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# *Paraquat resistance in black nightshade*

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This report presents data and conclusions based on several experimental trials within one season. Additional research is required to both substantiate these results and to allow their extrapolation. The application of agrichemicals should be undertaken with full cognisance of New Zealand laws and acceptable commercial practice.

# *Contents*

# 1 Executive summary

Paraquat resistance has been found in black nightshade (*Solanum nigrum* L.), a weed in kumara crops in the Dargaville–Ruawai region. The application rate of paraquat that caused 99% mortality of normal black nightshade seedlings was determined. Black nightshade seedling populations from the Dargaville–Ruawai region were tested using this diagnostic rate of 0.04 g ai/L. The populations were found to vary from relatively susceptible to paraquat through to highly resistant. Unguarded application of paraquat at concentrations required to kill resistant plants would cause significant damage to the kumara crop. A population of small-flowered nightshade (*S. americanum* Mill.) also proved highly resistant to paraquat applied at the diagnostic rate.

A field trial involving several alternative herbicides identified three products that controlled general weed growth while minimising crop damage: the two residual herbicides Sylon and Frontier, and the contact herbicide Organic Interceptor. Use of Sylon and Frontier resulted in no herbicide residues in harvested kumara roots A residue testing system for roots produced on plants exposed to Organic Interceptor is not generally available. The concentration of Organic Interceptor required to kill black nightshade seedlings with resistance to paraquat was explored in greenhouse trials. The 99% mortality concentration was approximately 52 g ai/L,

Additional research is required to determine:

- the degree of persistence of Organic Interceptor residues,
- the dynamics of crop development under Sylon applications, and
- the effectiveness of Frontier in soils with high levels of exchangeable cations.

# 2 Introduction

In recent years kumara (*Ipomoea batatas* (L.) Lam.) growers have noticed the emergence and increasing prevalence of a paraquat-resistant strain of black nightshade (*Solanum nigrum* L.) in fields within the Dargaville–Ruawai region. This is the first formal report of paraquat resistance within New Zealand weed flora. Based on advice in a well recognised growers' manual (Coleman 1972), the New Zealand kumara industry has been highly reliant on the herbicide paraquat for more than 33 years. Generally paraquat is applied repetitively over the crop at low rates during early kumara field establishment. Each paraquat application destroys successive batches of

newly emerged seedling weeds, while leaving the hardier kumara plants relatively unharmed (Lewthwaite & Triggs 2000).

Previously in New Zealand, a herbicide-resistant black nightshade biotype was found within pea crops in the Manawatu region. However, this biotype was resistant to the triazine herbicides, cyanazine, terbuthylazine, atrazine, prometryn, and possibly terbutryn (Harrington et al. 2001), which are photosystem II inhibitors. The herbicide paraquat is classed as a bipyridylium with a different mode of action because it works as a photosystem I inhibitor (Heap 2005).

Internationally, paraquat resistance has been found across various plant species (Heap 2005). Amongst solanaceous plants, paraquat resistance was reported in black nightshade within Malaysian vegetable crops in 1990 (Itoh et al. 1992), while paraquat resistance in small-flowered nightshade (*Solanum americanum* Mill.) was reported in USA tomato crops around the same time (Bewick et al. 1990; Chase et al. 1998).

This research project was established to examine potential replacement weed control strategies for the New Zealand kumara cropping system. Alternative approaches were suggested by international contacts, local agrichemical consultants and growers.

The project was jointly funded and supported by the MAF Sustainable Farming Fund, the New Zealand Vegetable & Potato Growers' Federation (Vegfed) - Fresh Vegetable Industry Research & Development Grants Committee and the Northern Wairoa Vegetable Growers' Association. The project will continue a further season with support from these agencies. However, the Vegfed contribution will be sourced from the Process Vegetable Industry Research & Development Committee.

# 3 Question 1: What is the response of a 'normal' black nightshade population to paraquat exposure?

## 3.1 Aim

To identify paraquat concentrations that would accurately differentiate standard and resistant black nightshade populations.

## 3.2 Method

A black nightshade seed population was collected from Pukekohe (P1). This population was considered standard because it had not been exposed to repeated applications of paraquat.

The black nightshade seed was chilled at 5°C for three weeks, to break dormancy. It was then sown in trays of peat/pumice potting mix. Following germination and development of the two cotyledons (seed leaves), the first true leaf became visible. Seedlings that had simultaneously reached this stage were transplanted into pots, so that each pot contained nine plants spread to maximise inter-plant distance.

Once the first true leaf had developed and the second true leaf was commonly just appearing (Plate 1), the pots of nightshade plants were sprayed with varying concentrations of paraquat. Each treatment was replicated across 20 pots, so that 180 individual plants were exposed to each paraquat concentration. Paraquat was applied in the Gramoxone® 250 formulation (containing 250 g/kg paraquat dichloride salt in the form of a soluble concentrate). The plants were maintained in an unheated greenhouse under natural lighting until living plants showed five true leaves, at which time the numbers of dead plants were recorded.

In experiment 1 a broad range of herbicide rates were applied to give a frame of reference, using relatively extreme concentrations that produced no plant death through to total plant death. The six rates of paraquat (active ingredient) applied were 0, 0.0009, 0.0086, 0.0291, 0.0870 and 0.2174 g ai/L. In experiment 2 the rates were modified on the basis of the first experiment, to give data focused between the extreme points of no plant death and total plant death. The eight rates of paraquat applied were 0.0026, 0.0088, 0.0121, 0.0163, 0.0184, 0.0200, 0.0239 and 0.0400 g ai/L.

Curves were fitted (GenStat 2003) to the data generated by each experiment, from which a common curve was constructed.

## *3.3 Results*

A common response curve based on the experimental data from both experiments is illustrated in Figure 1, while Table 1 provides the concentrations of active ingredient required for specific diagnostic thresholds (50, 95 and 99% lethal doses). Note: the working 99% lethal dose was initially estimated at 0.040 g ai/L, which was then used as the diagnostic rate in subsequent experiments.

*Plate 1: A test plot, illustrating the number, size and spatial arrangement of black nightshade (*Solanum nigrum *L.) seedlings before the herbicide paraquat was applied. Each plot was replicated 20 times for each spray concentration.*

