An Investigation into the Potential use of Sea Lettuce (*Ulva lactuca*) as a Soil Amendment in Vegetable Gardens and Orchards

Contract Report for Bay of Plenty Regional Council

July 2013

PlusGroup RESEARCH

Fiona Dean, Shirley Miller and Allister Holmes

Contents

1 BACKGROUND

Sea lettuce (*Ulva lactuca*) is a type of marine algae that is native to New Zealand. It frequently blooms in large numbers in Tauranga Harbour and once it washes up on the foreshore it creates a public nuisance. This is due to the algae forming thick mats which blanket the foreshore and undergo anaerobic decomposition, creating a gaseous release of sulphurous compounds. The smell from decomposing sea lettuce can become overwhelming at times, especially in certain areas of Tauranga Harbour such as Kulim Park, and the Bay of Plenty Regional Council has assisted in the removal of the sea lettuce from these areas. The Bay of Plenty Regional Council has been monitoring sea lettuce in the harbour since 1991, due to a large number of complaints made about the amount of sea lettuce accumulating in shallow areas of the harbour (Bay of Plenty Regional Council, 2011).

The Regional Council have been recently evaluating different methods of disposal of sea lettuce, which is currently being transported to a composting facility near Papamoa. One such proposal is the application of sea lettuce directly to kiwifruit and avocado orchards within close proximity to the harbour. The other option is to encourage home gardeners to utilise sea lettuce as a soil amendment in their vegetable gardens. Ideally the council would like to minimise transport distances and subsequent cost by utilising nearby orchards and properties as repositories for the sea lettuce.

Anecdotal evidence from avocado orchardists has suggested that sea lettuce has a number of properties that make it suitable as a mulch and soil amendment on orchards. For example, Tauranga Harbour Watch has produced a booklet outlining the potential benefits of using sea lettuce as a soil amendment in the home garden.

Sea lettuce has proven to be a useful soil amendment because it not only provides macro-nutrients such as nitrogen, phosphorus and potassium, but also contains many of the micronutrients required by plants (Eyras et al., 1998). Several studies have shown that seaweed may have different effects on different plants. A study in Patagonia, Argentina, showed that seaweed compost increased plant yield and plant biomass for tomato plants (Eyras et al., 2008). However, a study in Florida used seaweed and yard trimmings as an amendment, which resulted in a lower dry matter content of shoots of *yarrow* and shooting star plants (Moore, 2004). Potential problems with *Ulva spp* amendments found by researchers are the high sodium and heavy metal content which can be detrimental to healthy crop growth and soils (Cuomo et al., 1995).

2 OBJECTIVES

To determine:

1. Any detrimental effects of sea lettuce application to orchard or garden soils
2. The effect of sea lettuce application on the growth of vegetable plants

In order to carry out objective No. 1, the trial was conducted in such as way as to provide a ‘worst-case scenario’ in terms of the potential utilisation of sea lettuce as a soil amendment.

3 EXPERIMENTAL FIELD TRIAL

A small scale field trial was carried out over 6 months between November 2012 and May 2013 on a site near the Wairoa River in the Western Bay of Plenty which comprised a kiwifruit orchard, an avocado block and a vegetable garden. These were all within close proximity to one another with good quality, allophonic sandy loam soils.

Sea lettuce was collected by BOP Regional Council contractors on three occasions during the trial with a mechanical harvester from the foreshore at Kulim Park adjacent to Tauranga Harbour (Fig 1).

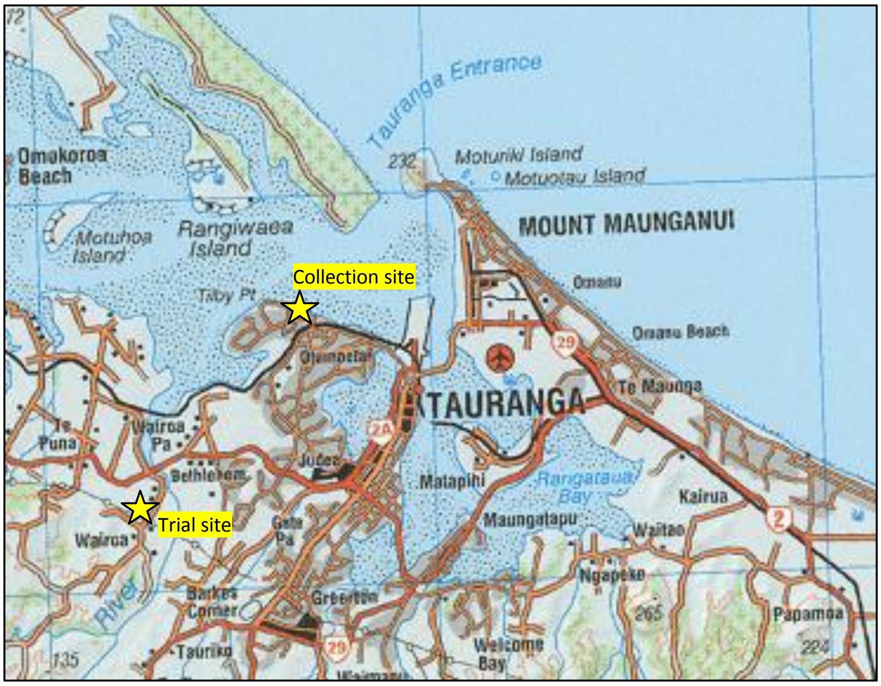


Fig. 1. Location of sea lettuce collection site and trial site

It was then left to de-water for 24hrs and transported by truck to the trial site where it was deposited in a large mound adjacent to where it was to be applied. The sea lettuce was not washed prior to use. The consistency of the sea lettuce was non-homogenous and contained a mixture of fresh and decomposing material which also contained sand and biological material such as eel grass, woody debris, shellfish, crabs and other marine life. Samples from each of the three batches of sea lettuce delivered to the site were analysed for chemical/nutrient composition.

3.1 Experimental Design, Sampling and Measurements

Kiwifruit plots

A total of twenty 0.5m x 2m plots were positioned under the canopy of the kiwifruit orchard and were randomly assigned to one of 4 treatments:

1. Control (no sea lettuce application)
2. 1 application
3. 2 applications
4. 3 applications

Prior to the initial applications of sea lettuce, soil samples were taken from each plot, composited according to treatment and analysed for chemical composition. The first application of sea lettuce was made on 13 November 2012 to all but the control plots (Photo 1). Two buckets-full (approx. 4.5kg each) were applied to each 1m^2 plot which were staked and cordoned off so as to prevent disturbance by orchard operations.

