of Zn which maybe toxic.

Appendix 2. Additional Crop 1 data



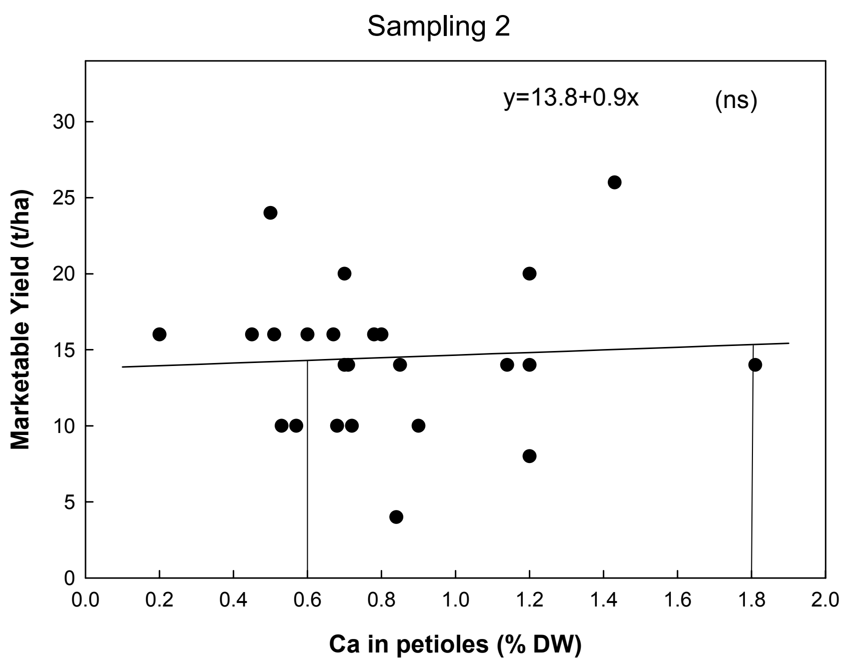
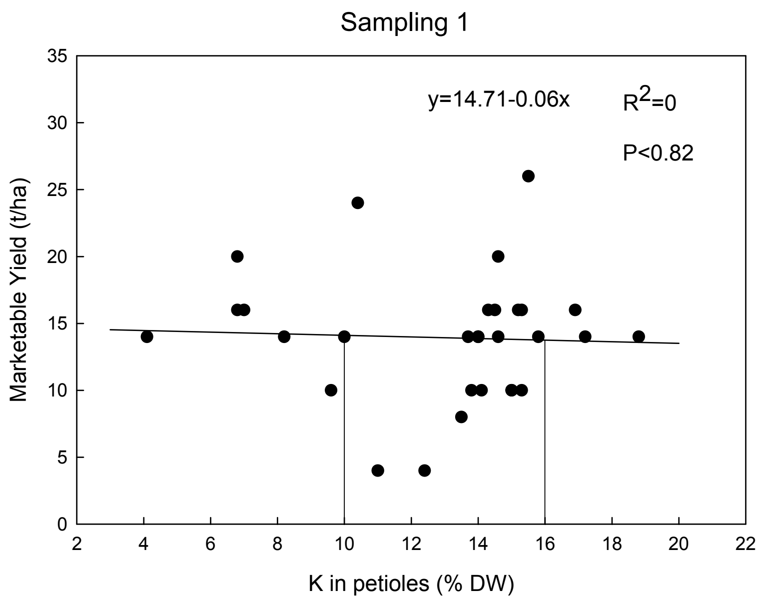


Figure 4. Ca in petioles (mg/kg DW) with yield at 2 sampling times. Vertical, lines correspond to range of concentrations from minimum (< is deficient), left line, to maximum (> is toxic), right line, at each time

Appendix 2. Additional Crop 1 data



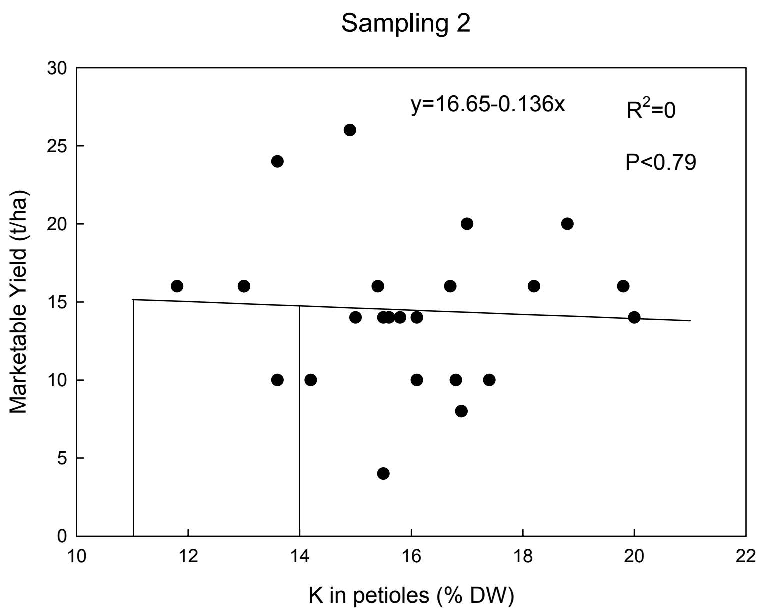
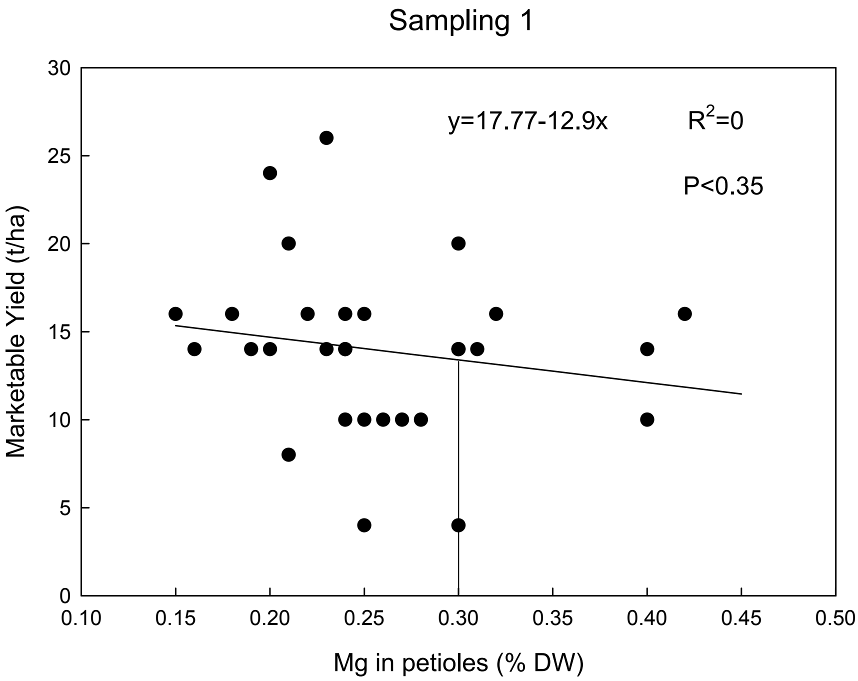


