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Weed control in the kumara crop

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1 Executive summary

The development of herbicide-resistant weeds is a persistent global issue that now affects the New Zealand kumara industry. Local growers of kumara (*Ipomoea batatas* (L.) Lam.) have begun reviewing their weed control practices due to the spread of paraquat-resistant biotypes of black nightshade (*Solanum nigrum* L.) and small-flowered nightshade (*S. americanum* Mill.). This research project examines potential replacement weed control strategies for the kumara cropping system. Paraquat diagnostic rates were estimated, to allow identification of resistant populations. It was found that resistant nightshade populations are well established throughout the main production area, and that under similar herbicide regimes resistant populations could quickly but independently develop in other regions. Various alternate herbicide systems were evaluated in a field trial, conducted at a paraquat-resistant black nightshade site. The primary approach assessed residual herbicides to control general weed growth followed by contact herbicides to clean up any escapes. The residual herbicides Sylon, Frontier and Lasso were all useful, but Sylon was most effective, particularly against paraquat-resistant nightshade. Oxy*250 was also effective in cleaning up nightshade escapes. Herbicide residues were not detected in roots harvested under the Sylon/Oxy*250 spray regime. To minimise crop damage it is important that careful attention is given to season/site-appropriate herbicide selection and the delivery system.

2 Introduction

Herbicide-resistant weeds have become an escalating problem on a global scale, causing increasing levels of concern for economically sustainable crop production. Repeated use of a herbicide at low dosage levels effectively selects any portion of a weed population which shows resistance, removing only susceptible plants. The relative frequency of resistance genes within the remaining population increases. Through repeated cycles of plant germination, followed by herbicide selection and subsequent seed production, high levels of herbicide resistance may be found throughout an entire local population. Difficulties are also found following the continual use of residual herbicides, where after repeated chemical exposure soil microbe populations may become more efficient at degrading herbicides (Kaufman 1987).

Agrichemical resistance is not new to the kumara (*Ipomoea batatas* (L.) Lam.) industry: in the Dargaville-Ruawai district the scurf fungus (*Monilochaetes infuscans*) is recognised as resistant to benomyl fungicides. Field herbicide resistance generally only becomes noticeable when the frequency of resistant weeds becomes quite high (Gressel 1986). However, paraquat-resistant biotypes of black nightshade (*Solanum nigrum* L.) and small-flowered nightshade (*S. americanum Mill.*) have become increasingly widespread in the Dargaville-Ruawai region.

This research project was established to examine the problem of paraquat resistance and to investigate potential replacement weed control strategies for the New Zealand kumara cropping system. It should be borne in mind that crop production takes place in a dynamic synthetic ecosystem and weed control strategies will need to be continually modified to remain effective.

The project was jointly funded and supported by the MAF Sustainable Farming Fund, Horticulture New Zealand – Process Vegetable Product Research & Development Grants Committee and the Northern Wairoa Vegetable Growers' Association.

3 Dargaville field trial

3.1 Aim

To evaluate various herbicide systems for use in the kumara crop, with particular reference to controlling paraquat-resistant black nightshade.

3.2 Materials and methods

Based on the previous season's results and industry input, a number of herbicide combinations were selected for application in a field trial (Table 1). The trial site was on a commercial property situated near Dargaville, in a field

with an established history of paraquat-resistant black nightshade. The trial was laid out in a modified alpha row-column design, four columns wide by 16 rows long (see images in Appendix I) 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 every 30 cm along each row, with an inter-row spacing of 75 cm. Each plot therefore contained a total of four rows with 10 plants in each row, the two outer rows serving as guard rows.

Residual herbicides (Afalon, Frontier, Lasso, Oxy*250-C and Sylon) were applied immediately after planting and watering was complete, on 29 December 2005. Spray mixtures were applied at various chemical-specific water rates (Table 2, see also the water analysis in Appendix II). For the Afalon treatment, the herbicide was washed from the transplants' leaves immediately after application (as in the South African production system). The Oxy*250-C treatment plots were initially sprayed with water (608 L/ha) to simulate dew, prior to herbicide application. The weather was calm and dry during the application of residuals, but rain fell on following days, ensuring herbicide activation (Figure 1). Soil nutrient levels, organic matter content and level of exchangeable cations were assessed during the trial period (see soil analysis in Appendix III).

The first applications of contact herbicides (Gramoxone, Organic Interceptor, Oxy*250 and Tough) were made under calm, dry conditions on 11 January 2005 (Table 2). Oxy*250 treatment plots were again sprayed with water (608 L/ha) to simulate early morning dew, prior to herbicide application. Weed growth was light but relatively even throughout the trial, with the most advanced nightshade seedlings showing 2–3 true leaves (Appendix I: Plate 2).

The final applications of contact herbicides (Gramoxone, Organic Interceptor, Oxy*250 and Tough) were made under calm conditions (Table 2) in the early morning of 6 February 2005 (Appendix I: Plate 3). The Oxy*250 treatment plots were sprayed with herbicide while leaves were still naturally covered with a heavy early morning dew (Appendix I: Plate 4).

On 3 March, weed samples were collected from four 40 x 40 cm quadrats per plot (two on ridges and two in the valleys) and the control plots were carefully hand-weeded. The season was generally dry, so weed germination was relatively light. 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 10 April 2006, root total yield, marketable yield (roots greater than 2.5 cm in diameter) and marketable root numbers were recorded per plot (Appendix I: Plate 5). Roots were cut open to check for internal defects and root sub-samples were oven-dried at 80°C to assess the ratio of root dry matter to water content.

*Table 1: Herbicide product combinations and application times for a sweetpotato (*I. batatas *(L.) Lam.) herbicide trial at Dargaville over the 2005-06 season. The trial was planted on 29 December 2005 and harvested on 10 April 2006.*

Residual application 29/12/2005	1st contact application 11/01/2006	2nd contact application 6/02/2006	Weed assessed 3/03/2006	Treatment name
-	-	-	Hand-weeded	Hand-weeded
Frontier	Gramoxone	Gramoxone		Frontier-Gramoxone
Frontier	Oxy*250-A	Oxy*250-A		Frontier-Oxy*250
Afalon	Gramoxone	Gramoxone		Afalon-Gramoxone
Afalon	Oxy*250-A	Oxy*250-A		Afalon-Oxy*250
Sylon	Gramoxone	Gramoxone		Sylon-Gramoxone
Sylon	Oxy*250-A	Oxy*250-A		Sylon-Oxy*250
Lasso	Oxy*250-A	Oxy*250-A		Lasso-Oxy*250
-	Gramoxone	Gramoxone		Gramoxone
-	Gramoxone	Tough-A		Gramoxone-Tough-A
-	Gramoxone	Tough-B		Gramoxone-Tough-B
-	Organic Interceptor-A	Organic Interceptor-A		Organic Interceptor-A
-	Organic Interceptor-B	Organic Interceptor-B		Organic Interceptor-B
-	Oxy*250-A	Oxy*250-A		Oxy*250-A
-	Oxy*250-B	Oxy*250-B		Oxy*250-B
Oxy*250-B	Oxy*250-B	Oxy*250-B		Oxy*250-C

Full trademark names of products are as follows: Frontier®, Gramoxone®250, Lasso® Micro-Tech®, Afalon®, Organic Interceptor™, Oxy*250 SC, Sylon®840, Tough® 450 EC. Note that the extensions -A, -B and -C are to distinguish different application rates.