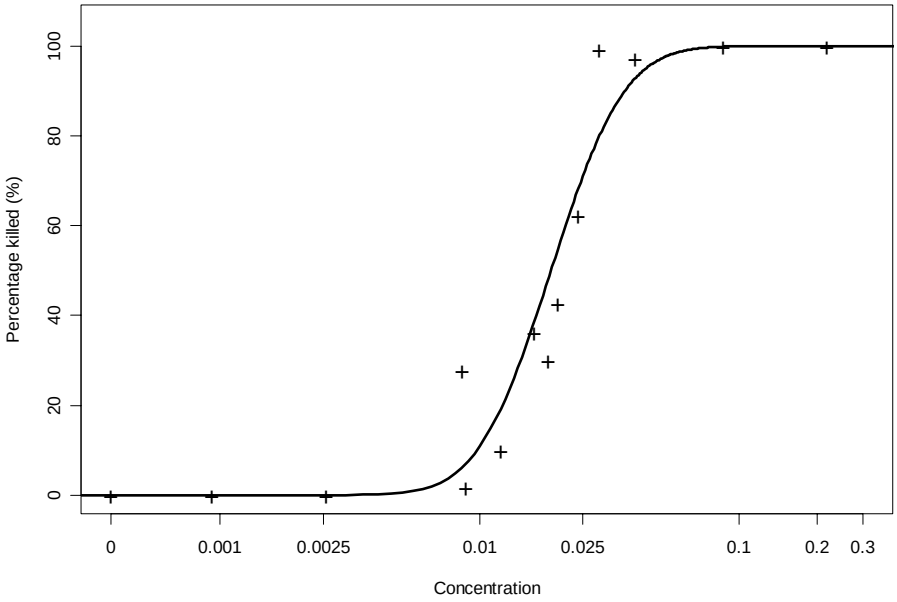


*Figure 1: A fitted response curve for the percentage of black nightshade (*Solanum nigrum *L.) seedlings killed at varying paraquat concentrations (g ai/L). The plants were a Pukekohe population (P1) and paraquat was applied as a foliar spray (application volume: 0.011 ml/cm$^2$). Concentration is presented on a logarithmic scale, and each cross represents the mean response of 180 treated plants, while the solid line indicates the fitted curve.*

*Table 1: Estimates of the paraquat concentration (g ai/L) required for lethal dose (LD) thresholds at 50, 95 and 99% plant death in black nightshade (*Solanum nigrum *L.) seedlings. The standard errors (SE) and 95% confidence limits of the estimates are given.*

| LD | Estimate | SE | Lower 95% | Upper 95% |
|---|---|---|---|---|
| 50 | 0.019 | 0.0004 | 0.018 | 0.020 |
| 95 | 0.044 | 0.0019 | 0.040 | 0.048 |
| 99 | 0.062 | 0.0035 | 0.056 | 0.070 |

# 4 Question 2: How do black nightshade populations collected from fields at Dargaville–Ruawai respond to a paraquat concentration that kills approximately 99% of a 'normal' population?

## 4.1 Aim

To (i) formally establish that paraquat-resistant black nightshade occurs in the Dargaville–Ruawai area, (ii) evaluate the ability of the $LD_{99}$ diagnostic rate to discriminate between resistant/sensitive populations, and (iii) formally establish the identity of the resistant nightshade species.

## 4.2 Method

Nightshade seed was collected (courtesy of commercial growers) from the Dargaville–Ruawai region, New Zealand's predominant kumara production area. Nightshade populations from this area have been exposed to repeated applications of paraquat under a well established kumara production system.

In experiment 3 the nightshade seed was prepared, germinated and transplanted in the same manner as in previous experiments. Having determined with initial data that paraquat applied at 0.040 g ai/L killed approximately 99% of a normal seed population, this single rate was applied across the seed populations obtained from the Dargaville–Ruawai region.

## 4.3 Results

Paraquat applied at 0.040 g ai/L killed almost all of the plants within both Pukekohe nightshade populations, P1 (98.9%) and P2 (97.8%). Population P1 was confirmed as black nightshade (*Solanum nigrum* L.), while (P2) was identified as a yellow-berried mutant (*Solanum nigrum* f. humile L. (Willd.)

Lindman) (Plate 2). Plant death in Dargaville–Ruawai black nightshade populations (Fig. 2) ranged from 1.1 to 96.7% (Plate 3). One of the populations (DR4) was identified as small-flowered nightshade (*Solanum americanum* Mill.). This paraquat concentration did not kill any plants in the *S. americanum* population (Plate 4).

*Plate 2: Standard black nightshade (*Solanum nigrum *L.) has berries that are black when mature.*

Solanum nigrum *f. humile L.* (*Willd.*) *Lindman has a mutation that produces yellow-green berries when mature.*

*Plate 3: Black nightshade from Pukekohe (centre plot) amongst black nightshade seedlings from the Dargaville–Ruawai area. All plants were sprayed with paraquat at a concentration of 0.040 g ai/L. The photograph was taken at the 5 true leaf stage. Note the lack of foliar damage in resistant plants.*

*Plate 4: Flower size in (left) small-flowered nightshade (*Solanum americanum *Mill.) and in (right) black nightshade (*Solanum nigrum *L.).*

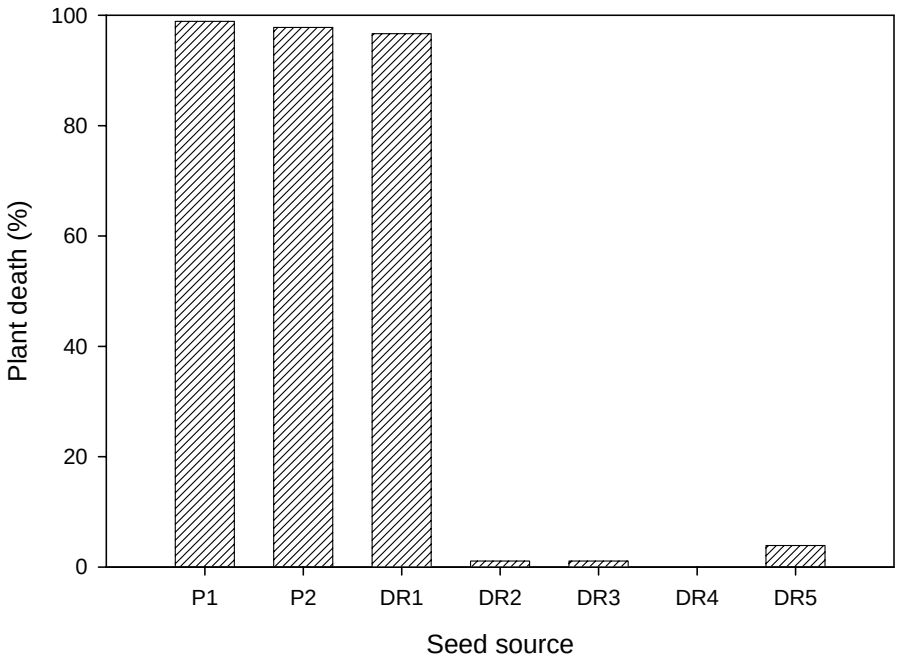


*Figure 2: Plant death within various seedling nightshade (Solanum spp.) populations following a single application of the herbicide paraquat at 0.040 g ai/L. The seed populations were obtained from Pukekohe (P1, P2) and the Dargaville–Ruawai kumara production region (DR1 to DR5).*

# 5 Question 3: How much paraquat is required to kill resistant black nightshade populations in Dargaville–Ruawai?

## 5.1 Aim

To determine whether there is a paraquat concentration that could destroy the resistant black nightshade populations in Dargaville-Ruawai without severely damaging kumara plants.

## 5.2 Method

Seed from the resistant black nightshade population DR3 was prepared, germinated and transplanted as in experiment 1. Here in experiment 4, paraquat was applied at 0.02, 0.04, 0.08, 0.16, 0.32, 0.64, 1.28, 2.56, 5.12, 10.24 g ai/L. Further data were obtained in experiment 5, which focused mainly on intermediate paraquat concentrations at 0.04, 0.64, 0.96, 1.28, 2.56, 5.12, 10.24, 15.36 g ai/L. A common curve was fitted (GenStat 2003) to the combined data set.