Figure 5. K in petioles (% DW) with yield at 2 sampling times. Vertical lines correspond to range of concentrations from minimum (< is deficient), left line, to maximum (> is toxic), right line, at each time

Appendix 2. Additional Crop 1 data



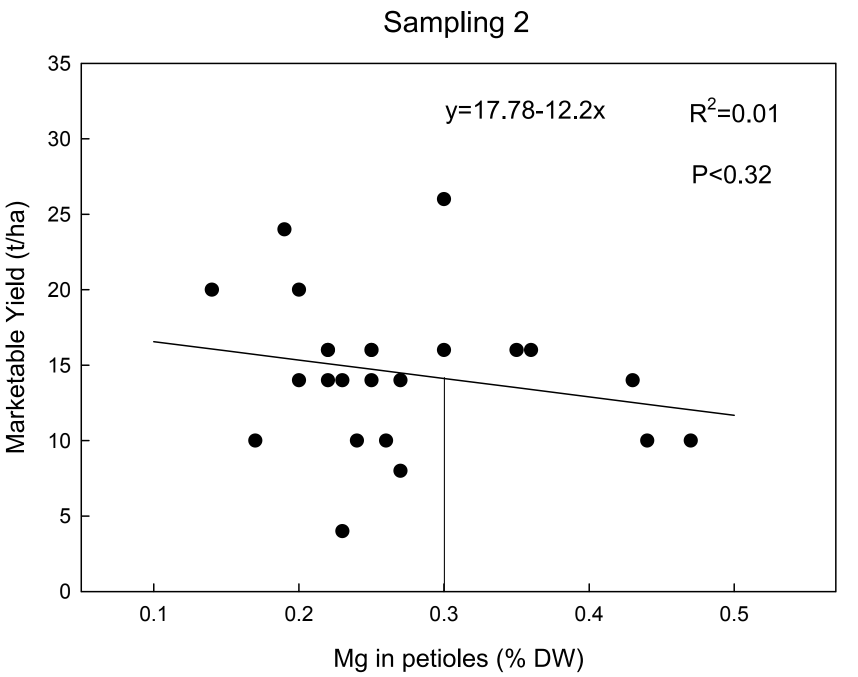


Figure 6. Mg in petioles (%DW) with yield at 2 sampling times. Vertical line corresponds to concentration below which deficiency may occur?