*Table 2: Chemical and application parameters for a sweetpotato (*I. batatas *(L.) Lam.) herbicide trial at Dargaville over the 2005-06 season.*

Product	Active ingredient	Concentrate formulation	Product application rate L/ha	Active ingredient L/ha	Water rate L/ha	Pressure bar	Number of applications	Season a.i. application L/ha
Frontier	Dimethenamid	900 g/L	2.0	1.80	300	3	1	1.800
Gramoxone	Paraquat dichloride	250 g/kg	0.4	0.10	300	3	2	0.200
Lasso	Alachlor	480 g/L	5.0	2.40	300	3	1	2.400
Afalon	Linuron	450 g/L	2.0	0.90	300	3	1	0.900
Organic Interceptor-A	Pine oil	510 g/L	35.3	18.00	300	3	2	36.000
Organic Interceptor-B	Pine oil	510 g/L	17.7	9.00	300	3	2	18.000
Oxy*250-A	Oxyfluorfen	250 g/L	0.4	0.10	481	1	2	0.200
Oxy*250-B	Oxyfluorfen	250 g/L	0.6	0.15	608	1	2	0.300
Oxy*250-C	Oxyfluorfen	250 g/L	0.6	0.15	608	1	3	0.450
Sylon	Acetochlor	840 g/L	2.5	2.10	300	3	1	2.100
Tough-A	Pyridate	450 g/L	1.0	0.45	300	3	1	0.450
Tough-B	Pyridate	450 g/L	0.5	0.225	300	3	1	0.225

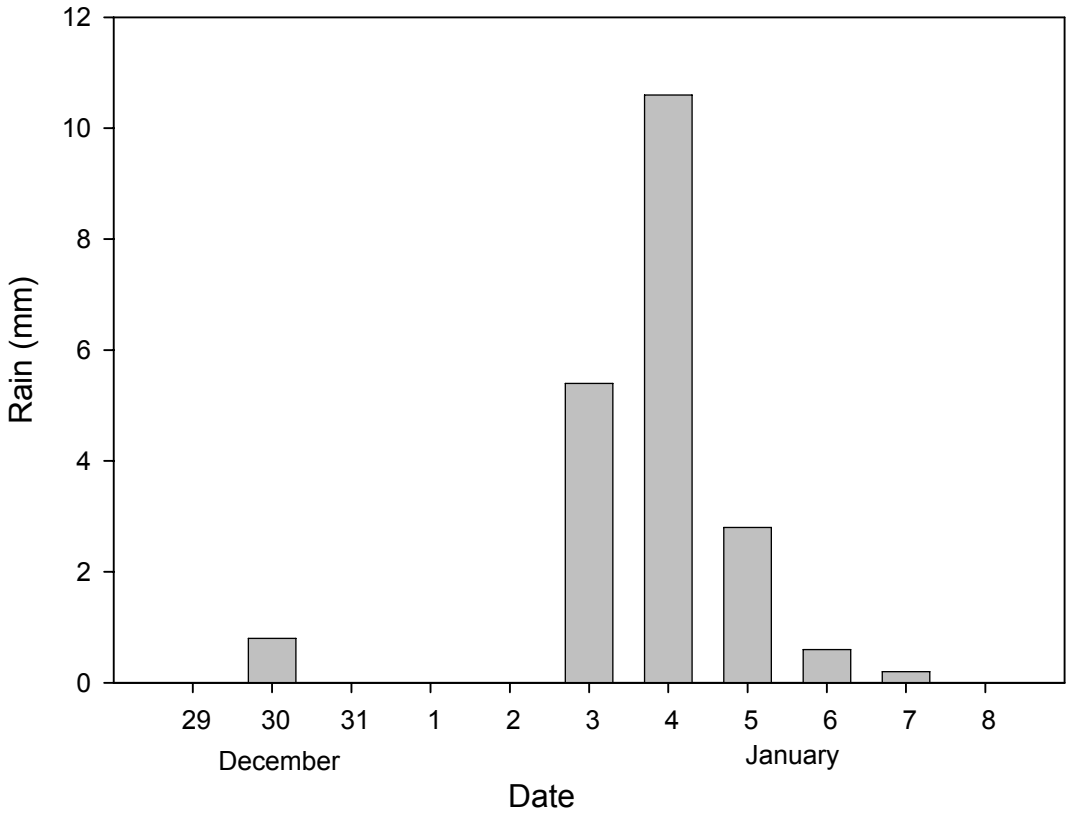


Figure 1: Daily rainfall (mm) at Dargaville over the period following residual herbicide application, 29 December 2006.

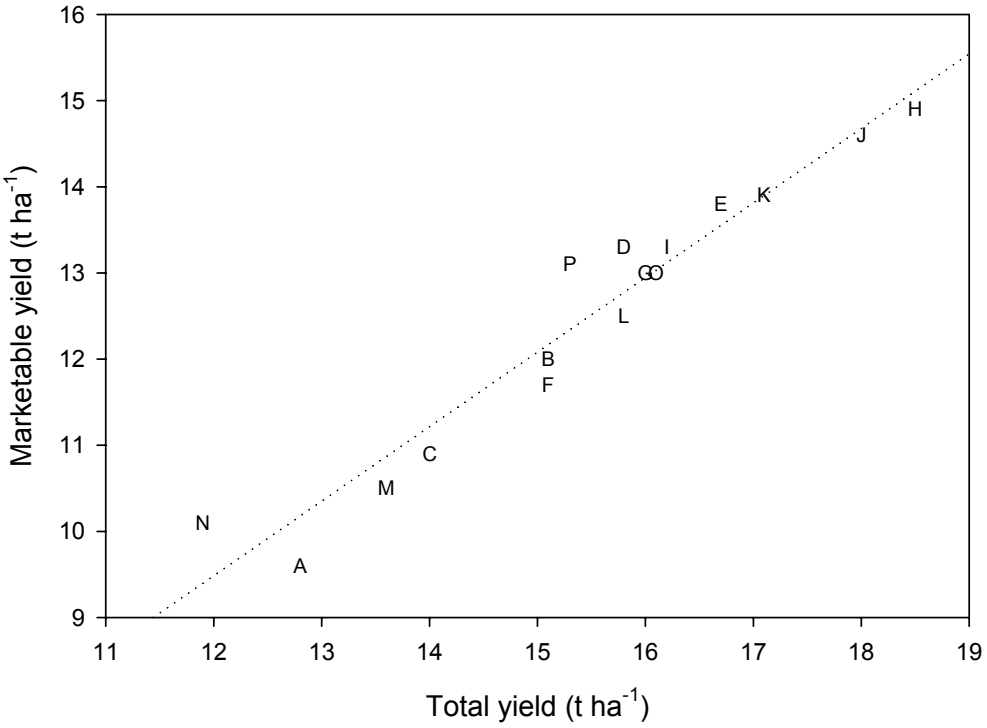
3.3 Results and discussion

Examining the trial results for evidence of crop damage, the herbicide regimes evaluated had a significant effect (Table 3) on total root yield (*P*<0.001), marketable yield (*P*<0.001), root dry matter content (*P*<0.001) and root number (*P*=0.020), but not on marketable percentage (*P*=0.24).

Table 3: Effects of various herbicide treatments on the yield of sweetpotato cultivar Owairaka Red at Dargaville during the 2005-06 season.

Treatment	Total yield t/ha	Marketable yield t/ha	% Marketable	Root dry matter %	Root number per m^2
Oxy*250-C	11.9	10.1	81.9	31.0	6.2
Afalon-Gramoxone	12.8	9.6	73.1	28.7	6.4
Oxy*250-B	13.6	10.5	76.1	29.8	7.1
Frontier-Gramoxone	14.0	10.9	76.9	27.2	7.3
Afalon-Oxy*250	15.1	12.0	77.1	28.5	7.6
Gramoxone-Tough-A	15.1	11.7	76.7	30.2	7.6
Sylon-Oxy*250	15.3	13.1	85.6	31.1	7.6
Frontier-Oxy*250	15.8	13.3	83.4	31.5	8.2
Oxy*250-A	15.8	12.5	80.1	29.0	8.2
Gramoxone-Tough-B	16.0	13.0	81.7	29.9	7.4
Sylon-Gramoxone	16.1	13.0	79.0	28.5	8.4
Lasso-Oxy*250	16.2	13.3	83.0	31.1	7.8
Gramoxone	16.7	13.8	79.5	28.6	8.6
Organic Interceptor-B	17.1	13.9	78.8	29.4	8.3
Organic Interceptor-A	18.0	14.6	79.3	30.2	9.8
Hand-weeded	18.5	14.9	80.0	30.7	9.7
$LSD_{0.95}$ (df = 30)	2.9	2.9	8.4	2.0	2.2
P value	<0.001	<0.001	0.24	<0.001	0.020