Photo 1. Sea lettuce plot under kiwifruit vines immediately after first application.

Subsequent applications of the same quantity were made on the 21 December for 2 and 3 application treatments and the 20th February for 3 application treatments. The sea lettuce was not dug into the soil and was left to break down over time (Photos 2 & 3). Soil was again sampled on the 16 May 2013, composited according to treatment and analysed.

Photo 2. Sea lettuce plot 16 days after application. Photo 3. Sea lettuce plot 1 month after application.

Avocado Plots

A total of twenty $1m^2$ plots were positioned under the canopy of each of twenty adjacent avocado trees. These were then randomly assigned to one of the 4 treatments. Prior to treatment the plots were weeded and soil was sampled from each plot, composited and analysed. Sea lettuce was then applied in the same manner and at the same rate and times as for the kiwifruit plots (Photos 4,5 &6).

Photo 4. Sea lettuce plot under avocado tree immediately after first application

Photo 5. Sea lettuce plot under avocado tree 10 days after application.

Photo 6. Sea lettuce plot under avocado tree one month after application.

Soil was again sampled on the 16th May 2013, composited according to treatment and chemically analysed.

Garden Plots

A vegetable garden was created by rotary hoeing an area of land adjacent to the kiwifruit block to a depth of about 30cm. Weeds were removed and twenty $1m^2$ plots were marked out with string lines and each randomly assigned to one of the four treatments. Prior to initial treatment a composite soil sample was sent for chemical analysis. Sea lettuce was then applied at the same times and rates as for the kiwifruit and avocado plots (Photo 7) and churned into the soil one week after the first application (13th November) and prior to planting (Photos 8 & 9).

Photo 7. Sea lettuce garden plots immediately after first application

Photo 8. Sea lettuce garden plot one week after application

Photo 9. Sea lettuce plot one week after application after churning

Vegetables chosen to plant were basil, spinach, capsicum and radish, representing two leaf crops, one fruit crop and one bulb crop. Vegetables were planted two weeks after the initial sea lettuce application. In each plot three spinach seedlings and three capsicum seedlings were planted 20 cm apart. Nine basil seeds were sown at a depth of 2 cm and 15 cm apart and 25 radish seeds were planted 5 cm apart (Photo 10). Not all plants survived and therefore additional replacement seeds were germinated in a laboratory on moist filter paper and replanted into the vegetable garden. The vegetables were irrigated twice daily using a sprinkler with an automatic tap timer for 10 minutes on each occasion. Weeds were removed weekly.

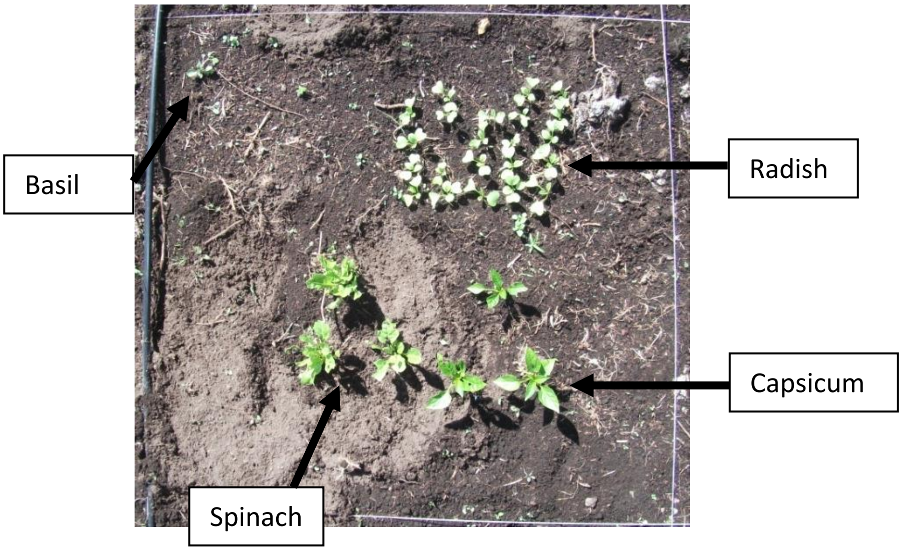


Photo 10. Sea lettuce garden plot with seedlings

Subsequent sea lettuce applications were made on the 21st December and 20th February and were mixed into the soil around the plants.

The first harvest of radishes in control, one application and two application plots was carried out on the 9th January, six weeks after planting. All radishes were harvested but ten representative radishes were chosen for measurement from each plot. For each subsequent harvest one representative plant of the spinach and capsicum plants and three basil plants were selected from each plot. Selection of a representative plant was based on a visual comparison of the plants in each plot where noticeably larger or smaller plants were discounted. Harvests details are shown in Table 1.

Table 1. Harvest details for garden plots

Harvest #	Harvest Date	Vegetable Harvested	Treatment plots
1	9th January	Radish	control, 1 & 2 app
2	18th January	Spinach	control, 1 & 2 app
3	14th February	Capsicum	control, 1 & 2 app
4	11th March	Basil	control, 1 & 2 app
5	9th April	Capsicum	control, 1, 2 & 3 app
6	16th May	Spinach	control, 1, 2 & 3 app

Images of the garden plots prior to the first radish harvest (Photo 11) and first capsicum harvest (Photo 12) are shown below.

Photo 11. Garden plots 19th December 2012

Photo 12. Garden plots 12th February 2012

Plants were harvested entirely, including roots, washed of excess soil and placed into labelled plastic bags for transportation to the laboratory. Once at the laboratory each plant was photographed and measurements of a number of different parameters for each crop were carried out as detailed in Table 2.