Appendix 2. Additional Crop 1 data

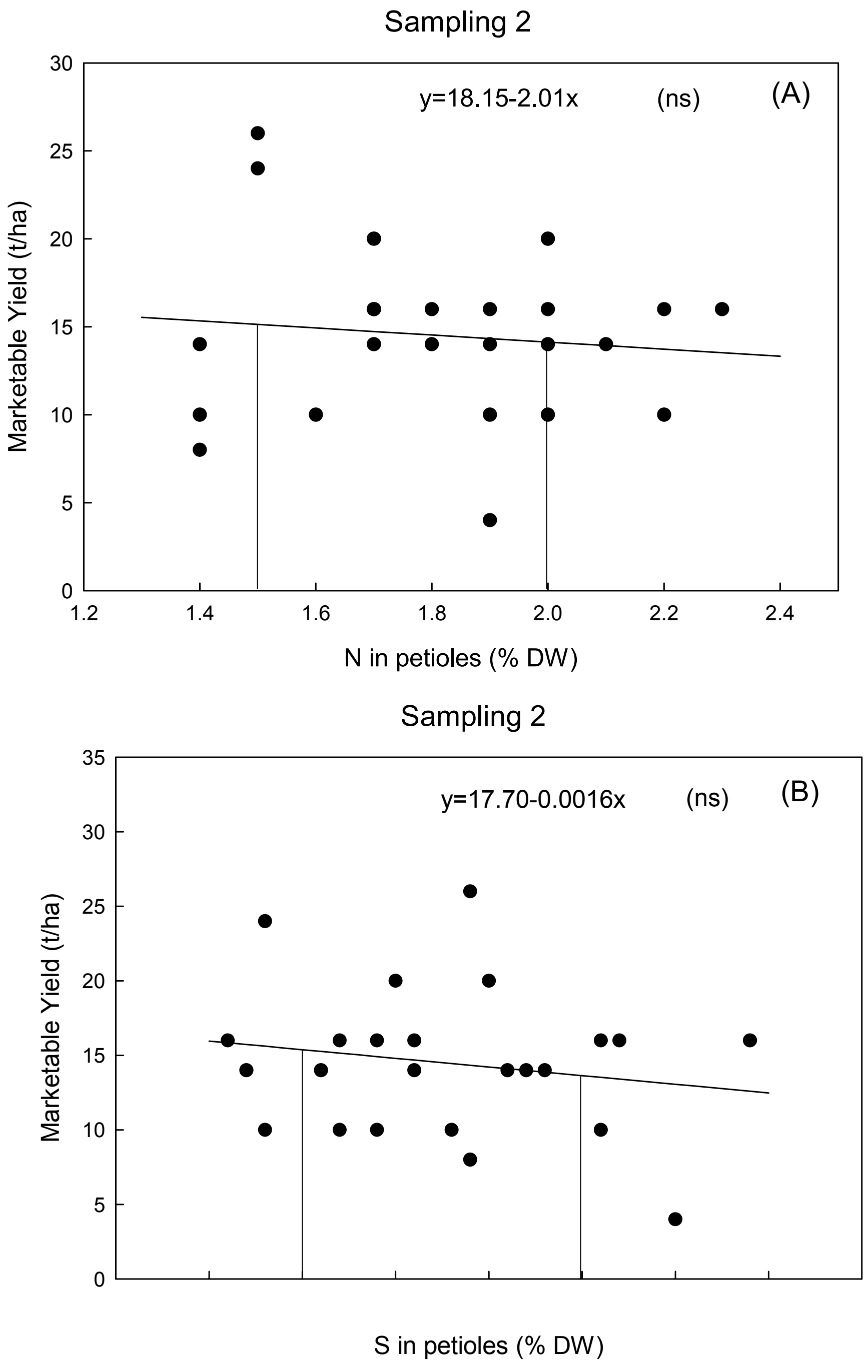
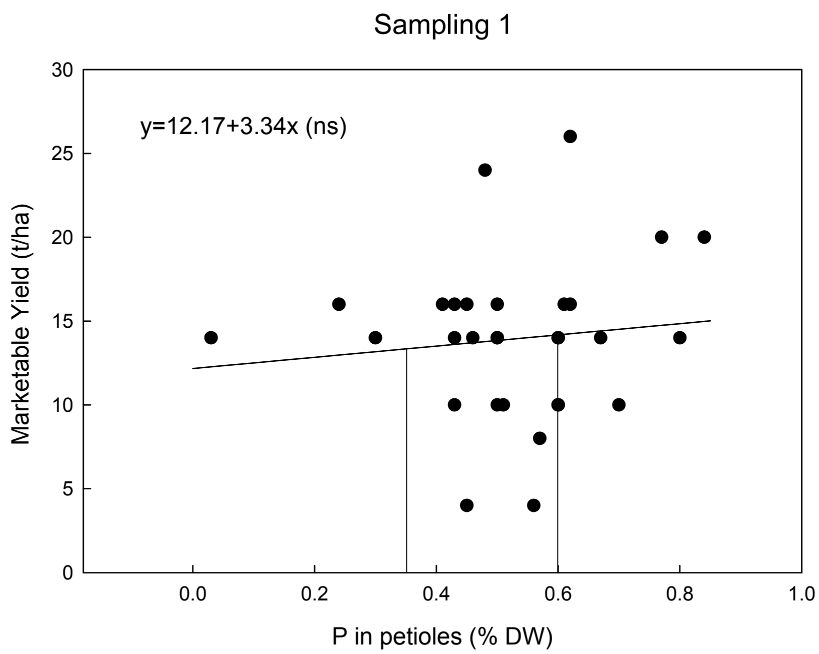


Figure 7. N (A) and S (B) in petioles (% DW) with yield at one sampling time. Vertical lines correspond to range of concentrations from minimum (< is deficient), left line, to maximum (> is toxic), right line, at each time

Appendix 2. Additional Crop 1 data



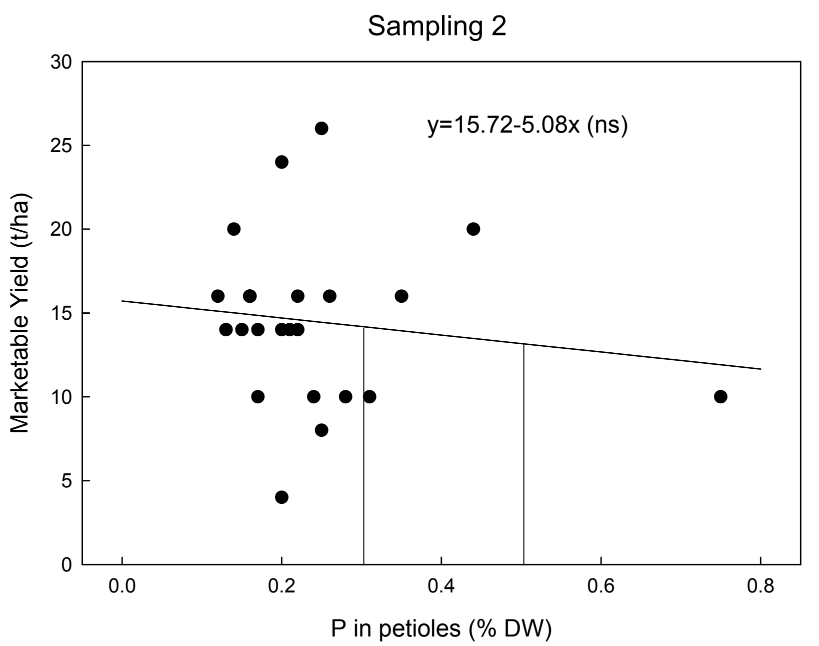


Figure 8. P in petioles (%DW) with yield at 2 sampling times. Vertical lines correspond to range of concentrations from minimum (< is deficient), left line, to maximum (> is toxic), right line, at each time