## 5.3 Results

The fitted curve (Fig. 3) shows a similar shape to that of standard nightshade populations (Fig. 1), but at higher paraquat concentrations. A comparison of $LD_{99}$ estimates for standard (Table 1) and resistant populations (Table 2) suggests that a concentration increase of more than 100-fold is required to kill resistant black nightshade. This concentration is much higher than the paraquat rate recommended for general weed control.

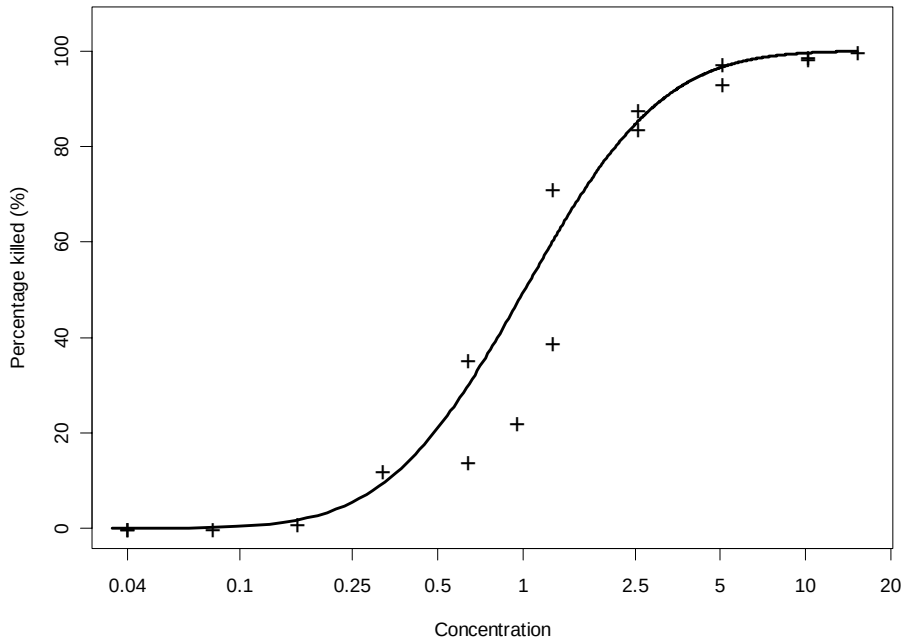


*Figure 3: A fitted response curve for the percentage of black nightshade (*Solanum nigrum *L.) seedlings killed at varying paraquat concentrations (g ai/L). The plants were from a resistant Dargaville–Ruawai population (DR3) and paraquat was applied as a foliar spray (application volume: 0.011 ml/cm$^2$). Concentration is presented on a logarithmic scale, and each cross represents the mean response of 180 treated plants, while the solid line indicates the fitted curve.*

*Table 2: Estimates of the paraquat concentration (g ai/L) required for lethal dose (LD) thresholds at 50, 95 and 99% plant death in seedling black nightshade (*Solanum nigrum *L.) plants. The standard errors (SE) and 95% confidence limits of the estimates are given. This table is based solely on experiment 5 data.*

| LD | Estimate | SE | Lower 95% | Upper 95% |
|---|---|---|---|---|
| 50 | 1.47 | 0.051 | 1.38 | 1.57 |
| 95 | 4.5 | 0.32 | 4.0 | 5.2 |
| 99 | 7.1 | 0.68 | 6.0 | 8.8 |

# 6 Question 4: Are there concentrations of the herbicide Buster that could kill paraquat-resistant black nightshade plants without significantly affecting kumara plant health?

## 6.1 Aim

To determine if lower rates of Buster herbicide are effective against black nightshade since the rates of Buster herbicide used over the crop in a field trial caused plant damage.

## 6.2 Method

Seed from the resistant black nightshade population DR3 was prepared, germinated and transplanted as in experiment 1. The herbicide Buster contains 200 g/L of glufosinate-ammonium as a water-soluble concentrate. Buster was applied at 0.032, 0.065, 0.130, 0.260, 0.520, 1.040 g ai/L. Plant death was recorded when living plants reached the five true leaf stage.

## 6.3 Results

The highest rate of Buster used in the field trial was 0.34 g ai/L, which caused crop damage. This greenhouse experiment (Fig. 4) suggests that low rates are not effective against paraquat-resistant black nightshade seedlings.

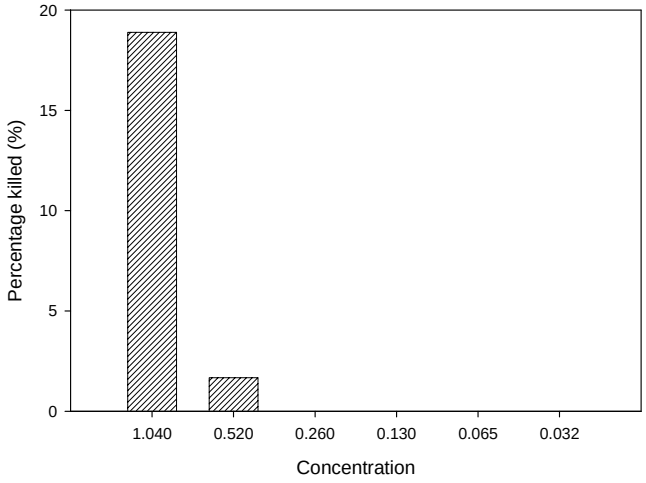


*Figure 4: Plant death within a paraquat-resistant black nightshade (Solanum nigrum L.) seedling population (DR3) at reducing concentrations of the herbicide Buster (g ai/L). The herbicide Buster contains 200 g/L of glufosinate-ammonium.*

# 7 Question 5: What concentrations of Organic Interceptor will kill paraquat-resistant black nightshade?

## 7.1 Aim

To determine the minimum concentrations of Organic Interceptor that are effective against paraquat-resistant black nightshade given that this herbicide gave effective general weed control in a field trial without causing significant crop damage.

## 7.2 Method

Seed from the resistant black nightshade population DR3 was prepared, germinated and transplanted as in experiment 1. The herbicide Organic Interceptor contains 680 g/L of essential oil as an emulsifiable concentrate. Organic Interceptor was applied to seedlings with 1 true leaf at concentrations of 0.5, 1.1, 2.1, 4.3, 8.5, 17, 34, 68 g ai/L in an application volume of 0.011 ml/cm$^2$ (as for previous experiments). Plant death was recorded when living plants reached the 5 true leaf stage.

In a second experiment, the plants were prepared as before, but allowed to grow to 7 true leaves and hardened outside for 10 days before being sprayed. The spray solution was applied until there was copious run off. In this second experiment, Organic Interceptor was applied at concentrations of 7, 14, 20, 27, 34, 41, 48, 54, 61, 68 g ai/L. Plant death was recorded when living plants reached the 12 true leaf stage.

## 7.3 Results

Although small seedlings with 1 true leaf were sprayed in the first experiment and hardened plants with 7 true leaves were sprayed in the second experiment, they both gave the same response curve ($P$ = 0.99). Effective herbicide concentrations were similar in both experiments (Fig. 5). The lethal dose thresholds at 50, 95 and 99% plant death, based on the experiment with one true leaf, are given in Table 3.