Table 2. Vegetable harvest – parameters measured

Vegetable	Plant part	Measurements
Radish	bulb	wet and dry weight, length, diameter, no. split
	leaves	wet and dry weight
Spinach	leaves	wet and dry weight, length, no. of leaves
	roots	wet and dry weight, length
Capsicum	leaves	wet and dry weight, length of plant (excl roots)
	roots	wet and dry weight, length
	fruit	number, wet and dry weight, length and diameter
Basil	leaves	wet and dry weight, length of plant (excl roots)
	roots	wet and dry weight
	flowers	wet and dry weight

Roots were removed from the main stem and washed thoroughly to remove soil and blotted dry with a paper towel prior to weighing. To obtain dry weights, plant components were dried at 55°C to a constant weight before weighing. The numbers of split radish bulbs as shown in Photo 13 were also recorded. For the spinach harvested on 16th May, only the plant lengths were measured due to time constraints.

Photo 13. Example of split radish bulbs

Plants were sampled for nutrient content analysis on 8th February for spinach and radish and 16th March for capsicum. Leaves, roots, fruit and bulbs were analysed separately. Basil plants were not analysed for nutritional composition.

Soil and Plant Chemical Analysis

Soil from each experimental plot was analysed for a number of chemical parameters. These were pH, organic matter, total exchange capacity, exchangeable cations, anions, base saturation, major and minor nutrients, total acidity and carbon. All of these parameters give an indication of the fertility of the soil.

Data Analysis

All of the results were collated into a rectangular data sheet and parametric and Kruskal-Wallis non-parametric ANOVA with post hoc Tukey's and multiple comparison tests were performed on the data using Statistica 11, a statistical software programme.

3.2 Results and Discussion

Sea lettuce

Levels of heavy metals in all batches of sea lettuce were below New Zealand Standard guideline levels for composts, soil conditioners and mulches and Bio-Gro Organic standards 2009 (Table 3).

Table 3. Nutritional/Chemical composition of sea lettuce

	Batch 1		Batch 2		Batch 3		Guideline NZ Std*	BioGro Std 2009 Appendix A**
	mg/kg	%	mg/kg	%	mg/kg	%		
Organic matter		6.6		9.4		14.5	>25%	-
Total C		3.9		5.5		8.4	-	-
Total N		0.30		0.31		0.36	>0.6%***	-
Dry Matter		41.5		42.3		56.1	-	-
P	280	0.03	268	0.03	333	0.03	>0.1%***	-
S	12,800	1.28	10,990	1.10	15,070	1.51	-	-
K	6,070	0.61	5,240	0.52	4,700	0.47	-	-
Ca	5,120	0.51	6,440	0.64	8,040	0.80	-	-
Mg	8,400	0.84	6,330	0.63	7,990	0.80	-	-
Na	14,230	1.42	10,090	1.01	24,600	2.46	-	-
Fe	3,300		2,400		3,800		-	-
Mn	34		21		38		-	-
Zn	15		13		13		<600	<300
Cu	<4		<4		<4		<300	<60
B	33		22		54		<200	-
Cr	2.0		1.8		4.9		<600	<150
As	1.9		2.0		4.6		<20	<20
Pb	2.1		2.0		3.2		<250	<250
Ni	1.0		0.9		1.4		<60	<60
Hg	<0.01		0.01		0.01		<2	<1
Cd	0.03		0.05		0.03		<3	<1

*New Zealand Standard Composts, Soil Conditioners and Mulches: NZS 4454:2005, Table 3.1. ** BioGro Organic Standards 2009, Appendix A, Table A3: Limits for Heavy Metals in Soils and Composts. ***If a contribution to plant nutrition is claimed.

Sodium levels in each batch of sea lettuce (1, 2 and 3) were 1.42%, 1.01% and 2.46% respectively and iodine levels were 1.75, 3.7, and 2.3mg/kg. The levels of sodium are within the range expected considering its marine origin. However, levels of iodine are much less than those reported as typical (200-250ppm) in a recent Tauranga Harbour Watch (2011) brochure: 'Sea lettuce and the garden'.

Soil

Soil chemical properties were considerably altered as a result of direct applications of sea lettuce. Sodium levels increased dramatically in all plots after each application of sea lettuce (Table 4, Fig. 2). The vegetable plots had the greatest increase in sodium from the baseline level (582%).

Table 4. Percentage increase in sodium (ppm) from initial soil values with sea lettuce applications.

Crop	Initial	Control	% incr.	I App.	% incr.	2 App.	% incr.	3 App.	% incr.
vegetable	28	72	157	126	350	142	407	191	582
kiwifruit	33	27	0	213	545	97	194	135	309
avocado	29	51	76	98	238	109	276	182	528

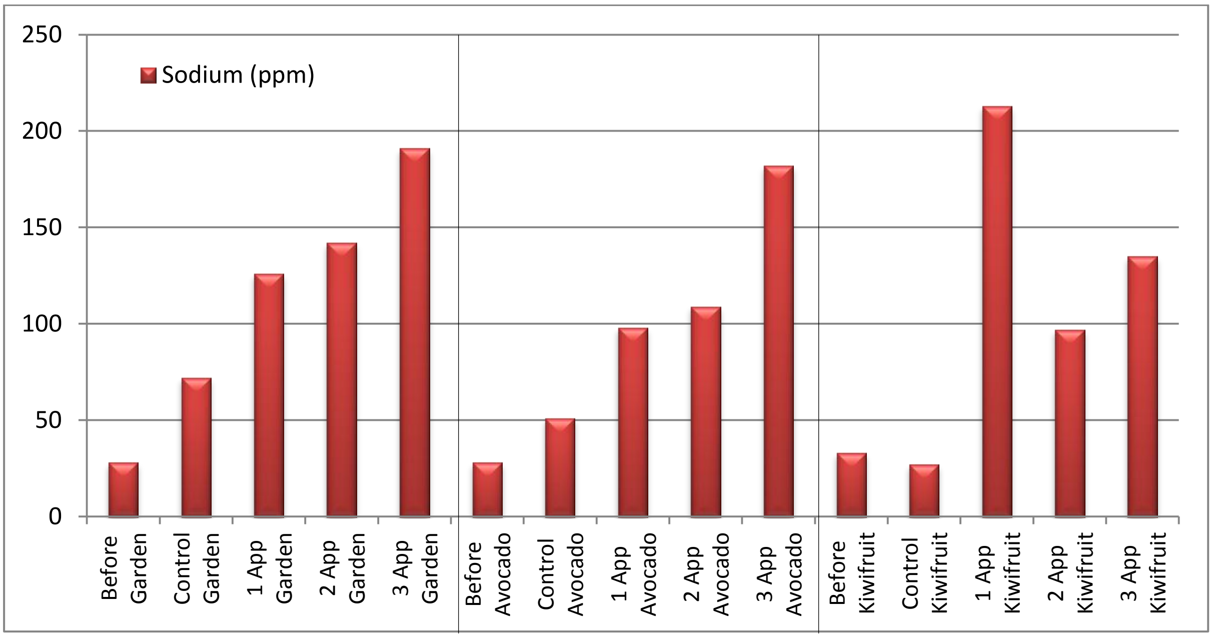


Fig. 2. Increase in soil sodium with sea lettuce applications (ppm).