Appendix 3. Additional Crop 2 data

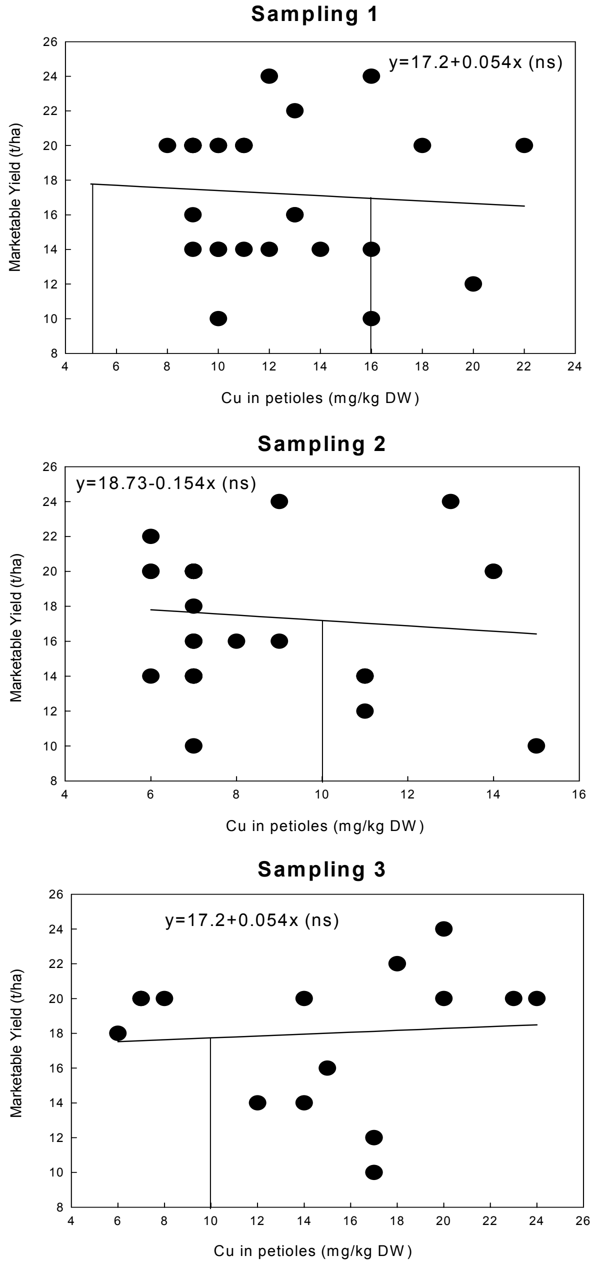


Figure 1. Cu in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to range of concentrations from minimum (< is deficient), left line, to maximum (> is toxic), right line (sampling 1) or for maximum (sampling 2 &3)

Appendix 3. Additional Crop 2 data

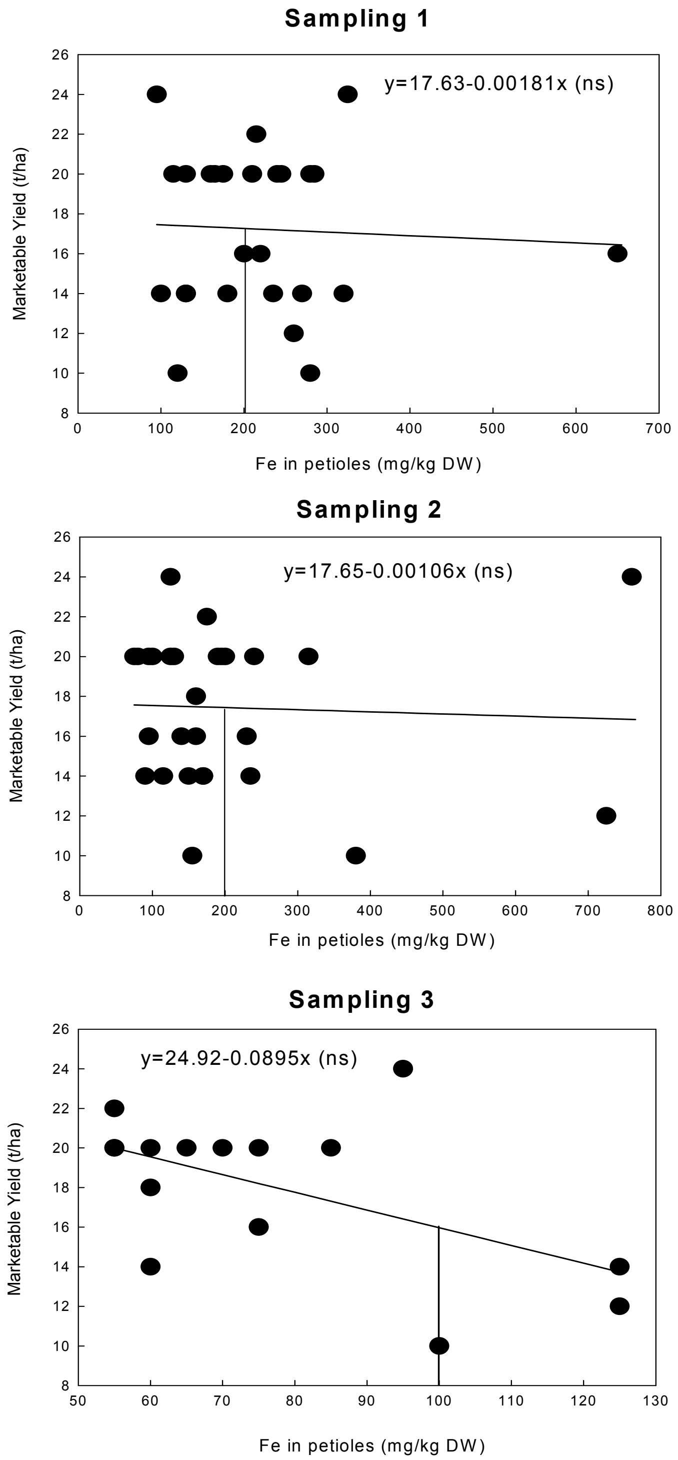


Figure 2. Fe in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to concentration considered a maximum (> is toxic) for sampling 1 &2 or a minimum (sampling 3).