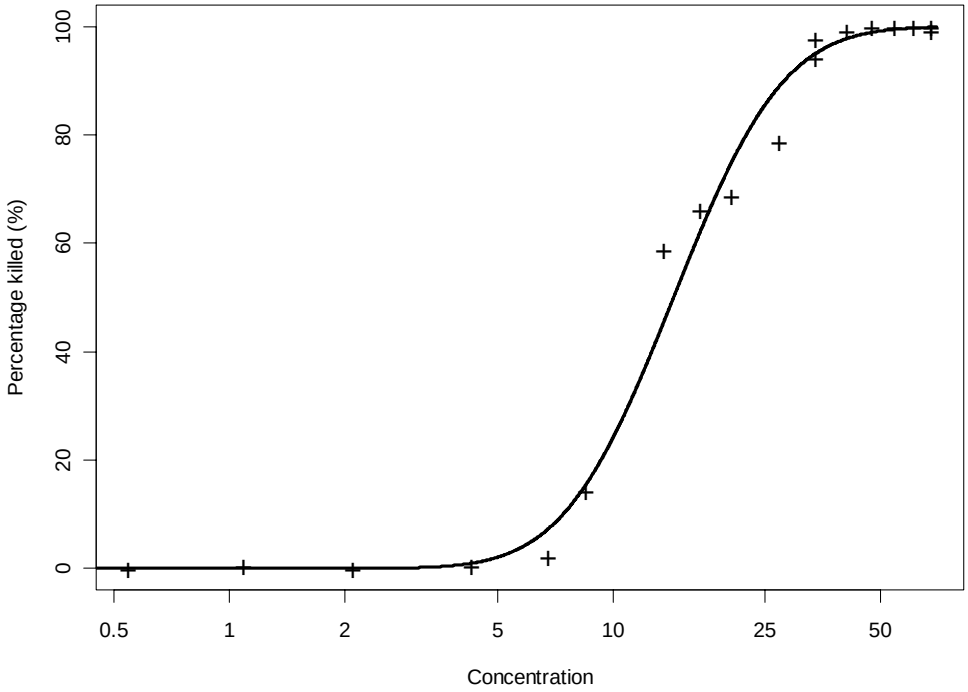


*Figure 5: A fitted response curve for the percentage of black nightshade (*Solanum nigrum *L.) seedlings killed at varying Organic Interceptor concentrations (g ai/L). Organic Interceptor contains 680 g/L of essential oil. The plants were from a resistant Dargaville–Ruawai population (DR3). This curve is based on combined data sets, from seedlings sprayed at either one or seven true leaves. Concentration is presented on a logarithmic scale, and each cross represents the mean response of 180 treated plants, while the solid line indicates the fitted curve.*

*Table 3: Estimates of the Organic Interceptor concentration (g ai/L) required for lethal dose (LD) thresholds at 50, 95 and 99% plant death in paraquat-resistant seedling black nightshade (*Solanum nigrum *L.) plants. Organic Interceptor contains 680 g/L of essential oil. The standard errors (SE) and 95% confidence limits of the estimates are given. This table is based solely on experimental data from seedlings with one true leaf at the time of spray application.*

| LD | Estimate | SE | Lower 95% | Upper 95% |
|---|---|---|---|---|
| 50 | 14.3 | 0.50 | 13.3 | 15.3 |
| 95 | 36 | 2.2 | 32 | 41 |
| 99 | 52 | 4.3 | 45 | 62 |

# 8 Question 6: Are there alternative herbicides to paraquat that control the general weed load without causing crop damage?

## 8.1 Aim

To evaluate the ability of various herbicides to control weed growth without having any economically significant phytotoxic effects on the kumara crop.

## 8.2 Method

Weed management systems used in kumara crops around the world were noted through international contacts. Local agrichemical consultants and growers were invited to offer opinions on herbicide regimes that could be suitable for kumara production, with particular reference to the control of paraquat-resistant black nightshade plants.

A number of herbicides were selected (Table 4) for application in a replicated field trial conducted on a commercial property. The trial was laid out in a modified alpha row-column design, four columns wide by 16 rows long. The 16 treatments were replicated four times. Each plot was four rows wide by 3 m long, with a 1 m long gap between plots along columns. Transplants were inserted at 30 cm intervals along each row, with an inter-row spacing of 75 cm. Each plot therefore contained a total of 4 rows with 10 plants in each row, the 2 outer rows serving as guard rows.

The season was relatively cool and dry. Weed germination was described by growers as generally lower than usual. However, growers have also stated that the growth of paraquat-resistant black nightshade was particularly bad this season. Planting of commercial crops continued well beyond the day the trial was established, 14 December 2004. Residual herbicides were applied immediately after planting and watering were complete. Spray solutions were applied at 294 L/ha (refer water analysis in Appendix II). For the Linuron treatment, the herbicide was washed from the transplants' leaves immediately after application (as in the South African production system). The weather was calm and dry during the application of residuals, but rain fell on following days, ensuring herbicide activation (Fig. 6). A concern with the efficacy of residual herbicides in Dargaville soils is the high levels of exchangeable cations (see soil analysis in Appendix III), which may bind up applied chemicals.

Contact herbicides were applied under calm dry conditions on 3 January 2005. The Oxy treatments (1 and 2) were reapplied at their initial rates. Weed growth was still relatively light and patchy, with the most advanced nightshade seedlings showing 3–4 true leaves. Some growers have

indicated that they typically prefer to apply the first application of the contact herbicide paraquat at low rates within 7 to 10 days of transplanting.

The herbicide treatments Gramoxone, Preeglone, Basagran, Emblem (1), Buster (1), Organic Interceptor and the Oxy treatments were reapplied on 14 January, by which time weed growth was more pronounced and general throughout the trial.

On 14 February, treatment weed samples were collected from a 40 x 40 cm quadrat per plot and the control plots were thoroughly hand-weeded. The weed samples were used to evaluate weed numbers, species and biomass (dry weight at 80°C) under the different herbicide regimes.

At harvest, on 12 April 2005, root total yield, marketable yield (roots greater than 2.5 cm in diameter) and marketable root numbers were recorded per plot. Roots were cut open to check for internal defects and root sub-samples were oven-dried at 80°C to assess root dry matter:water content.