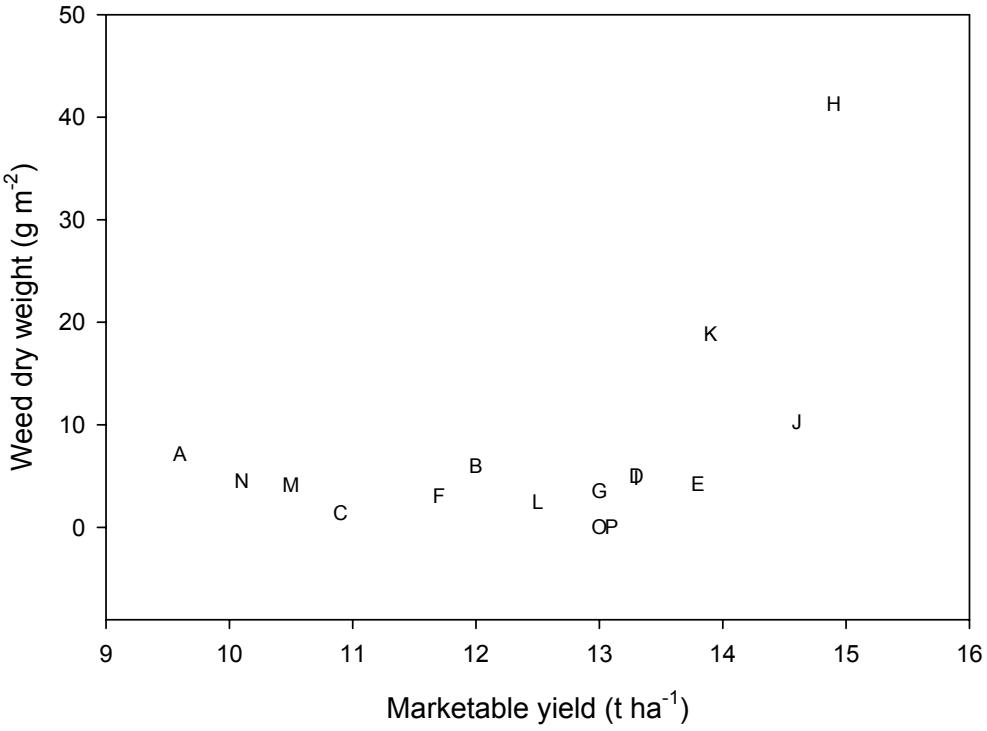
On average (Figure 2), marketable yield increased by 0.95 t/ha (SE = 0.062) for every 1 t/ha increase in total yield (P<0.001, R^2 = 94.7%).



Herbicide treatment key: (A) Afalon-Gramoxone, (B) Afalon-Oxy*250, (C) Frontier-Gramoxone, (D) Frontier-Oxy*250, (E) Gramoxone, (F) Gramoxone-Tough-A, (G) Gramoxone-Tough-B, (H) Hand-weeded, (I) Lasso-Oxy*250, (J) Organic Interceptor-A, (K) Organic Interceptor-B, (L) Oxy*250-A, (M) Oxy*250-B, (N) Oxy*250-C, (O) Sylon-Gramoxone, (P) Sylon-Oxy*250.

Figure 2: Comparison of total and marketable yield (t/ha) for sweetpotato cultivar Owairaka Red under different herbicide regimes. In the absence of any major defects, roots over 2.5 cm in diameter were considered marketable.

As the season was dry, weed competition was relatively low and marketable root yield was not related to weed density as assessed by weed canopy dry weight (Figure 3). The highest marketable yields were seen in the hand-weeded treatment (H), and the Organic Interceptor treatments (J and K), which also had the highest weed populations (Table 4). As there was no correlation between crop root yield and weed population density, the crop effects seen in Table 3 are indicative of direct herbicide phytotoxic effects, rather than a response via modifying weed competition. Based on these results, any of the weed control measures applied to this trial site could not be justified by improved economic returns within the evaluation season. However, failure to restrain weed growth and subsequent seed set could cause major problems in ensuing seasons.



Herbicide treatment key: (A) Afalon-Gramoxone, (B) Afalon-Oxy*250, (C) Frontier-Gramoxone, (D) Frontier-Oxy*250, (E) Gramoxone, (F) Gramoxone-Tough-A, (G) Gramoxone-Tough-B, (H) Hand-weeded, (I) Lasso-Oxy*250, (J) Organic Interceptor-A, (K) Organic Interceptor-B, (L) Oxy*250-A, (M) Oxy*250-B, (N) Oxy*250-C, (O) Sylon-Gramoxone, (P) Sylon-Oxy*250.

Figure 3: Weed dry weight (g/m^2) relative to marketable root yield (t/ha) within a sweetpotato Owairaka Red herbicide trial at Dargaville in the 2005-06 season.

Herbicide applications had a significant effect (Table 4) on weed growth, as measured by weed dry weight (P<0.001) and number (P<0.001). The trial site had a history of paraquat-resistant black nightshade, which was confirmed in the greenhouse by evaluating seed collected from the site. The number of nightshade plants growing under different herbicide regimes differed significantly (P<0.001). Black nightshade plants made the greatest contribution to total weed numbers (75.6%) under the Gramoxone (a.i. paraquat) treatment, compared with the overall treatment mean of 46.9% (Table 5).

The hand-weeded treatment gives a measure of weed number, mass and composition without the use of herbicides. Compared with the hand-weeded treatment, all other treatments showed a significant reduction in overall weed dry weight, but the Organic Interceptor treatments did not differ from hand-weeded plots in either overall weed numbers or in number of nightshade plants (Table 4). The Organic Interceptor treatment of the previous season appeared more effective in controlling the weed population, but under the trial conditions and application rates examined here, Organic Interceptor was not effective in weed control. It should also be noted that the Organic Interceptor formulation has been altered between the two seasons, as shown by the changing concentration of active ingredient from 680 g/L to 510 g/L.

Table 4: Effects of various herbicide treatments on the weed population within a sweetpotato Owairaka Red trial at Dargaville during the 2005-06 season.

Treatment	Weed dry weight g/m^2	Weed number/m^2	Nightshade number/m^2	Nightshade %
Sylon-Oxy*250	0.0	0.4	0.0	0.0
Sylon-Gramoxone	0.0	1.2	0.4	12.5
Frontier-Gramoxone	1.4	2.3	1.6	58.3
Oxy*250-A	2.5	7.8	2.7	29.5
Gramoxone-Tough-A	3.1	16.8	7.4	49.6
Gramoxone-Tough-B	3.5	18.4	6.3	36.6
Oxy*250-B	4.1	7.8	1.2	18.7
Gramoxone	4.2	10.2	6.6	75.6
Oxy*250-C	4.5	11.7	2.3	22.5
Lasso-Oxy*250	4.8	5.5	1.6	20.0
Frontier-Oxy*250	5.0	3.1	1.2	25.0
Afalon-Oxy*250	6.0	13.3	4.7	30.6
Afalon-Gramoxone	7.1	9.4	6.3	69.2
Organic Interceptor-A	10.3	23.1	15.2	73.5
Organic Interceptor-B	18.8	28.1	14.1	49.1
Hand-weeded	41.3	30.9	17.6	55.4
$LSD_{0.95}$ (df = 30)	15.1	10.08	5.61	
P value	<0.001	<0.001	<0.001	

Table 5: Weed population species composition (%) within a herbicide trial at Dargaville during the 2005-06 season.

Common name	Botanical name	Weed composition %
Nightshade	*Solanum nigrum*	46.9
Fathen	*Chenopodium album*	13.0
Redroot	*Amaranthus retroflexus*	26.3
White clover	*Trifolium repens*	9.9
Field speedwell	*Veronica arvensis*	1.6
Sow thistle spp.	*Sonchus spp.*	0.2
Scarlet pimpernel	*Anagallis arvensis*	0.4
Grass spp.		1.6

The primary weed management system evaluated in this trial was to apply a residual herbicide to control general weed growth followed by a contact spray to clean up any weed escapes. A comparison of the deleterious effects of herbicide regimes using either Gramoxone or Oxy*250 as the contact sprays, regardless of residual herbicide used, showed a very similar marketable yield response (Figure 4). The same comparison for total weed number showed a similar response (Figure 5). However, a contact herbicide comparison for black nightshade plants as a percentage of total weed numbers showed that the Oxy*250 group gave a significant reduction in nightshade plant numbers relative to those in the Gramoxone group (Figure 6).

Comparisons of three residual herbicide treatment groups based on Afalon, Frontier or Sylon, each supported by spraying with either Gramoxone or Oxy*250, showed similar marketable yield responses (Figure 7). However, the groups showed quite dissimilar responses in total weed dry weight (Figure 8), with the use of Sylon allowing minimal weed growth. Total weed numbers across these groups were similar (Table 4), so weeds growing under the Sylon treatment were of particularly reduced size. The three groups showed quite dissimilar responses in nightshade-specific weed control (Figure 9). Although the residual herbicides lowered the general weed population, the contact herbicide Gramoxone selectively allowed more of the paraquat-resistant black nightshade plants to escape. In each of the three examples in Figure 9, cleaning up weed escapes with applications of Gramoxone was not as effective for black nightshade as using Oxy*250, owing to the resistant nightshade contribution.