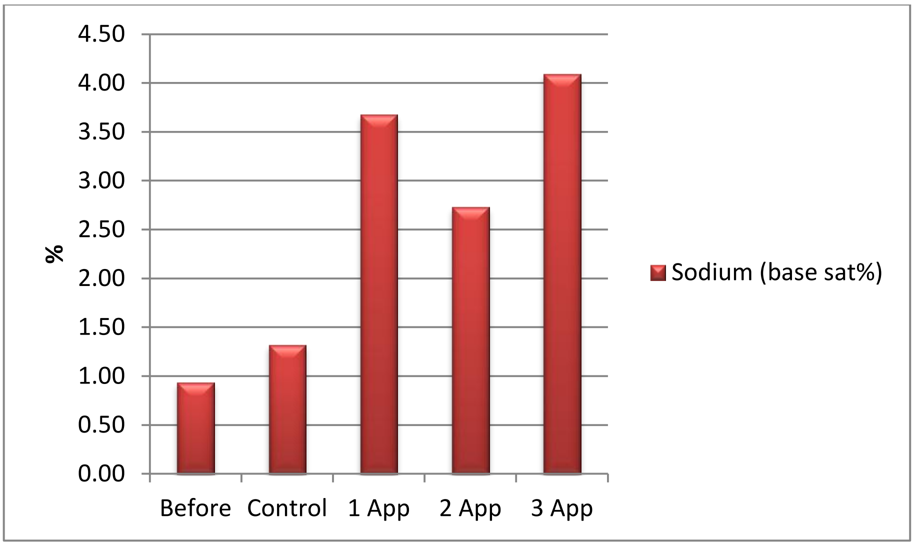


Fig. 3 Average increase in sodium in soil with sea lettuce applications (base saturation %) for three crops.

Base saturation (%) of sodium in the control soils was significantly lower than soils receiving one and three applications of sea lettuce ($p < 0.05$) (Fig 3).

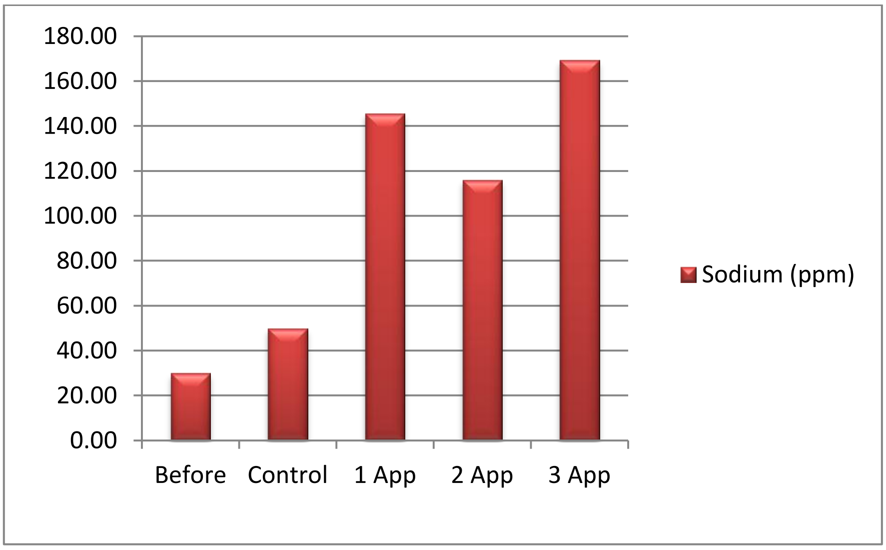


Fig. 4. Average increase in sodium in soil with sea lettuce applications (ppm) for three crops.

Sodium levels (ppm) in soils receiving three applications of sea lettuce were significantly greater ($p < 0.05$) than the control soils (Fig. 4). The difference between control soils and those receiving one application were almost significant ($p = 0.054$). The lack of significance in the apparent differences in means between control soils and those receiving one and two applications of sea lettuce may be attributed to the high degree of variability in the data. Raw data is included in Appendix A and graphical representations of the data in the form of box and whisker plots are included in Appendix B. These plots show the spread of data about the mean including the interquartile range as indicated by the "box" and differences between the upper and lower quartiles and maximum and minimum values as indicated by the "whiskers".

The increase in sodium in the control plots may be attributed to lateral infiltration from adjacent treatment plots. The substantial increase in sodium for the 1 application kiwifruit plots may be due to a non-homogenous quantity of sandy sea lettuce high in sodium being applied. A typical sodium range for kiwifruit orchard soils in the region would be between 20 and 45ppm. The recommended range for sodium (base saturation) is between 1 and 2 percent (Alan McCurran, BioSoil and Crop pers. comm.). The soils receiving one, two and three sea lettuce applications all greatly exceeded these levels. Levels above 2.5% base saturation can lead to adverse physical and chemical soil properties which may impact upon plant growth. Base saturation is an important measure of soil fertility and is expressed as a percentage of the total cation exchange sites occupied by calcium, magnesium, potassium, hydrogen and sodium. An increase in one cation may therefore result in a decrease in another, causing an imbalance. For example, an increase in the base saturation of sodium will also result in a decrease in the levels of other cations such as calcium. Changes in the concentration of hydrogen ions will also affect soil pH.