*Table 4: Hand-weeded control and herbicide treatments applied in a field trial established at a commercial property in Dargaville on 14 December 2004.*

| Treatment number | Treatment name | Product rate ml or g/L | Number of applications |
|---|---|---|---|
| 1 | Hand weed | - | 1X |
| **Contact herbicides** | | | |
| 2 | Gramoxone | 1.36 | 2X |
| 3 | Preeglone | 1.36 | 2X |
| 4 | Totril | 1.36 | 1X |
| 5 | Basagran | 1.36 | 2X |
| 6 | Emblem (1) | 0.68 | 2X |
| 7 | Emblem (2) | 1.36 | 1X |
| 8 | Buster (1) | 0.85 | 2X |
| 9 | Buster (2) | 1.70 | 1X |
| 10 | Organ Interceptor | 140.00 | 2X |
| **Residual herbicides** | | | |
| 11 | Sylon | 8.50 | 1X |
| 12 | Frontier | 6.80 | 1X |
| 13 | Linuron | 6.80 | 1X |
| 14 | Forsite | 3.40 | 1X |
| 15 | Oxy*250 (1) | 0.68 | 3X |
| 16 | Oxy*250 (2) | 0.85 | 3X |

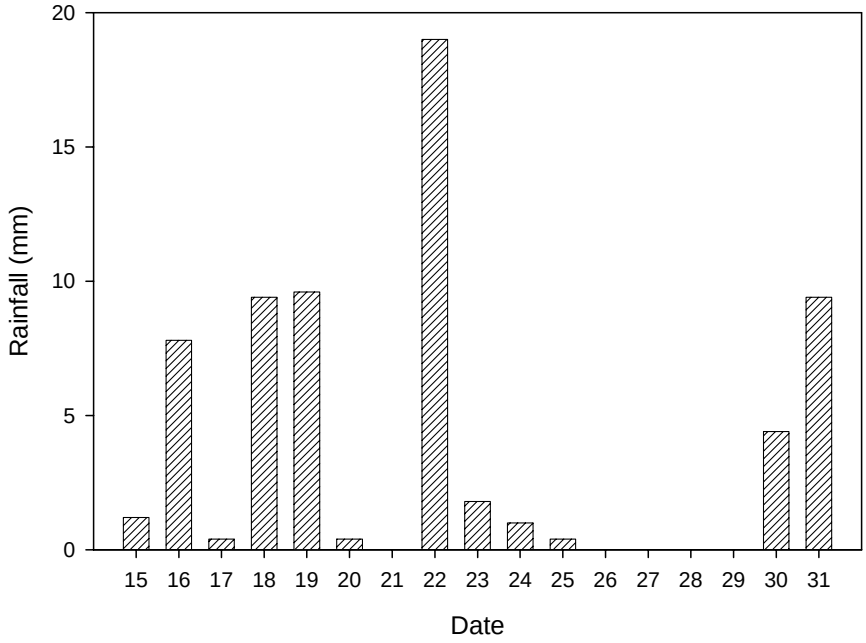


*Figure 6: Rainfall at Dargaville over the period (15–31 December 2004) immediately following trial establishment and the application of residual herbicides. Data courtesy of the National Institute of Water and Atmospheric Research Ltd.*

## *8.3 Results*

There were significant differences ($P < 0.001$) in root yield under the various herbicide regimes (Table 5). Root dry matter content did not differ between treatments ($P = 0.19$) nor were there any obvious root shape distortions. There was no significant difference ($P = 0.67$) in monocotyledon weed production (Table 6) under the different herbicide regimes, as estimated by shoot dry weight. However, herbicides targeted specifically at monocotyledonous weeds were not applied in this trial. The dicotyledonous weeds showed significant production differences ($P < 0.001$) between treatments. A scatter plot of dicotyledon weed production against marketable root yield (Fig. 7) provides a broad index of herbicide efficacy. There were no discernible root residues at harvest of the herbicides tested: Frontier, Sylon and Oxy (2) (see Appendix IV).

*Table 5: The yield and number of kumara* (Ipomoea batatas *(L.) Lam. Cultivar Owairaka Red) storage roots produced under different herbicide regimes. Marketable roots were those greater than 2.5 cm in diameter.*

| Herbicide | Total yield (t/ha) | Marketable yield (t/ha) | Number of marketable roots/$m^2$ |
|---|---|---|---|
| Emblem(1) | 10.4 | 9.4 | 4.97 |
| Emblem(2) | 12.0 | 11.3 | 5.56 |
| Totril | 13.5 | 12.6 | 5.92 |
| Handweed | 15.7 | 14.2 | 7.21 |
| Forsite | 15.4 | 14.3 | 6.51 |
| Buster(2) | 15.2 | 14.4 | 6.24 |
| Oxy(2) | 16.0 | 15.2 | 6.35 |
| Oxy(1) | 15.8 | 15.3 | 6.63 |
| Buster(1) | 16.9 | 16.0 | 6.72 |
| Basagran | 17.7 | 16.7 | 8.05 |
| Preeglone | 18.1 | 17.0 | 7.54 |
| Frontier | 18.3 | 17.2 | 6.93 |
| Linuron | 18.8 | 17.7 | 7.82 |
| Gramoxone | 18.9 | 18.0 | 7.63 |
| Sylon | 20.4 | 19.5 | 7.69 |
| Organ-Interceptor | 22.4 | 21.7 | 7.65 |
| SED | 1.9 | 1.9 | 0.93 |
| *P*-value | < 0.001 | < 0.001 | 0.04 |

*Table 6: Weed species present within a kumara herbicide trial established at Dargaville on 14 December 2004.*

| Common name | Botanical name |
|---|---|
| **Dicotyledon** | |
| Alligator weed | *Alternanthera philoxeroides* |
| Black nightshade | *Solanum nigrum* |
| Broad-leaved dock | *Rumex obtusifolius* |
| Cleavers | *Galium aparine* |
| Creeping buttercup | *Ranunculus repens* |
| Creeping mallow | *Modiola caroliniana* |
| Dandelion | *Taraxacum officinale* |
| Fathen | *Chenopodium album* |
| Field speedwell | *Veronica arvensis* |
| Herb Robert | *Geranium robertianum* |
| Milkweed | *Euphorbia peplus* |
| Oxtongue | *Picris echioides* |
| Prickly sow thistle | *Sonchus asper* |
| Prostrate amaranth | *Amaranthus deflexus* |
| Redroot | *Amaranthus retroflexus* |
| Scrambling fumitory | *Fumaria muralis* |
| Sow thistle | *Sonchus oleraceus* |
| Stagger weed | *Stachys arvensis* |
| Twin cress | *Coronopus didymus* |
| White clover | *Trifolium repens* |
| **Monocotyledon** | |
| Barnyard grass | *Echinochloa crus-galli* |
| Floating sweet grass | *Glyceria fluitans* |
| Kikuyu | *Pennisetum clandestinum* |
| Perennial ryegrass | *Lolium perenne* |
| Summer grass | *Digitaria sanguinalis* |

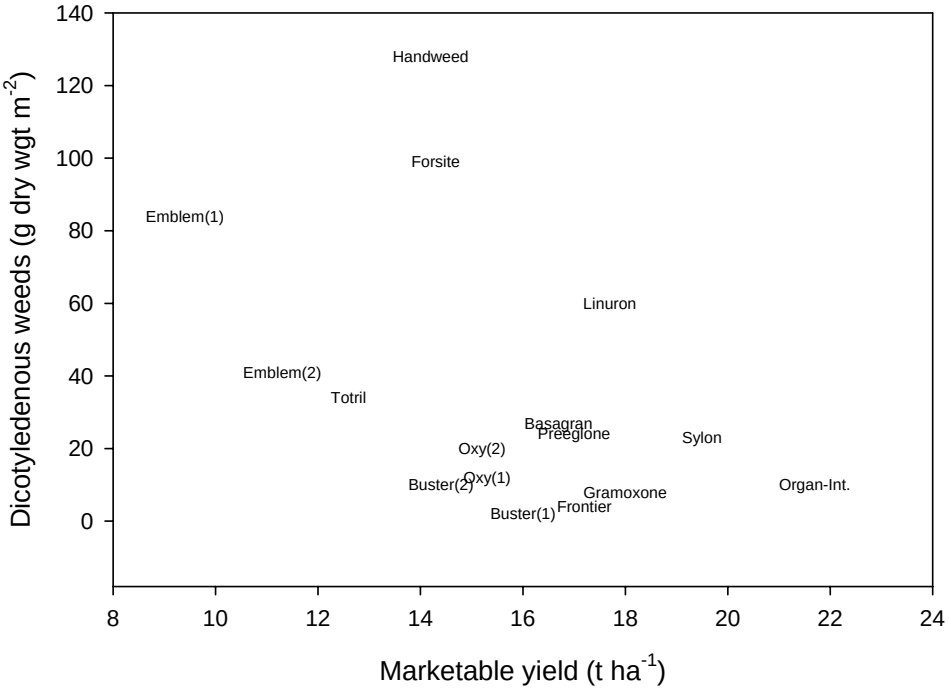


*Figure 7: A scatter plot of dicotyledonous weed production (shoot dry weight g/m$^2$) against marketable root yield for kumara* (Ipomoea batatas *(L.) Lam. cultivar Owairaka Red) under various herbicide regimes.*