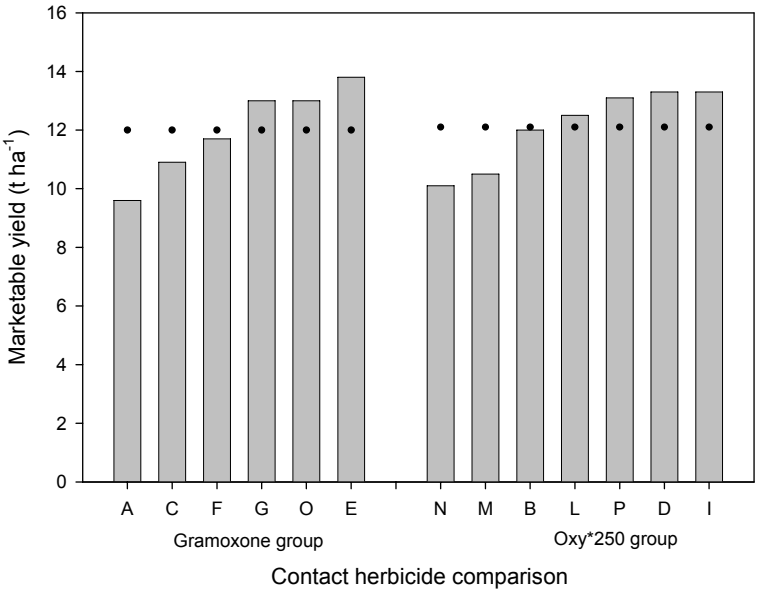


*Figure 4: Marketable yield (t/ha) for treatments including the contact herbicide Gramoxone compared with those including Oxy*250, disregarding other weed control measures. The mean marketable yield within each of the two groups is indicated by the dotted line.*

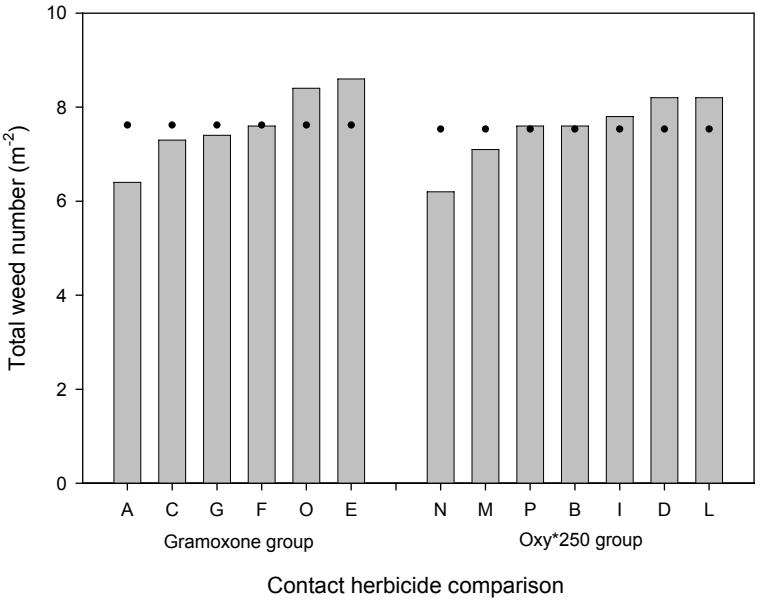


*Figure 5: Total weed number (per m^2) for treatments including the contact herbicide Gramoxone compared with those including Oxy*250, disregarding other weed control measures. The mean total weed number within each of the two groups is indicated by the dotted line.*

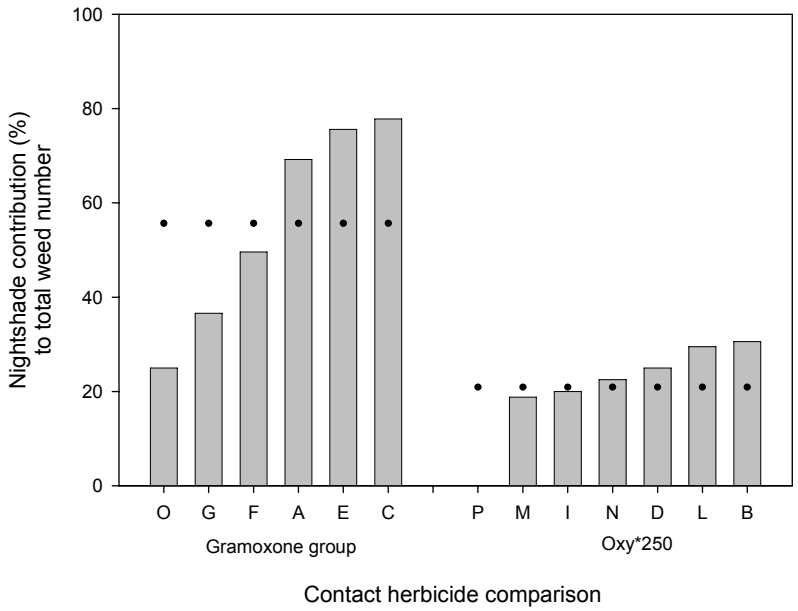


*Figure 6: Contribution of nightshade plants to total weed number (%) compared for treatments including the contact herbicide Gramoxone and those including Oxy*250, disregarding other weed control measures. The mean contribution of nightshade plants to total weed number within each of the two groups is indicated by the dotted line.*

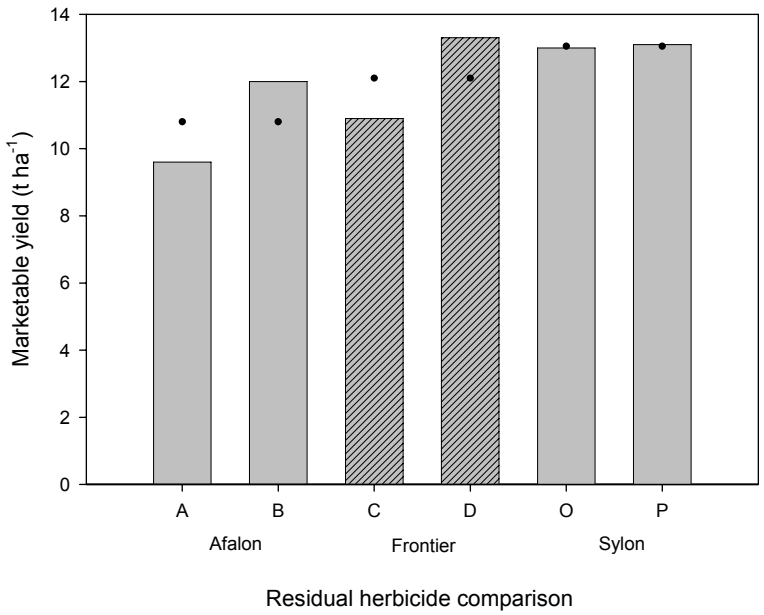


*Figure 7: Marketable yield (t/ha) for treatments including the residual herbicides Afalon, Frontier and Sylon. Within each residual herbicide group the contact herbicide Gramoxone is presented first, then the contact Oxy*250. The mean marketable yield within each of the groups is indicated by a dot.*

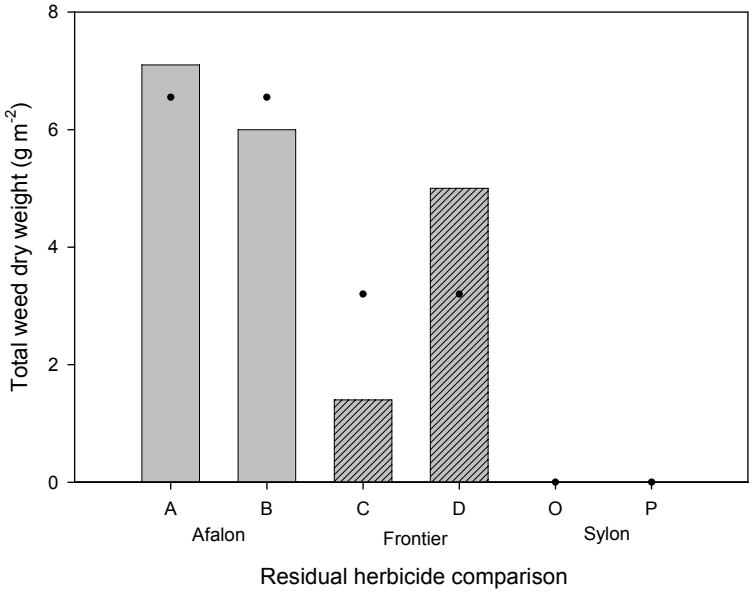


*Figure 8: Total weed dry weight (g/m^2) for treatments including the residual herbicides Afalon, Frontier and Sylon. Within each residual herbicide group the contact herbicide Gramoxone is presented first, then the contact Oxy*250. The mean total weed dry weight within each of the groups is indicated by a dot.*