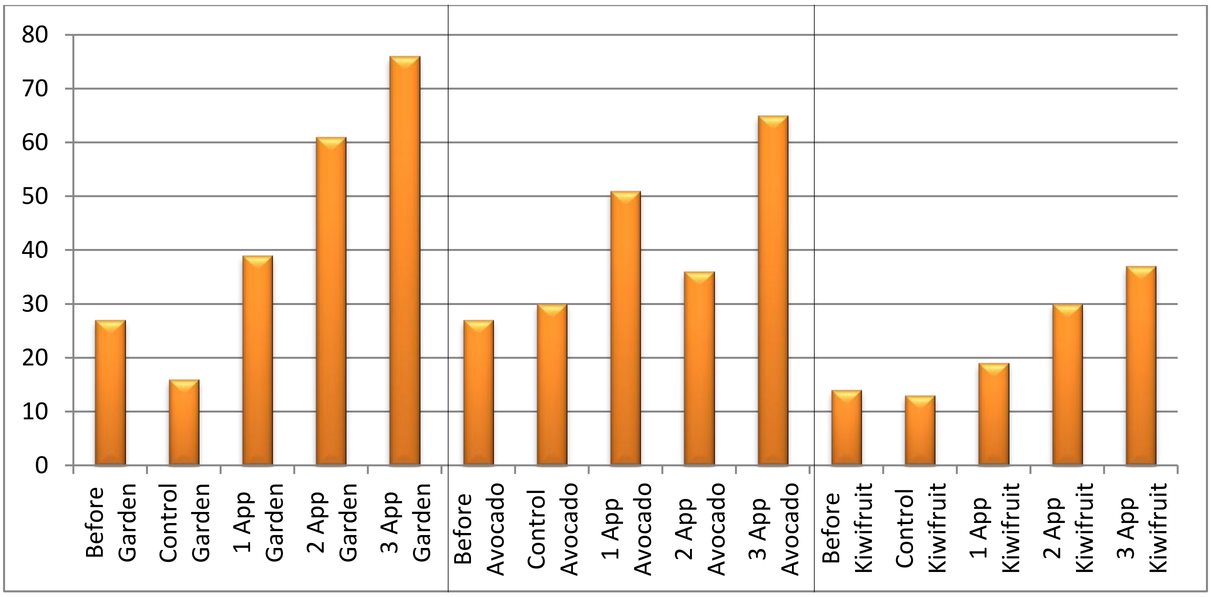


Fig. 5. Increase in soil sulphur with sea lettuce applications.

Soil sulphur also increased markedly with sea lettuce applications (Fig. 5). Although not directly toxic, excess sulphur can lead to a decrease in soil pH. The mean level of sulphur in soils receiving three applications of sea lettuce were significantly higher than the control soils ($p < 0.05$). The garden soils showed the most dramatic increase in sulphur after sea lettuce applications, increasing from a baseline level of 13ppm to 76ppm after three applications.

For calcium, no significant differences were found between treatments ($p < 0.05$). However, there was a noticeable reduction in calcium base saturation with sea lettuce applications, especially for the kiwifruit orchard soil, where the control plots had a value of 79% compared with 59% for the plots receiving three applications. There was also a corresponding increase in magnesium levels although the increase was not significant ($p < 0.05$) (Fig 6).

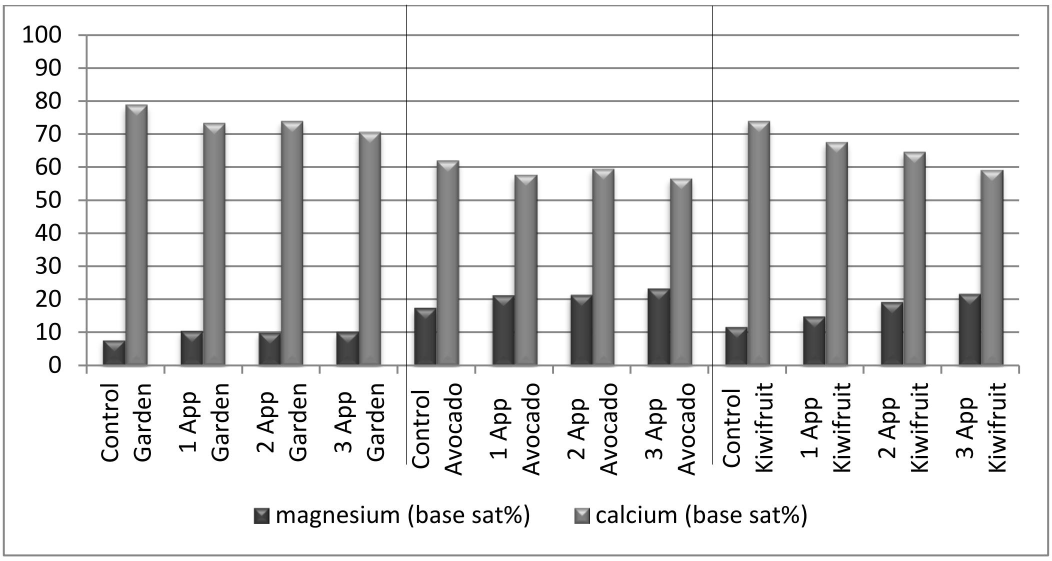


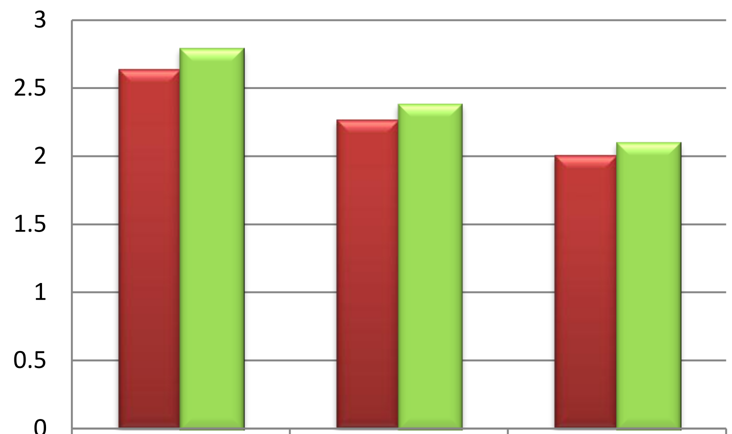
Fig. 6. Changes in soil calcium and magnesium levels with sea lettuce applications.

Vegetable crops

Harvest data for each of the vegetable crops were analysed and a number of differences between treatments were apparent. It was also noted that control plots had many more weeds than the treatment plots. The results for each vegetable crop are detailed below.