# 9 General conclusions

In this project, diagnostic paraquat rates were determined to allow identification of standard, mixed and resistant black nightshade plant populations. Some black nightshade plant populations sourced from Dargaville–Ruawai were almost completely composed of paraquat-resistant plants. The degree of paraquat resistance in Dargaville–Ruawai plants was assessed using a test population. Paraquat concentrations required to kill significant numbers of resistant plants in the test population were well above those suggested for general weed control. Such levels would be expected to cause significant crop damage. Based on paraquat susceptibility within a standard black nightshade population, the resistant nightshades included two species: black nightshade (*Solanum nigrum* L.) and small-flowered nightshade (*S. americanum* Mill.).

Like paraquat, Buster has little systemic activity, but differs from paraquat in its mode of action. However, based on field and greenhouse trials, the concentration of Buster required to kill significant numbers of black nightshade seedlings would also damage the unprotected crop.

Concentrations of Organic Interceptor required to kill black nightshade seedlings at the 1 true leaf stage were similar to those required for hardened

plants at the 7 true leaf stage. However, the plants in either case required thorough coverage with spray solution. Two applications of a 1:6.14 product:water solution (i.e. 14% product solution) over a trial crop in the field did not cause significant kumara damage but did reduce the general weed load. Based on greenhouse trials to date, a 1:9 product:water solution of Organic Interceptor with sufficient plant coverage may be adequate to control black nightshade seedlings. At present there is no standard analytical method available for testing the persistence of Organic Interceptor residues in kumara roots. However, a research laboratory method that may be applicable has been developed for other plant tissues. Evaluating the persistence of Organic Interceptor residues in kumara roots is an objective for next season.

The field trial was based on kumara cultivar Owairaka Red and highlighted the potential of herbicides Organic Interceptor, Sylon and Frontier to control weeds in general without causing substantial crop damage. Further work is required to evaluate:

- the persistence of residues from Organic Interceptor,
- the effect of Sylon on crop development rate,
- and the effectiveness of Frontier in soils with high levels of exchangeable cations.

Additional research is also required to evaluate herbicides with action more specifically targeted against black nightshade.

# 10 Acknowledgements

This project was jointly funded and supported by:

- MAF Sustainable Farming Fund,
- New Zealand Vegetable & Potato Growers' Federation (Vegfed) – Fresh Vegetable Industry Research & Development Grants Committee,
- Northern Wairoa Vegetable Growers' Association.

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# *Appendices*

## *Appendix I  Kumara weed control systems and comments on herbicides used/being evaluated for kumara crops*

*Table 1A: International kumara weed control systems.*

| Country | Weed control system | Information source |
|---|---|---|
| Australia | Intertillage, hand weeding and herbicides.  Occasionally polyethylene film mulch. | Mr. Eric Coleman<br>Sweetpotato extension |
| China | Stale seed bed and hand weeding. Occasionally polyethylene film mulch. | Ms. Zhixian Ji<br>Sweetpotato breeder |
| Italy | Intertillage and hand weeding | Dr. Giorgio Gianquinto<br>Sweetpotato researcher |
| Japan | Polyethylene film mulch, intertillage, hand weeding and herbicide. | Dr. Makoto Nakatani<br>Sweetpotato researcher |
| Malaysia | Intertillage, hand weeding and herbicide. | Dr. Abdul Aziz Aita<br>Researcher |
| USA: Louisiana | Intertillage, hand weeding and herbicide. | Dr. Mike Cannon<br>Sweetpotato researcher |
| USA: North Carolina | Intertillage, hand weeding and herbicide. | Dr. Jonathan Schultheis<br>Sweetpotato researcher |
| South Africa | Intertillage, hand weeding and herbicide. | Dr. James Allemann<br>Agronomist |
| South Korea | Polyethylene film mulch, hand weeding and herbicide. | Mr. Byeong Choon Jeong<br>Sweetpotato researcher |

*Table 2A: Unsubstantiated comments on herbicides used/being evaluated for the kumara crop from international sources.*

| Country | Herbicides |
|---|---|
| Australia | Currently registered in Australia:<br>Sertin (sethoxydim) for grasses. Can be sprayed over sweetpotato plants. Dacthal/Warrant (chlorthal dimethyl) registered but not widely used. Controls annual grasses and some broadleaved weeds. Dual Gold (S-metalochlor) and various metalochlor products. Paraquat and Diquat.<br>Unregistered but may have some efficacy:<br>Stomp (pendimethalin), Simazine, Surflan (oryzalin), Goal (oxyfluorfen).<br>Note: Fusilade not currently registered. |
| China | Glyphosate used to create a stale seed bed. |
| Italy | - |
| Japan | Glyphosate or paraquat is used around plants before the canopy closes. If polyethylene film mulch is used, trifluralin granules are used between the ridges, just after planting. |
| Malaysia | The use of paraquat is being phased out and guarded applications of Buster are now used. |
| USA: Louisiana | Command 3ME (clomazone) has been used for many years as the main pre-emergence weed control. Some growers have started using Valor (flumioxazin) (pre-transplanting application) and are evaluating a Command/Valor combination.<br>Evaluations are also underway with Spartan (sulfentrazone) and Sandea (halosulfuron). Dual (metolachlor) has also been used, but can cause yield and quality problems. |
| USA: North Carolina | Glyphosate to control emerged weeds prior to transplanting. Command (clomazone) post transplant control of annual grasses and broadleaf weeds. Devrinol (nanpropamide) in plant beds and production fields for annual grasses and broadleaf weeds. Dual (metolachlor) emergency label obtained for a second year to help control pigweed. Fusilade (fluazifop), Poast (sethoxydim) and Select (clethodim) to control emerged annual and perennial grasses. Sandea (halosulfuron) emergency label to control nutsedge. |
| South Africa | Linuron and EPTC (registered for sweetpotato in S. Africa).<br>EPTC is a thiocarbamate, sold under trade names Eptam Super, EPTC Plus, or Eradicate Plus (these include a safener to protect the crop). An emulsifible concentrate applied pre-planting and incorporated. Mainly used for annual grasses and nutsedge.<br>Linuron is a substituted urea, sold as a wettable powder, a suspension concentrate or a water dispersible granule. Trade names Linuron SC, Linuron WP, Afalon SC, Linagan 50 SC, or Linex 4DF. Applied pre-planting or immediately after planting (the latter only if irrigation is available to wash off leaves). Pre-emergence weed control of certain broad-leaved weeds and grasses. |
| South Korea | Lasso (alachlor) prior to weed emergence. Requires moisture within 10 days of application. |