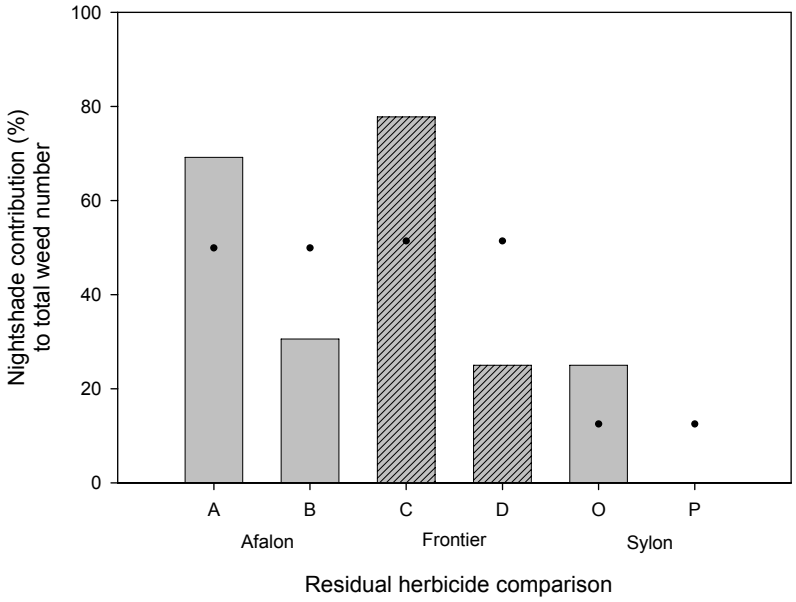


*Figure 9: Mean contribution of nightshade plants to total weed number (%) for treatments including the residual herbicides Afalon, Frontier and Sylon. Within each residual herbicide group the contact herbicide Gramoxone is presented first, then the contact Oxy*250. The contribution of nightshade plants to total weed number within each of the groups is indicated by a dot.*

4 Acetochlor evaluation

4.1 Aim

To determine whether applications of the residual herbicide acetochlor (Sylon) delay development of storage roots in the kumara cultivar Owairaka Red.

4.2 Materials and methods

The trial was situated at the Pukekohe Research Centre, and laid out in a randomised complete block arrangement on a Patumahoe clay loam soil site. The experiment was a complete two-way factorial design with each of the six factor combinations (i) Sylon; absent or present and (ii) Harvest date; 72, 98, 119 days after transplanting (DAT), being 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 every 30 cm along each row, with an inter-row spacing of 75 cm. Each plot therefore contained a total of four rows with 10 plants in each row, the two outer rows serving as guard rows. The residual herbicide Sylon (840 g/L acetochlor) was applied (2.1 L a.i. per ha) immediately after planting (19 January), and watered-in with overhead irrigation. Weeds were further controlled with two applications of the contact herbicide Gramoxone (250 g/kg paraquat) at 0.1 L a.i. per ha, followed by hand-weeding. Overhead irrigation was used to supplement rainfall throughout the trial period. Roots were hand-harvested at the three dates (72, 98, 119 DAT) and divided into two groups, those less than 2.5 cm in diameter and those equal to or greater than 2.5 cm. Roots were cut open to check for internal defects and root subsamples were oven-dried at 80°C to assess the ratio of root dry matter to water content.

4.3 Results and discussion

There was no evidence of an acetochlor-induced delay in storage root development over the trial's growing period (Table 8). As measured by total root weight on both a fresh weight and a dry weight basis, use of acetochlor significantly increased yield by 31% (P=0.028) and 33% (P=0.026), respectively. An increase was also evident for both root size categories, but the level of variability was such that it was not formally significant.

Comparison of the Sylon-Gramoxone treatment with Gramoxone alone in the Dargaville field trial (Table 3), also gave no evidence of an acetochlor induced yield loss.

A manufacturer's recommended precaution to prevent crop damage through acetochlor use, is to avoid prolonged cold and wet post-planting conditions, and soils with very low organic matter.

Table 8: Effects of acetochlor (Sylon) herbicide treatment on the yield of sweetpotato cultivar Owairaka Red at Pukekohe during the 2005-06 season.

	Roots < 2.5cm		Roots ≥ 2.5cm		Total root			
Sylon	Number per m^2	Weight g/m^2	Number per m^2	Weight g/m^2	Number per m^2	Weight g/m^2	Dry weight g/m^2	Dry matter content (%)
Absent	3.2	99	6.0	437	9.3	536	101	18.6
Present	5.0	133	5.5	571	10.5	704	134	18.4
$LSD_{0.95}$	2.3	59	1.4	142	2.7	147	29	0.64
P value	0.13	0.24	0.47	0.062	0.35	0.028	0.026	0.46

5 *Paraquat resistance in* S. americanum

5.1 Aim

To estimate the paraquat concentration required to kill resistant small-flowered nightshade (*S. americanum* Mill.) populations from the Dargaville-Ruawai production area.

5.2 Materials and methods

Small-flowered nightshade seed from the Dargaville-Ruawai and Waitakere regions was chilled at 5°C to break dormancy. The seed 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, the pots of small-flowered nightshade plants were sprayed with varying concentrations of paraquat. For the Dargaville-Ruawai population, each treatment was replicated across 20 pots, so that 180 individual plants were exposed to each paraquat concentration, apart from the lowest concentration which was replicated across nine pots. The six rates of paraquat (active ingredient) applied were 0.040, 0.16, 0.64, 2.56, 10.24 and 15.36 g ai/L. For the Waitakere population, each treatment was replicated across six pots, so that 54 individual plants were exposed to each paraquat concentration. The five rates of paraquat (active ingredient) applied were 0.010, 0.020, 0.040, 0.16 and 0.64 g ai/L. 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.

Curves were fitted (GenStat 2003) to the data generated by each population.

5.3 Results and discussion

The preliminary fitted curves for resistant and standard small-flowered nightshade populations (Figure 10) show similar shapes, but the resistant population requires higher paraquat concentrations to produce a response. A comparison of LD_{99} estimates for standard and resistant populations (Table 6) suggests that a concentration increase of more than 18-fold is required to kill resistant small-flowered nightshade. The shape of curves fitted for black nightshade (*S. nigrum* L.) seedlings (Figure 11) last season were similar to those for small-flowered nightshade populations. However based on these preliminary estimates of lethal dose concentrations for the paraquat-resistant small-flowered nightshade population (Table 6), the resistant black nightshade (Table 7) requires more than a 4-fold increase in concentration to produce similar death rates.

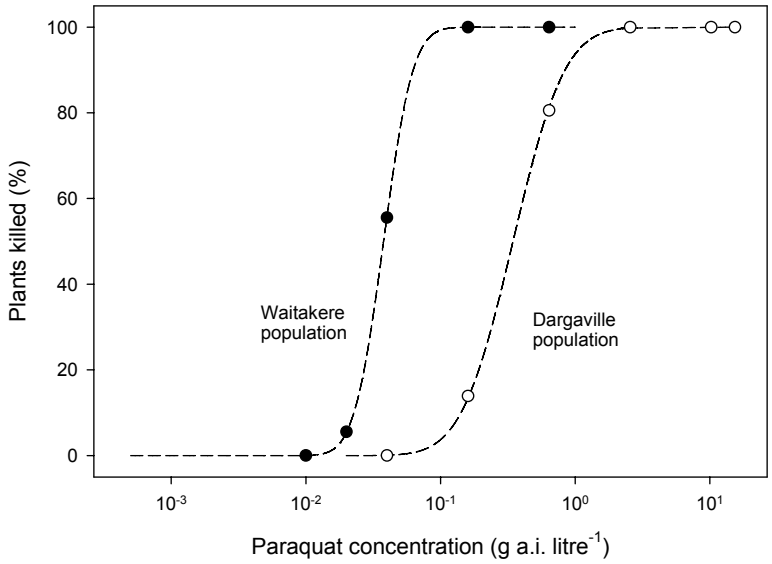


*Figure 10: Preliminary evaluation of fitted response curves for the percentage of small-flowered nightshade (*S. americanum Mill.*) seedlings killed at varying paraquat concentrations (g a.i. per litre). Small-flowered populations from Waitakere and Dargaville-Ruawai were compared. Paraquat concentration is presented on a logarithmic scale. Each dot represents the mean response of 54 plants for the Waitakere population and 180 treated plants for the Dargaville population (apart from the Dargaville resistance test treatment of 0.040 g a.i. per litre, which was based on 81 plants).*