Appendix 3. Additional Crop 2 data

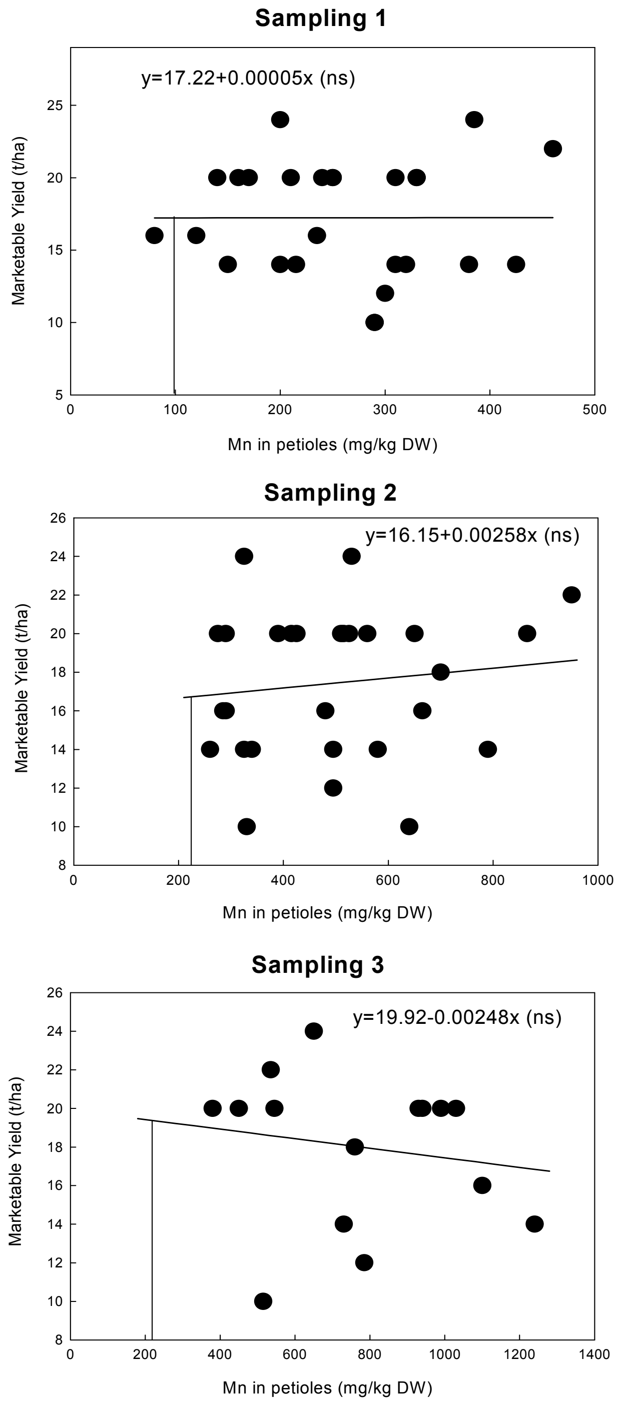


Figure 3. Mn in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to concentration considered a maximum (> is toxic).

Appendix 3. Additional Crop 2 data

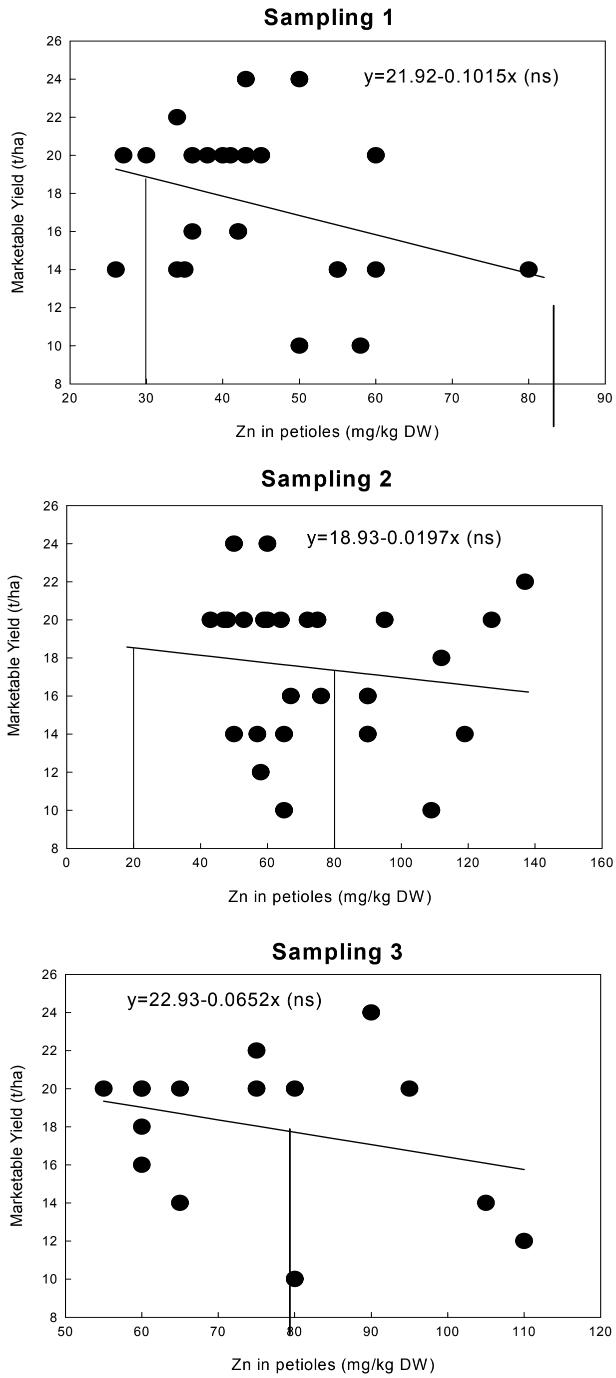


Figure 4. Zn in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to range of concentrations from minimum (< is deficient) left line, to maximum (> is toxic), right line (sampling 2) a minimum (sampling 1) or maximum (sampling 3).