## *Appendix II Water analysis*


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**Client:** Crop & Food Research
**Address:** 49 Cronin Road, R D 1
PUKEKOHE
**Contact:** Steve Lewthwaite

**Laboratory No:** 366142
**Date Registered:** 25/01/2005
**Date Completed:** 28/01/2005
**Page Number:** 1 of 3

### Client's Reference: Water Sample

***The results for the analyses you requested are as follows:***

### Sample Type: Water,

| Sample Name | DW1 |
|---|---|
| Lab No | 366142/1 |
| pH [7.0 - 8.5] (pH units) | 7.8 |
| Electrical Conductivity [<150] (mS/m) | 52.3 |
| Electrical Conductivity [<1500] (µS/cm) | 523 |
| Approx Total Dissolved Salts [<1000] (g.m-3) | 350 |
| Alkalinity [No Guideline] (g.m-3 as CaCO3) | 114 |
| Free carbon dioxide [No Guideline] (g.m-3) | 4 |
| Calcium [No Guideline] (g.m-3) | 19.6 |
| Magnesium [No Guideline] (g.m-3) | 9.66 |
| Total Hardness [<200] (g.m-3 as CaCO3) | 89 |
| Sodium [<200] (g.m-3) | 77.0 |
| Potassium [No Guideline] (g.m-3) | 4.6 |
| Nitrate-N [<11.3] (g.m-3) | 0.16 |
| Chloride [<250] (g.m-3) | 93.1 |
| Sulphate [<250] (g.m-3) | < 0.5 |
| Boron [<1.4] (g.m-3) | 0.101 |
| Total Iron [<0.2] (g.m-3) | 0.29 |
| Total Manganese [<0.05] (g.m-3) | < 0.005 |
| Total Copper [<1] (g.m-3) | < 0.005 |
| Total Zinc [<3] (g.m-3) | 0.006 |

**Note:** Values given in square brackets in the result tables above are Guideline values taken from the publication 'Drinking Water Standards for New Zealand', Dept of Health (2000).

Note that the units $g.m^{-3}$ are the same as mg/L and ppm.

# *Routine Water Assessment for Sample Nr 366142/1*

***pH/Alkalinity and Corrosiveness Assessment***

The pH of a water sample is a measure of its acidity or basicity. Waters with a low pH can be corrosive and those with a high pH can promote scale formation in pipes and hot water cylinders. The guideline level for pH in drinking water is 7.0-8.5. Below this range the water will be corrosive and may cause problems with disinfection if such treatment is used.

The alkalinity of a water is a measure of its acid neutralising capacity and is usually related to the concentration of carbonate, bicarbonate and hydroxide. Low alkalinities (<25 $g.m^{-3}$) promote corrosion and high alkalinities can cause problems with scale formation in metal pipes and tanks.

The pH of this water is within the NZ Drinking Water Guidelines, the ideal range being 7.0 to 8.0. With the pH and alkalinity levels found, it is unlikely this water will be corrosive towards metal piping and fixtures. The high alkalinity of this water may cause an increase in the pH in the root zones of plants which are irrigated using this water.

***Hardness/Total Dissolved Salts Assessment***

The water contains a moderate amount of dissolved solids and would be regarded as being slightly hard.

***Nitrate Assessment***

Nitrate-nitrogen at elevated levels is considered undesirable in natural waters as this element can cause a health disorder called methaemaglobinaemia. Very young infants (less than six months old) are especially vulnerable, and the World Health Organisation suggests a maximum permissible level of 10 $g.m^{-3}$.

Nitrate-nitrogen was detected in this water but at such a low level to not be of concern.

For household use, it is important that the water is not contaminated with human or animal wastes (e.g. from septic tanks or effluent ponds). Bacteriological analyses may be required if such contamination could exist. For further details, please contact this laboratory.

***Boron Assessment***

Boron may be present in natural waters and if present at high concentrations can be toxic to plants.

Boron was found at a low level in this water but would not give any cause for concern.

***Metals Assessment***

Iron and manganese are two problem elements that commonly occur in natural waters. These elements may cause unsightly stains and produce a brown/black precipitate. Iron is not toxic but manganese, at concentrations above 0.5 $g.m^{-3}$, may adversely affect health. At concentrations below this it may cause stains on clothing and sanitary ware.

Iron was found in this water at a low level. Manganese was not detected in the water. Treatment to remove iron and/or manganese may be required.

Copper and zinc at low levels are both essential elements for people, animals and plants.

***Final Assessment***

The parameter Iron did NOT meet the guidelines laid down in the publication 'Drinking Water Standards for New Zealand' published by the NZ Department of Health, Wellington, NZ (2000) for water which is suitable for drinking purposes.

## Sample Containers

The following table shows the sample containers that were associated with this job.

| Container Description | Container Size (mL) | Number of Containers |
|---|---|---|
| Nitric Preserved Pottle | 100 | 1 |

Details of sample bottle preparation procedures are available upon request.

## Summary of Methods Used and Detection Limits

The following table(s) gives a brief description of the methods used to conduct the analyses for this job.
The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

***Substance Type: Water***

| Parameter | Method Used | Detection Limit |
|---|---|---|
| Sample filtration for general testing | Sample filtration through 0.45$\mu$m membrane filter. | N/A |
| Total (nitric acid) digest | Boiling nitric acid digestion. | N/A |
| pH [7.0 - 8.5] | pH meter APHA 4500-$H^+$ B 20$^{th}$ ed. 1998 | 0.1 pH units |
| Electrical Conductivity [<150] | Conductivity meter, 25°C APHA 2510 B 20$^{th}$ ed. 1998 | 0.1 mS/m |
| Electrical Conductivity [<1500] | Conductivity meter, 25°C APHA 2510 B 20$^{th}$ ed. 1998 | 1 $\mu$S/cm |
| Approx Total Dissolved Salts [<1000] | Calculation: from Electrical Conductivity | 2 g.m-3 |
| Alkalinity [No Guideline] | Titration to pH 4.5 APHA 2320 B (Modified for alk <20) 20$^{th}$ ed. 1998 | 1 g.m-3 as CaCO3 |
| Free carbon dioxide [No Guideline] | Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-$CO_2$ D 20$^{th}$ ed. 1998 | 1 g.m-3 |
| Calcium [No Guideline] | Boiling nitric acid digestion. ICP-OES | 0.02 g.m-3 |
| Magnesium [No Guideline] | Boiling nitric acid digestion. ICP-OES | 0.005 g.m-3 |
| Total Hardness [<200] | Calculation: from Ca and Mg APHA 2340 B 20$^{th}$ ed. 1998 | 1 g.m-3 as CaCO3 |
| Sodium [<200] | Boiling nitric acid digestion. ICP-OES | 0.5 g.m-3 |
| Potassium [No Guideline] | Boiling nitric acid digestion. ICP-OES | 0.1 g.m-3 |
| Nitrate-N [<11.3] | Filtered sample. Ion Chromatography. APHA 4110 B 20$^{th}$ ed. 1998 | 0.05 g.m-3 |
| Chloride [<250] | Filtered sample. Ion Chromatography. APHA 4110 B 20$^{th}$ ed. 1998 | 0.5 g.m-3 |
| Sulphate [<250] | Filtered sample. Ion Chromatography. APHA 4110 B 20$^{th}$ ed. 1998 | 0.2 g.m-3 |
| Boron [<1.4] | Boiling nitric acid digestion. ICP-OES | 0.005 g.m-3 |
| Total Iron [<0.2] | Boiling nitric acid digestion. ICP-OES | 0.01 g.m-3 |
| Total Manganese [<0.05] | Boiling nitric acid digestion. ICP-OES | 0.005 g.m-3 |
| Total Copper [<1] | Boiling nitric acid digestion. ICP-OES | 0.005 g.m-3 |
| Total Zinc [<3] | Boiling nitric acid digestion. ICP-OES | 0.005 g.m-3 |

**Analyst's Comments:**

These samples were collected by yourselves and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the submitter.