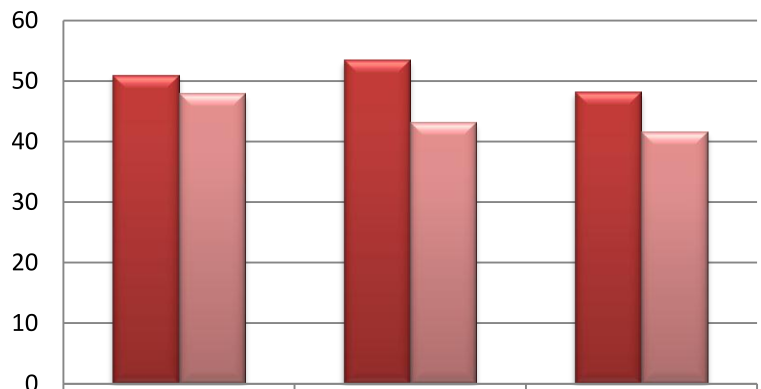
Radish

There were significant differences in dry weights of bulbs and leaves between control and two application plots ($p < 0.05$) (Fig. 7). However, there were no significant differences in the weight of plants between the control plots and plots after only one application. Mean dry weights of radish bulbs in the control plots were 2.64g compared with 2.01g for radish plots that had 2 applications, a significant decrease. Bulb diameters for 1 and 2 application plots were also significantly less than the control (Fig. 8 & Photo 14). This may be attributed to the increased levels of sodium in the soil. Hamza et al. (2007) showed that radish bulbs decrease in turgor and size when grown in low osmotic potential mediums. The high solubility of sodium chloride decreases the water potential outside the root membrane. This negative potential draws water from the roots of the radish, therefore causing the radish to shrink.



	Control	1 App	2 App
bulb dry weight (g)	2.63877551	2.268	2.008
Leaves dry weight (g)	2.785714286	2.378	2.096

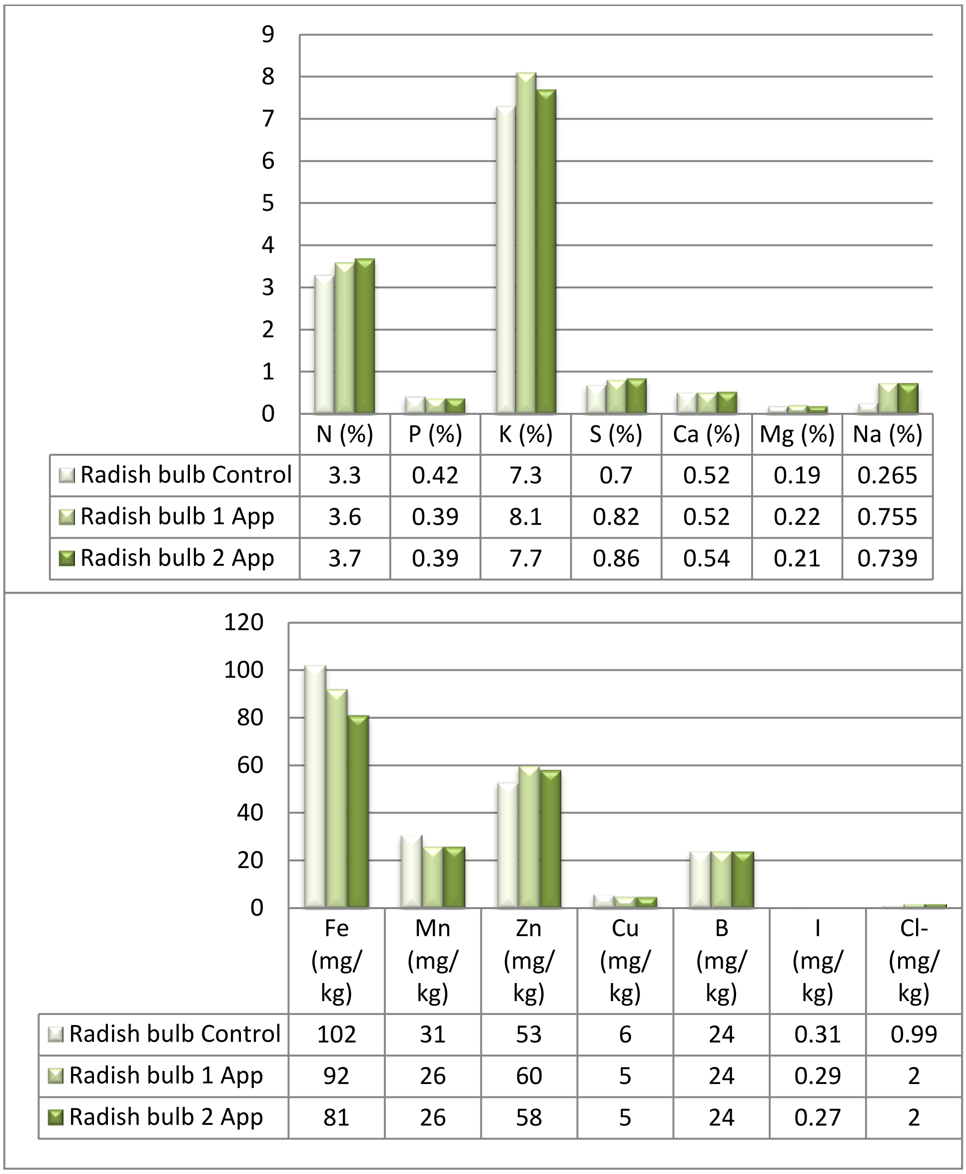
Fig 7. Mean dry weights of radish bulbs and leaves



	Control	1 App	2 App
Bulb Length (mm)	51.03795918	53.4806	48.226
Diam (mm)	47.99714286	43.1814	41.6326

Fig 8. Mean dry weights of radish bulbs and leaves

Levels of nitrogen, potassium, sulphur and sodium were higher in radish bulbs harvested from sea lettuce plots compared to control plants (Fig. 9). Zinc levels (mg/kg) were also higher, although both iron, and interestingly, iodine were lower for the sea lettuce treated radishes. However, iodine levels in the leaves were greater for the plants grown in treated plots (control = 0.56, 1 app = 0.59, 2 app = 0.61mg/kg).