Appendix 3. Additional Crop 2 data

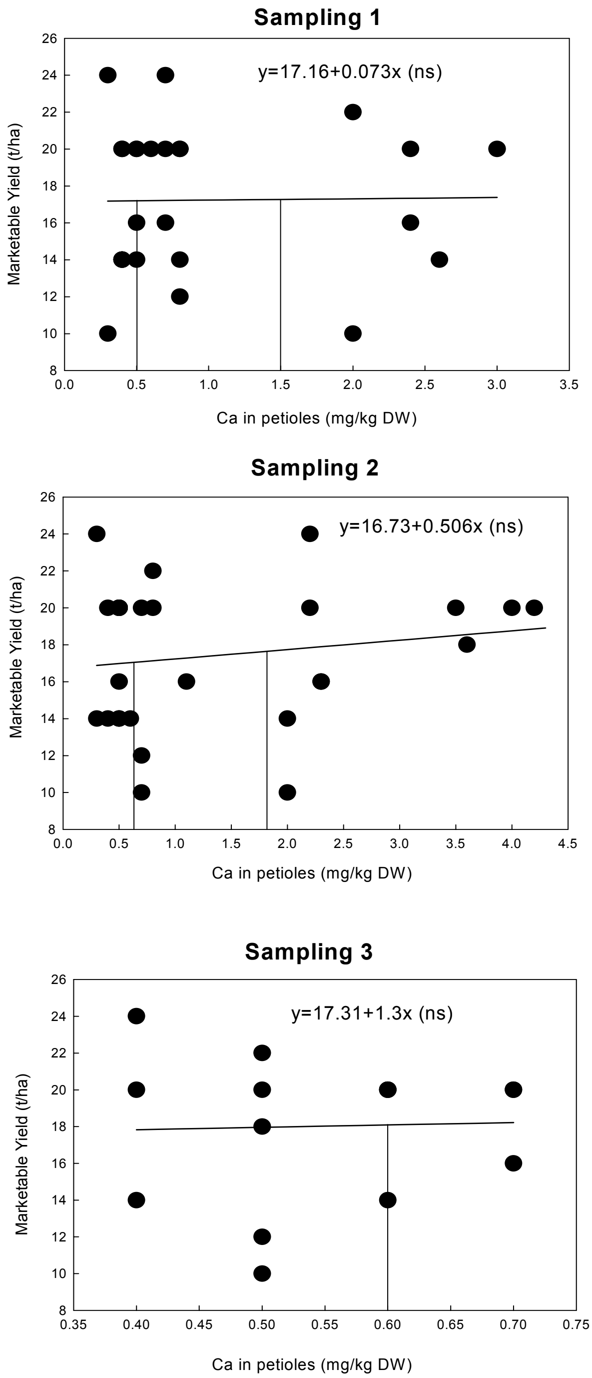


Figure 5. Ca in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to range of concentrations from minimum (< is deficient) left line, to maximum (> is toxic), right line (sampling 1 &2) or minimum only (sampling 3).

Appendix 3. Additional Crop 2 data

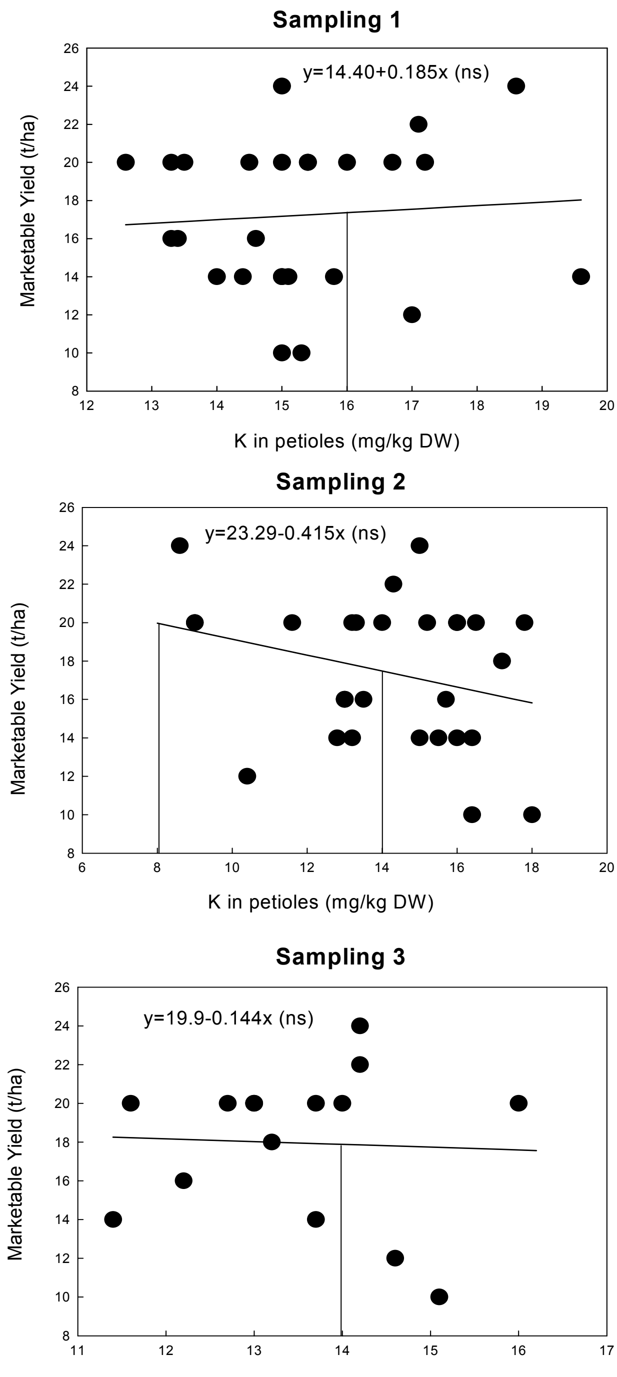


Figure 6. K in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to range of concentrations from minimum (< is deficient), left line, to maximum (> is toxic), right line (sampling 2) or maximum only (sampling 1 & 3).