*Table 6: Estimates of the paraquat concentration (g a.i. per litre) required for lethal dose (LD) thresholds of 50, 95 and 99% plant death in two populations of small-flowered nightshade (*S. americanum *Mill.). Standard errors (SE) and 95% confidence levels are given. This table is based solely on preliminary experimental data from seedlings with one true leaf at the time of spray application.*

Population	LD	Estimate g a.i./litre	SE g a.i./litre	Lower 95% g a.i./litre	Upper 95% g a.i./litre
Waitakere					
	50	0.038	0.0704	0.034	0.044
	95	0.072	0.1686	0.058	0.111
	99	0.095	0.2188	0.071	0.167
Dargaville					
	50	0.345	0.0555	0.310	0.384
	95	1.080	0.0991	0.910	1.341
	99	1.734	0.1291	1.390	2.305

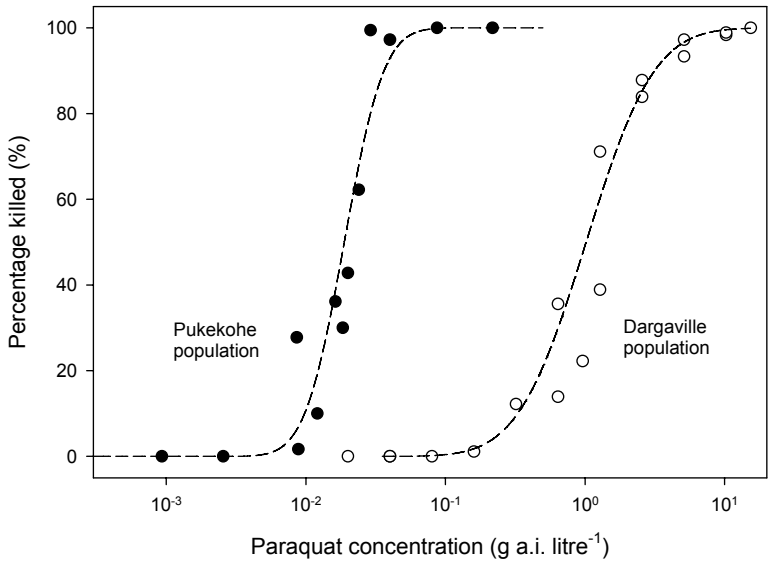


*Figure 11: Fitted response curves for the percentage of black nightshade (*S. nigrum *L.) seedlings killed at varying paraquat concentrations (g/litre). Black nightshade populations from Pukekohe and Dargaville-Ruawai were compared. Paraquat concentration is presented on a logarithmic scale and each dot represents the mean response of 180 treated plants.*

Table 7: Estimates of the paraquat concentration (g a.i. per litre) required for lethal dose (LD) thresholds of 50, 95 and 99% plant death in two populations of black nightshade (S. nigrum *L.). Standard errors (SE) and 95% confidence levels are given. This table is based solely on experimental data from seedlings with one true leaf at the time of spray application.*

Population	LD	Estimate g a.i./litre	SE g a.i./litre	Lower 95% g a.i./litre	Upper 95% g a.i./litre
Pukekohe					
	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
Dargaville					
	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 Paraquat resistance selection in black nightshade

Seed from a standard Pukekohe black nightshade population was sown in the 2004-05 season. The seedlings were transferred to pots and grown until the second true leaf was just appearing. A total of 20 pots of plants were prepared, at nine plants per pot, giving 180 individual plants. The plants were sprayed with paraquat at a concentration of 0.040 g ai/L. Two of these plants survived, so the survival rate was 1.1%. The surviving plants were grown on and their ripe berries harvested. The extracted seed was sown in the 2005-06 season, and the process repeated. A total of 24 pots of plants were prepared, at nine plants per pot, giving 216 individual plants. Following an application of paraquat, again at 0.040 g ai/L, six plants survived, giving a survival rate of 2.8%. It appears that paraquat-resistant black nightshade selection is relatively rapid under repeated low application rates.

7 General conclusions

Although paraquat remains a useful tool in controlling weeds of the kumara crop, it will require increasing support from other herbicides. This can be seen in the local development of paraquat-resistant biotypes of black and small-flowered nightshade, along with the wide spectrum of paraquat-resistant species seen globally. Selection of paraquat-resistant biotypes can occur rapidly, as was demonstrated by artificial selection for a resistant population from within a normal Pukekohe black nightshade population. The

establishment of diagnostic paraquat rates for black and small-flowered nightshade populations will assist in determining site-specific weed control strategies.

Residual and contact herbicide combinations appear useful for general weed control in the kumara crop. A residual herbicide lowers the number of viable weeds, while a contact spray cleans up any weed escapes. Of the residual herbicides, acetochlor (Sylon) was particularly effective (Figure 8), including good control of paraquat-resistant nightshade (Table 4).

There was no evidence that the use of acetochlor delayed crop development (Table 8), but there is a manufacturer's recommendation to avoid prolonged cold and wet post-planting conditions, and soils with very low organic matter.

The residual herbicides Sylon, Frontier and Lasso were all useful, but require rain or soil incorporation to increase their effectiveness. Frontier needs to be applied at relatively higher rates on soils with high cation exchange capacities.

The contact spray Organic Interceptor, as applied in this season's field trial, was not effective in weed control. Oxyfluorfen (Oxy*250) was effective against paraquat-resistant nightshade (Figure 6), but requires careful application. To minimise crop damage, oxyfluorfen is applied at high water rates, at very low pressure and through spray nozzles that form large droplets. It is preferable that application takes place when there is a heavy dew, to facilitate chemical shedding by the kumara leaves. The acetochlor/oxyfluorfen combination provided the greatest control over paraquat-resistant nightshade germination and growth.

There are further potentially useful herbicide systems to explore, and only a small sample could be evaluated here. Knowing that herbicides will be constantly challenged by the development of weed resistance and changing weed spectrum suggests a need for equal persistence in evaluating new techniques for weed control.

8 Acknowledgements

Horticulture New Zealand and the MAF Sustainable Farming Fund are both thanked for supporting and funding this project. New Zealand kumara growers and agrichemical supply companies are thanked for their many suggestions and inputs. The advice of M. Freeman on Oxy*250 application techniques is gratefully acknowledged. T. Conner is thanked for supplying the Waitakere *S. americanum* seed. The generous assistance and support of D. & G. Suckling was much appreciated.

9 References

Gressel J 1986. Modes and genetics of herbicide resistance in plants. Pesticide resistance: Strategies and tactics for management. Washington DC, National Academy Press, Pp 54-73.

Kaufman DD 1987. Accelerated biodegradation of pesticides in soil and its effect on pesticide efficacy. Proceedings 1987 British Crop Protection Conference, Weeds. Vol 2: 515-522.