Peter Robinson, MSc(Hons), PhD FNZIC
Environmental Division Manager

Terry Cooney, MSc(Hons), PhD MNZIC
General Manager

# *Appendix III  Soil analysis*

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## ANALYSIS RESULTS



**Client:** Crop & Food Research
**Address:** 49 Cronin Road
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**Client Phone:** 09 238 6414

**Laboratory No.:** 263459/1
**Registered:** 25-Jan-2005
**Reported:** 28-Jan-2005
**Order No.:** 29004
**Submitted By:** Mr S Lewthwaite
**Client Ref:**

**Sample Name:** DS1
**Sample Type:** SOIL Sweet Potato (S75)

| Analysis | | Level Found | Medium Range | Low / Medium / High |
|---|---|---|---|---|
| pH | | 5.8 | 5.9 - 6.8 | |
| Olsen P | (mg/L) | 11 | 50 - 100 | |
| Potassium | (me/100g) | 0.59 | 0.70 - 1.40 | |
| Calcium | (me/100g) | 20.6 | 6.0 - 12.0 | |
| Magnesium | (me/100g) | 5.49 | 1.00 - 3.00 | |
| Sodium | (me/100g) | 0.37 | 0.00 - 0.50 | |
| CEC | (me/100g) | 34 | 12 - 25 | |
| Base Saturation | (%) | 79 | 60 - 85 | |
| Volume Weight | (g/mL) | 0.92 | 0.60 - 1.00 | |
| Available N | (kg/ha) | 160 | 100 - 150 | |
| Base Saturation | | K 1.7 Ca 60 | Mg 16.1 Na 1.1 | |
| MAF Units | | K 11 Ca 24 | Mg 114 Na 16 | |

The above nutrient graph compares the levels found with reference interpretation levels. NOTE: It is important that the correct sample type be assigned, and that the recommended sampling procedure has been followed. R J Hill Laboratories Limited does not accept any responsibility for the resulting use of this information.

**No Laboratory Comments**

Submitter: Mr S Lewthwaite, Crop & Food Research, c/o Crop & Food Research, 49 Cronin Road, R D 1, PUKEKOHE

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## ANALYSIS RESULTS



**Client:** Crop & Food Research
**Address:** 49 Cronin Road, R D 1, PUKEKOHE
**Client Phone:** 09 238 6414

**Laboratory No.:** 263459
**Registered:** 25-Jan-2005
**Reported:** 28-Jan-2005
**Order No.:** 29004
**Submitted By:** Mr S Lewthwaite
**Client Ref:**

The following table gives a brief description of the analysis methods for this job. The COV (coeffient of variation) gives a measure of precision and is sometimes referred to as the Relative Standard Deviation, ie the standard deviation expressed as a percentage of the absolute value.

For further details and explanations, please contact the laboratory.
These samples were collected by yourselves (or your agent) and analysed as received at this laboratory.

| Analyte | Method | COV(%) |
|---|---|---|
| **Soil** | | |
| Soil Preparation (Dry and Grind)* | Air dried at 35 - 40°C overnight (residual moisture typically 4%) and crushed to pass through a 2 mm screen. | - |
| Sample Registration* | Samples were analysed as received. | - |
| pH | 1:2 (v/v) soil:water slurry followed by potentiometric determination of pH. | 1 |
| Phosphorus | Olsen extraction followed by Molybdenum Blue colorimetry. | 6 |
| Potassium, Calcium, Magnesium, Sodium | 1M Neutral ammonium acetate extraction followed by ICP-OES. | 4 |
| CEC | Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity. | 4 |
| Base Saturation | Calculated from Extractable Cations and Cation Exchange Capacity. | 4 |
| Volume Weight | The weight/volume ratio of dried, ground soil. | 2 |
| Available Nitrogen* | Determined by NIRS, calibration based on Avaliable N by Anaerobic incubation followed by extraction using 2M KCl followed by Berthelot colorimetry. (Calculation based on 15cm depth sample). | - |

* Indicates a non IANZ accredited test.



**Signatory:** W.M. Norwood

Submitter: Mr S Lewthwaite, Crop & Food Research, c/o Crop & Food Research, 49 Cronin Road, R D 1, PUKEKOHE

## *Appendix IV Results of root residue tests*

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**Client:** Crop & Food Research
**Address:** 49 Cronin Road, R D 1
PUKEKOHE
**Contact:** Steve Lewthwaite

**Laboratory No:** 374834
**Date Registered:** 14/04/2005
**Date Completed:** 27/04/2005
**Page Number:** 1 of 2

***The results for the analyses you requested are as follows:***

***Sample Type: Biological Materials, Vegetable***

| Sample Name | Lab No | Dimethenamid (mg/kg as rcvd) |
|---|---|---|
| Sample 1 Frontier | 374834/1 | < 0.01 |

***Sample Type: Biological Materials, Vegetable***

| Sample Name | Lab No | Acetochlor (mg/kg as rcvd) |
|---|---|---|
| Sample 2 Sylon | 374834/2 | < 0.01 |

***Sample Type: Biological Materials, Vegetable***

| Sample Name | Lab No | Oxyfluorfen (mg/kg as rcvd) |
|---|---|---|
| Sample 3 Oxy | 374834/3 | < 0.01 |

## *Summary of Methods Used and Detection Limits*

The following table(s) gives a brief description of the methods used to conduct the analyses for this job.
The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

***Substance Type: Biological Materials***

| Parameter | Method Used | Detection Limit |
|---|---|---|
| Acetochlor | Ethyl acetate extraction, SPE cleanup, GC-ECD/NPD analysis | 0.01 mg/kg as rcvd |
| Dimethenamid | Ethyl acetate extraction, SPE cleanup, GC-ECD/NPD analysis | 0.01 mg/kg as rcvd |
| Oxyfluorfen | Ethyl acetate extraction, SPE cleanup, GC-ECD/NPD analysis | 0.01 mg/kg as rcvd |

**Analyst's Comments:**

These samples were collected by yourselves and analysed as received at the laboratory.

Samples are held at the laboratory for one month (where appropriate) after reporting of results. After this date they are discarded unless otherwise advised by the submitter.



Colin Malcolm, BSc
Pesticides Client Manager