Appendix 3. Additional Crop 2 data

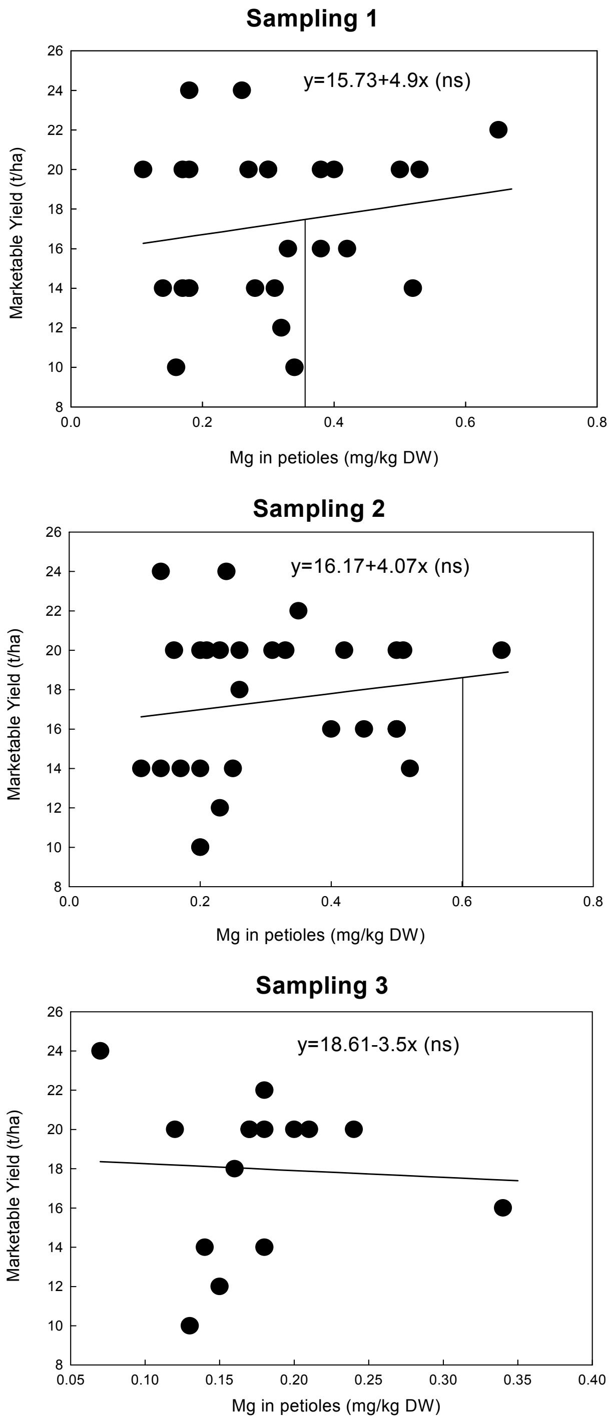


Figure 7. Mg in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to concentration considered a minimum (< is deficient) for sampling 1 & 2.

Appendix 3. Additional Crop 2 data

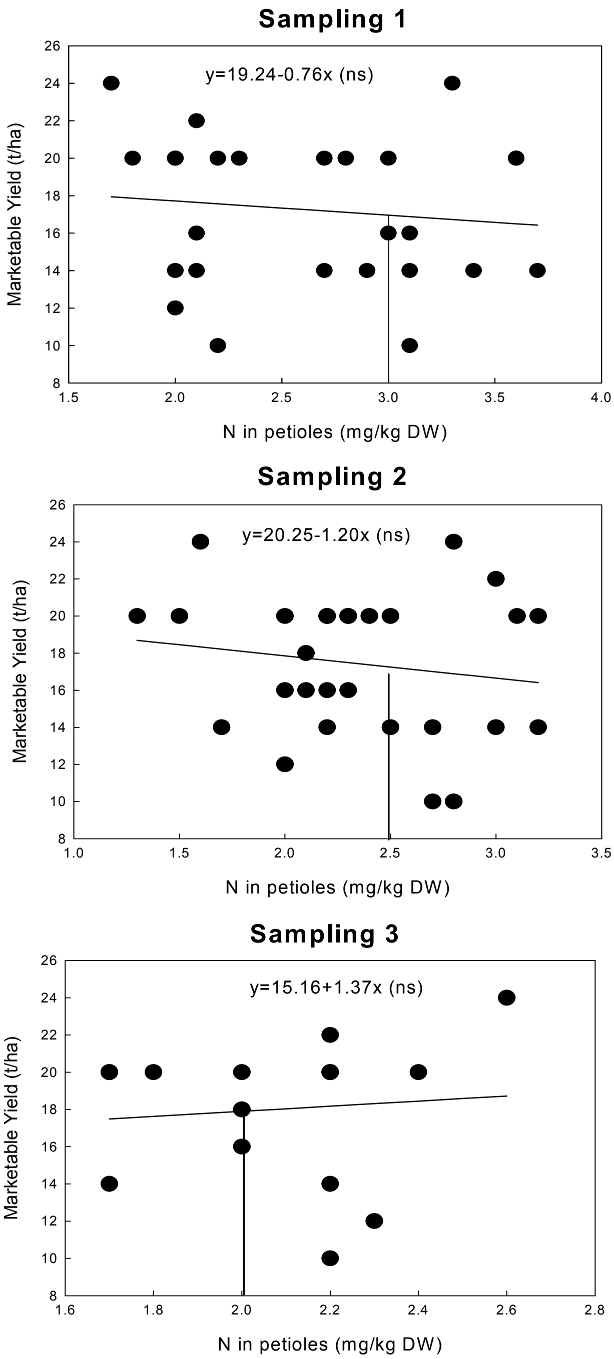


Figure 8. N in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to concentrations considered a minimum (< is deficient) at each sampling.