Appendix I Images from Dargaville herbicide trial site

*Plate 1: The Dargaville herbicide trial site just prior to sweetpotato (*I. batatas *(L.) Lam.) cultivar Owairaka Red plant establishment, 29 December 2005. This site has an established history of sweetpotato production coincident with high population densities of seedling paraquat-resistant black nightshade (*S. nigrum *L.).*

*Plate 2: Seedling paraquat-resistant black nightshade (*S. nigrum *L.) and seedling redroot (*Amaranthus retroflexus *L.) at the Dargaville site at the time of first contact herbicide application, 11 January 2006.*

*Plate 3: The sweetpotato (*I. batatas *(L.) Lam.) herbicide trial site at the time of second contact herbicide application, 6 February 2006.*

*Plate 4: Morning (8 am) dew levels on sweetpotato (*I. batatas *(L.) Lam.) cultivar Owairaka Red leaves at the time of second contact herbicide application, 6 February 2006.*

*Plate 5: Harvest of the sweetpotato (*I. batatas *(L.) Lam.) cultivar Owairaka Red herbicide trial at Dargaville, 10 April 2006.*

Appendix II Water chemical analyses: Pukekohe (Puke 1) Dargaville (Darga 1)

Hill Laboratories

R J Hill Laboratories Limited

Address: 1 Clyde Street, Private Bag 3205, Hamilton, New Zealand
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Facsimile: +64 (7) 858-2001
Email: mail@hill-labs.co.nz
Internet: www.hill-labs.co.nz

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

Laboratory No: 406235
Date Registered: 10/02/2006
Date Completed: 3/03/2006
Page Number: 1 of 4

The results for the analyses you requested are as follows:

Sample Type: Water,

Sample Name	Puke 1	Darga 1
Lab No	406235/1	406235/2
pH [7.0 - 8.5] (pH units)	6.3	9.8
Electrical Conductivity [<150] (mS/m)	28.7	11.9
Electrical Conductivity [<1500] (µS/cm)	287	119
Approx Total Dissolved Salts [<1000] (g.m-3)	192	80
Alkalinity [No Guideline] (g.m-3 as CaCO3)	28	43
Free carbon dioxide [No Guideline] (g.m-3)	27	< 1
Calcium [No Guideline] (g.m-3)	12.0	17.1
Magnesium [No Guideline] (g.m-3)	12.6	0.212
Total Hardness [<200] (g.m-3 as CaCO3)	82	44
Sodium [<200] (g.m-3)	21.9	5.6
Potassium [No Guideline] (g.m-3)	1.6	1.1
Nitrate-N [<11.3] (g.m-3)	17.0	0.30
Chloride [<250] (g.m-3)	26.1	7.8
Sulphate [<250] (g.m-3)	2.6	1.2
Boron [<1.4] (g.m-3)	0.042	0.039
Total Iron [<0.2] (g.m-3)	< 0.01	< 0.01
Total Manganese [<0.05] (g.m-3)	< 0.005	< 0.005
Total Copper [<1] (g.m-3)	0.089	< 0.005
Total Zinc [<3] (g.m-3)	0.287	0.034

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 406235/1

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.

With the pH and alkalinity levels found, this water could be corrosive towards metal piping and fixtures.

Hardness/Total Dissolved Salts Assessment
The water contains a low 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 at a significant level in this water, and we would advise against giving this water to very young children.

Such a high nitrate-nitrogen level is unusual and may indicate contamination from nearby septic tanks or effluent ponds. If this is a possibility then the water should also be checked for the presence of pathogenic bacteria. We cannot provide this analysis ourselves but can recommend appropriate laboratories if you so wish.

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.

Neither element was detected in this water, which is a pleasing feature. Treatment to remove iron and/or manganese should not be necessary.

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

Final Assessment
The parameters pH and Nitrate-N 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.

Routine Water Assessment for Sample Nr 406235/2

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.

With the pH and alkalinity levels found, it is unlikely this water will be corrosive towards metal piping and fixtures. This water has an unusually high pH which could be indicative of contact with new concrete or cement or from alkaline cleaning agents. Water with such a high pH may have an unusual taste and a soapy feel.

Hardness/Total Dissolved Salts Assessment
The water contains a very low amount of dissolved solids and would be regarded as being soft.

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.

Neither element was detected in this water, which is a pleasing feature. Treatment to remove iron and/or manganese should not be necessary.

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

Final Assessment
The parameter pH 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	2

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 0.45µm 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 20th ed. 1998	0.1 pH units
Electrical Conductivity [<150]	Conductivity meter, 25°C APHA 2510 B 20th ed. 1998	0.1 mS/m
Electrical Conductivity [<1500]	Conductivity meter, 25°C APHA 2510 B 20th ed. 1998	1 µS/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) 20th 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 20th 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 20th 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 20th ed. 1998	0.05 g.m-3
Chloride [<250]	Filtered sample. Ion Chromatography. APHA 4110 B 20th ed. 1998	0.5 g.m-3
Sulphate [<250]	Filtered sample. Ion Chromatography. APHA 4110 B 20th 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 nutrient analysis: Dargaville trial site (Darga S1)

Hill Laboratories

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Internet: www.hill-labs.co.nz

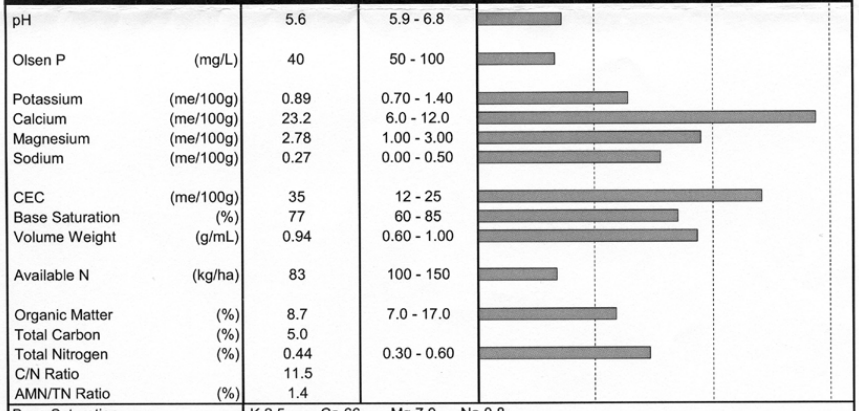
ANALYSIS RESULTS

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

Laboratory No.: 291800/1
Registered: 10-Feb-2006
Reported: 20-Feb-2006
Order No.: 29135
Submitted By: Mr S Lewthwaite
Client Ref:

Sample Name: Darga S1
Sample Type: SOIL Sweet Potato (S75)

Analysis		Level Found	Medium Range
pH		5.6	5.9 - 6.8
Olsen P	(mg/L)	40	50 - 100
Potassium	(me/100g)	0.89	0.70 - 1.40
Calcium	(me/100g)	23.2	6.0 - 12.0
Magnesium	(me/100g)	2.78	1.00 - 3.00
Sodium	(me/100g)	0.27	0.00 - 0.50
CEC	(me/100g)	35	12 - 25
Base Saturation	(%)	77	60 - 85
Volume Weight	(g/mL)	0.94	0.60 - 1.00
Available N	(kg/ha)	83	100 - 150
Organic Matter	(%)	8.7	7.0 - 17.0
Total Carbon	(%)	5.0	
Total Nitrogen	(%)	0.44	0.30 - 0.60
C/N Ratio		11.5	
AMN/TN Ratio	(%)	1.4	



Base Saturation	K 2.5	Ca 66	Mg 7.9	Na 0.8
MAF Units	K 17	Ca 27	Mg 59	Na 12
Anaerobically Mineralisable N	59 ug/g			

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.

Laboratory Comments

Analysis Comments
The high CEC level found in this soil indicates that it has a high capacity to retain cation nutrients (potassium, calcium, magnesium and sodium). The normal ranges and the derived histograms are based on a typical soil with a CEC level between 12 and 25 me/100g.

The % base saturation data for each element, shown at the base of the nutrient graph, provides an alternative presentation that may be more appropriate for soils with atypical CEC values.Normal %BS levels, as a general guide, are: K 2%-5%, Ca 50%-75%, Mg 5%-15%, Na 1%-2%.

End of Laboratory Comments

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

Hill Laboratories

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Email: mail@hill-labs.co.nz
Internet: www.hill-labs.co.nz

ANALYSIS RESULTS

Client: Crop & Food Research
Address: 49 Cronin Road, R D 1, PUKEKOHE

Client Phone: 09 238 6414

Laboratory No.: 291800
Registered: 10-Feb-2006
Reported: 20-Feb-2006
Order No.: 29135
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
Anaerobically Mineralisable N*	As for Available Nitrogen but reported as ug/g.	-
Available Nitrogen*	Anaerobic incubation followed by extraction using 2M KCl followed by Berthelot colorimetry. (Calculation based on 15cm depth sample).	-
Total Nitrogen*, Total Carbon*	Dumas combustion.	-
Organic Matter	Organic Matter is 1.72 x Total Carbon.	5

* Indicates a non IANZ accredited test.

Signatory: W.M. Homewood

Wendy Homewood
Quality Assurance Officer

Appendix IV Sweetpotato root tissue herbicide residue analysis

Sample name	Herbicide applied	Active ingredient
Herb A	Gramoxone	Paraquat dichloride
Herb B[a]	Sylon	Acetochlor
Herb C[a]	Lasso	Alachlor
Herb D[a]	Frontier	Dimethenamid
Herb E[a]	Afalon	Linuron

[a]As these samples were from plots sprayed with Oxy*250, this evaluation also tests for the presence of oxyfluorfen.