	N (%)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)	Na (%)
Radish bulb Control	3.3	0.42	7.3	0.7	0.52	0.19	0.265
Radish bulb 1 App	3.6	0.39	8.1	0.82	0.52	0.22	0.755
Radish bulb 2 App	3.7	0.39	7.7	0.86	0.54	0.21	0.739

	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	B (mg/kg)	I (mg/kg)	Cl- (mg/kg)
Radish bulb Control	102	31	53	6	24	0.31	0.99
Radish bulb 1 App	92	26	60	5	24	0.29	2
Radish bulb 2 App	81	26	58	5	24	0.27	2

Fig 9. Nutrient composition of radish bulbs

Radishes – Control

Radishes – 2 applications

Photo 14. Visual comparison of radishes grown in control and 2 application plots

Spinach

Although there appeared to be an increase in total leaf weight per plant with sea lettuce treatments (Fig. 10), the results were not statistically significant. This is again attributed to the wide range in data values as indicated by the box and whisker plots (Appendix B). There was also no correlation between treatment and length of leaves.

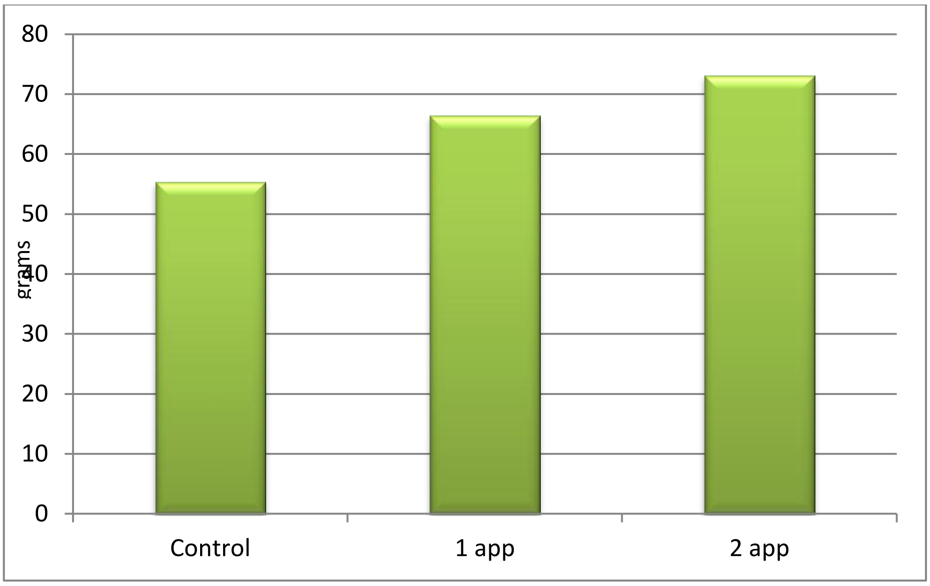
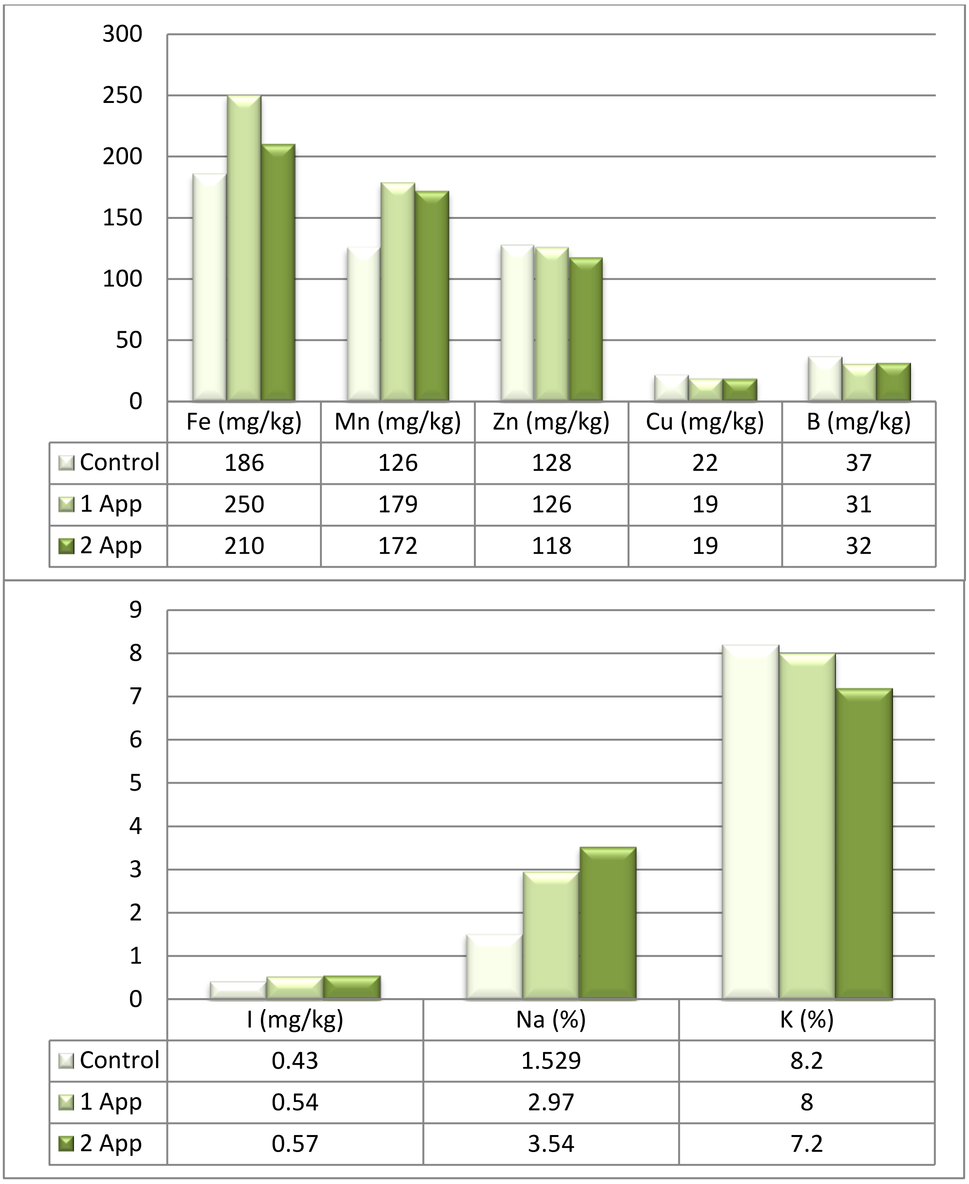


Fig 10. Mean dry weights of total spinach leaves per plant

Nutrient analysis of the spinach leaves determined that levels of iodine, iron and manganese increased with treatments. However, sodium levels also increased markedly and this corresponded with a decrease in potassium levels (Fig. 11). However, spinach is a halophytic plant, meaning it can tolerate higher levels of salt.