Appendix 3. Additional Crop 2 data

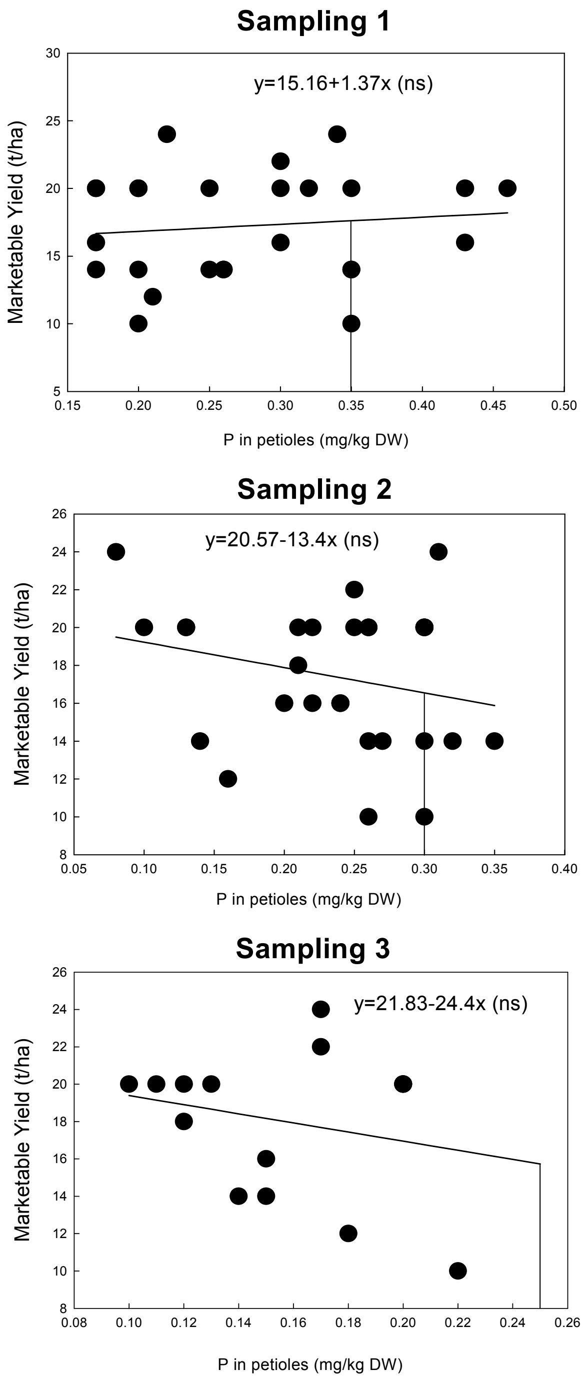


Figure 9. P in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to concentrations considered a minimum (< is deficient) at each sampling.

Appendix 3. Additional Crop 2 data

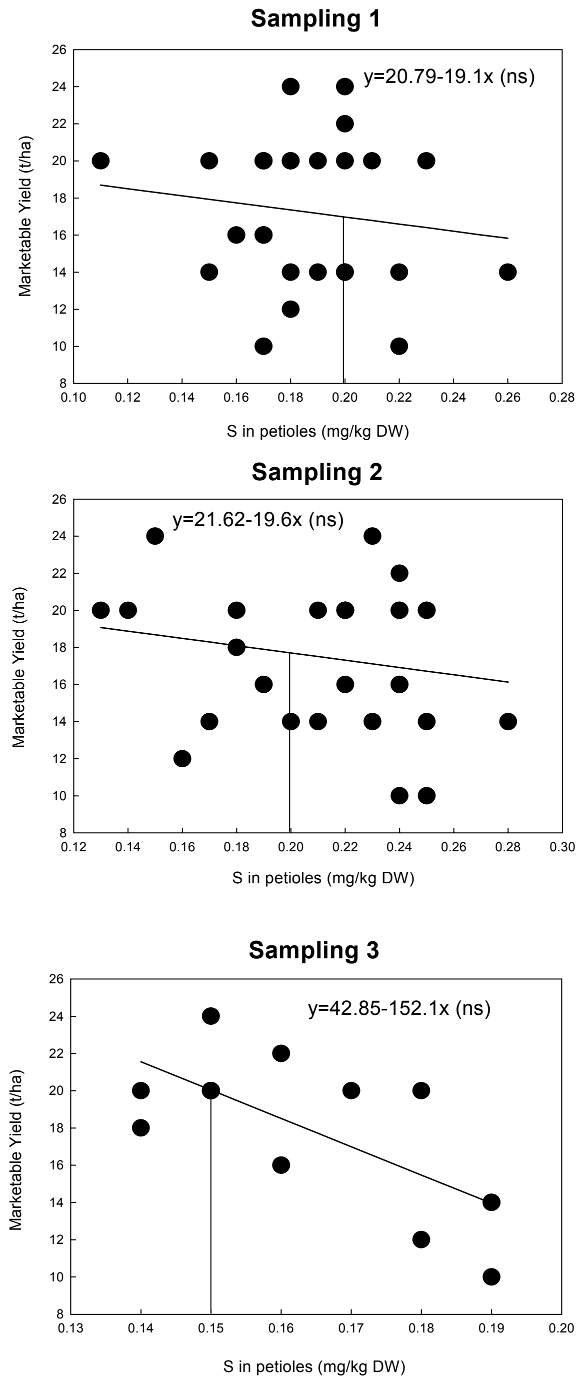


Figure 10. S in petioles (mg/kg DW) with yield at 3 sampling times. Vertical lines correspond to concentrations considered a minimum (< is deficient) at each sampling.

Appendix 4. Rotation data for Crop 1 & Crop 2

Table 1. Annual cropping sequences (rotation) used by growers in the year of the surveys. The number in each cell is the number of growers using the rotation for each crop and quartile. The number of different rotations used for each Quartile is shown as the Total of each column.

Cropping sequence	Crop 1			Crop 2	
	Quartile			Quartile	
	1	2	3	1	2
beet + leeks*, potato	1				
beet, leeks, potato			1		
beet, potato		1			
cabbage, cabbage, potato		1			
cabbage, potato, potato	1		1		
carrots, carrots, potato		1			
carrots, leeks, potato		1			
carrots, potato			1	1	1
carrots, potato, potato		1	1		
carrots, radish, potato			1		
leeks + carrots, potato		1			
leeks + carrots, potato, potato		1			
leeks, leeks, potato	4		2		
leeks, potato	1		2		1
leeks, potato, potato	1	1			
potato, fallow			1	1	
potato, potato		1			
radish, potato, potato	1				
radish, radish ,potato			1		
strawberry, potato		1			
cabbage, potato				3	3
paddy, potato				9	10
radish, potato				1	
Total	9	10	11	15	15

* + = interplanted crops, i.e. leeks + carrots = leek and carrot in one planting