Hill Laboratories

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Internet: www.hill-labs.co.nz

Client: Crop & Food Research
Address: Private Bag 4704, Christchurch
Contact: Steve Lewthwaite

Laboratory No: 414567
Date Registered: 13/04/2006
Date Completed: 26/05/2006
Page Number: 1 of 3

Client's Reference: Herbicide 05-06

The results for the analyses you requested are as follows:

Sample Type: Biological Materials, Vegetable

Sample Name	Lab No	Diquat (mg/kg as rcvd)	Paraquat (mg/kg as rcvd)
Herb A	414567/1	< 0.1	< 0.2

Note: "<" = No residues were found above this detection limit.

Sample Type: Biological Materials, Vegetable

Multiresidue Pesticide Analysis

Sample Name	Herb B	Herb C	Herb D	Herb E
Lab No	414567/2	414567/3	414567/4	414567/5
Units	(mg/kg as rcvd)	(mg/kg as rcvd)	(mg/kg as rcvd)	(mg/kg as rcvd)
Multiresidue Screen	No Residues Detected. See Appendix A1			

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
Diquat	Water extraction, SPE clean up. HPLC analysis	0.1 mg/kg as rcvd
Paraquat	Water extraction, SPE clean up. HPLC analysis	0.2 mg/kg as rcvd
Multiresidue Pesticide Analysis	Extraction, GPC cleanup, analysis by GC-ECD/NPD. Confirmation by GC-MS.	See Appendix A1

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
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Appendix 1: Pesticides - Multiresidue GC Screen

The following table lists the compounds covered by the Multi-residue Pesticide and Herbicide Screen along with the detection limits in mg/kg on an as received basis. These detection limits were determined using an apple matrix and statistically evaluated using US-EPA protocols. (V11-02-05-GFC)

Compound	DL mg/kg
Acephate	0.02
Acetochlor	0.01
Alachlor	0.01
Aldrin	0.005
Atrazine	0.01
Atrazine-desethyl	0.01
Atrazine-desisopropyl	0.03
Azaconazole	0.01
Azinphos methyl	0.02
Azoxystrobin	0.02
Benalaxyl	0.01
Bendiocarb	0.01
Benodanil	0.01
Benoxacor	0.01
BHC (alpha)	0.005
BHC (beta)	0.005
BHC (delta)	0.005
Bifenox	0.01
Bifenthrin	0.01
Bitertanol	0.01
Bromacil	0.01
Bromophos ethyl	0.01
Bromopropylate	0.01
Bupirimate	0.01
Buprofezin	0.01
Butachlor	0.01
Butamifos	0.01
Cadusafos	0.01
Captafol	0.01
Captan	0.01
Carbaryl	0.02
Carbofenothion	0.01
Carbofuran	0.01
Carboxin	0.01
Chlordane, cis-	0.005
Chlordane, trans-	0.005
Chlorfenvinphos (E+Z)	0.01
Chlorfluazuron	0.01
Chlorobenzilate	0.01
Chlorothalonil	0.01
Chlorphenapyr	0.01
Chlorpropham	0.01
Chlorpyrifos	0.01
Chlorpyrifos methyl	0.01
Chlorthal-dimethyl	0.01
Chlortoluron	0.01
Chlozolinate	0.01
Clomazone	0.02
Coumaphos	0.02
Cyanazine	0.01
Cyanophos	0.01
Cyfluthrin	0.01
Cyhalothrin	0.01
Cypermethrin	0.01
Cyproconazole	0.01
Cyprodinil	0.02
DDD (2,4')	0.005

Compound	DL mg/kg
DDD (4,4')	0.005
DDE (2,4')	0.005
DDE (4,4')	0.005
DDT (2,4')	0.005
DDT (4,4')	0.005
Deltamethrin	0.01
Demeton-S-methyl	0.03
Diazinon	0.01
Dichlobenil	0.01
Dichlofenthion	0.01
Dichlofluanid	0.01
Dichloran	0.01
Dichlorvos	0.03
Dicofol	0.05
Dicrotophos	0.01
Dieldrin	0.005
Difenoconazole	0.01
Diflufenican	0.01
Dimethenamid	0.01
Dimethoate	0.02
Dimethylvinphos	0.01
Dinocap	0.05
Dioxabenzofos (Salithion)	0.01
Diphenylamine	0.02
Disulfoton	0.05
Diuron	0.02
Edifenphos	0.01
Endosulphan I	0.005
Endosulphan II	0.005
Endosulphan sulphate	0.005
Endrin	0.005
Endrin Aldehyde	0.005
Endrin Ketone	0.005
EPN	0.01
Epoxiconazole	0.02
EPTC	0.01
Esfenvalerate	0.01
Esprocarb	0.02
Ethion	0.01
Ethoprophos	0.01
Etridiazole	0.02
Etrimphos	0.01
Famphur	0.01
Fenamiphos	0.01
Fenarimol	0.01
Fenchlorphos	0.01
Fenitrothion	0.01
Fenobucarb	0.02
Fenoxaprop-ethyl	0.02
Fenpiclonil	0.01
Fenpropathrin	0.01
Fenpropimorph	0.01
Fensulfothion	0.01
Fenthion	0.01
Fenvalerate	0.01
Fluazifop-butyl	0.01
Flucythrinate	0.01

Compound	DL mg/kg
Fludioxonil	0.02
Fluometuron	0.01
Flusilazole	0.02
Flutriafol	0.02
Fluvalinate	0.01
Folpet	0.01
Fonofos	0.01
Furalaxyl	0.01
Furathiocarb	0.02
Halfenprox	0.01
Haloxyfop-methyl	0.01
HCB	0.005
Heptachlor	0.005
Heptachlor Epoxide	0.005
Hexaconazole	0.01
Hexazinone	0.01
Hexythiazox	0.03
Imazalil	0.03
Indoxacarb	0.01
Iodofenphos	0.01
Iprobenfos	0.01
Iprodione	0.01
Isazophos	0.01
Isofenphos	0.01
Isoprocarb	0.02
Kresoxim methyl	0.01
Leptophos	0.01
Lindane (gamma-BHC)	0.005
Linuron	0.05
Malathion	0.01
Mepronil	0.02
Metalaxyl	0.02
Methacrifos	0.01
Methamidophos	0.02
Methidathion	0.01
Methiocarb	0.02
Methoxychlor	0.005
Metolachlor	0.01
Metribuzin	0.01
Mevinphos	0.01
Monocrotophos	0.01
Myclobutanil	0.01
Naled	0.03
Napropamide	0.02
Nitrofen	0.01
Nitrothal-isopropyl	0.01
Norflurazon	0.01
Omethoate	0.03
Oxadiazon	0.01
Oxadixyl	0.01
Oxychlordane	0.005
Oxyfluorfen	0.01
Paclobutrazol	0.01
Parathion ethyl	0.01
Parathion methyl	0.01
Penconazol	0.01
Pendamethalin	0.01

Compound	DL mg/kg
Permethrin	0.01
Phenthoate	0.01
Phorate	0.01
Phosalone	0.02
Phosmet	0.01
Phosphamidon	0.01
Pirimicarb	0.01
Pirimiphos methyl	0.01
Prochloraz	0.01
Procymidone	0.01
Profenofos	0.01
Prometryn	0.01
Propachlor	0.02
Propaphos	0.01
Propazine	0.01
Propetamphos	0.01
Propham	0.01
Propiconazole	0.01
Propoxur	0.02
Propyzamide	0.01
Prothiofos	0.01
Pyraclofos	0.02
Pyrazophos	0.01
Pyrazoxyfen	0.02
Pyrethrin	0.03
Pyrifenox	0.01
Pyrimethanil	0.01
Pyriproxyfen	0.02
Quinalphos	0.01
Quintozene	0.01
Quizalofop-ethyl	0.01
Simazine	0.01
Simetryn	0.02
Sulfentrazone	0.01
Sulfotep	0.01
Tebufenpyrad	0.01
Terbacil	0.01
Tebuconazole	0.01
Terbufos	0.01
Terbumeton	0.01
Terbuthylazine	0.01
Terbuthylazine desethyl	0.01
Terbutryn	0.02
Tetrachlorvinphos	0.01
Tetradifon	0.01
Thenylchlor	0.01
Thiobencarb	0.01
Thiometon	0.02
Tolclofos-methyl	0.01
Tolylfluanid	0.01
Triadimefon	0.01
Tri-allate	0.02
Triazophos	0.01
Trifloxystrobin	0.02
Trifluralin	0.01
Vinclozolin	0.02