	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	B (mg/kg)
Control	186	126	128	22	37
1 App	250	179	126	19	31
2 App	210	172	118	19	32

	I (mg/kg)	Na (%)	K (%)
Control	0.43	1.529	8.2
1 App	0.54	2.97	8
2 App	0.57	3.54	7.2

Fig 11. Nutrient levels of spinach leaves.

Capsicum

The length and diameter of capsicum fruit harvested in April were significantly greater (p <0.05) for plots receiving three applications of sea lettuce compared with the control plots (Fig. 12) although, there was no significant difference between the plots receiving one application and the others, again due to a wide range in data values (Appendix B). The fruit from plots receiving two applications were no different to the control fruit in terms of size. There was no significant difference in plant length or weight between treatments. Levels of potassium, magnesium, copper, chloride and zinc in capsicum fruit all increased with each application of sea lettuce (Fig. 13).

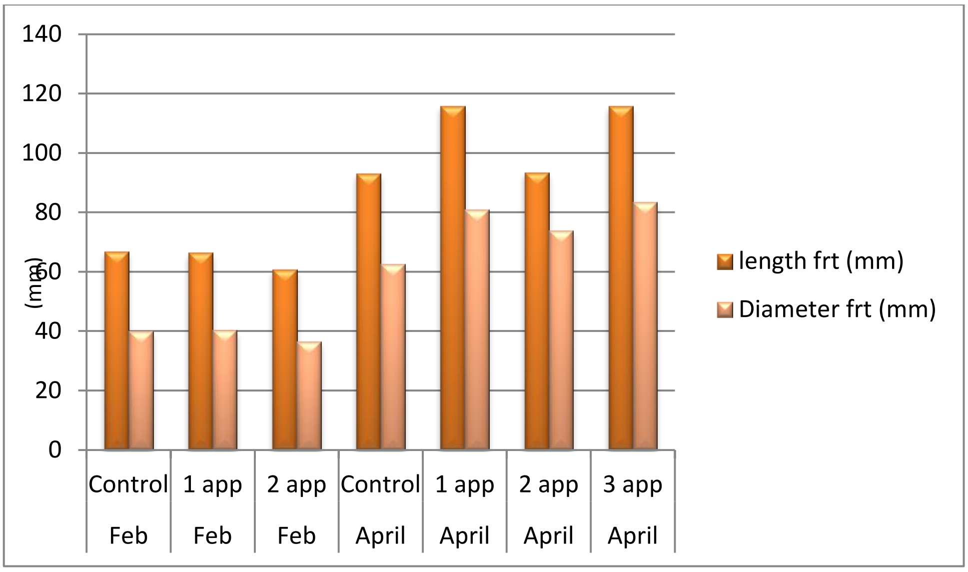
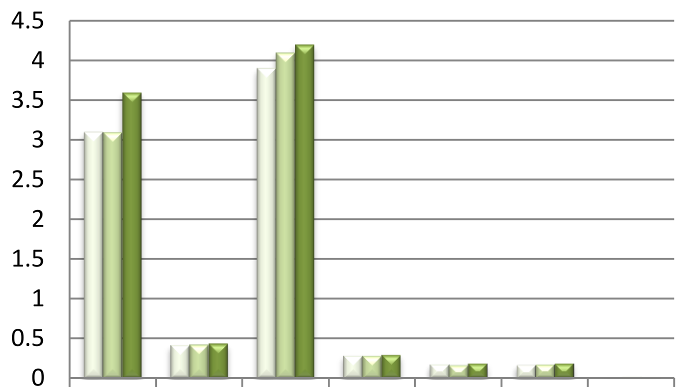
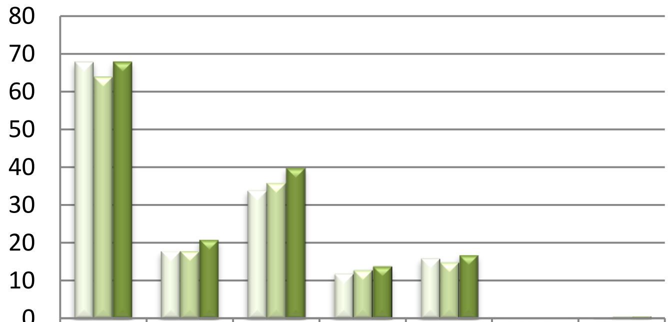


Fig 12. Mean length and diameter of capsicum fruit



	N (%)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)	Na (%)
Capsicum fruit Control	3.1	0.42	3.9	0.29	0.18	0.17	0.016
Capsicum fruit 1 App	3.1	0.43	4.1	0.29	0.17	0.18	0.017
Capsicum fruit 2 App	3.6	0.44	4.2	0.3	0.19	0.19	0.016



	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	B (mg/kg)	I (mg/kg)	Cl- (mg/kg)
Capsicum fruit Control	68	18	34	12	16	0.06	0.32
Capsicum fruit 1 App	64	18	36	13	15	0.04	0.65
Capsicum fruit 2 App	68	21	40	14	17	0.07	0.76

Fig 13. Nutrient levels of capsicum fruit.

Basil

The average length and dry weight of stem/leaves, roots and flowers of basil plants in plots receiving two and three applications of sea lettuce were less than the control plants (Fig. 14). Plants grown in soil with two applications of sea lettuce were significantly shorter than the control plants (p <0.05). The dry root weights of basil plants grown in plots receiving two applications of sea lettuce were significantly less than those grown in plots receiving one application ($p < 0.05$). However there was no significant difference between the control plants and the others due to the large range in values.

The mean dry weight of stem and leaves and flowers for plants grown in sea lettuce plots were less than the control plants. However, the results were not statistically significant, again due to the high variability in the data.

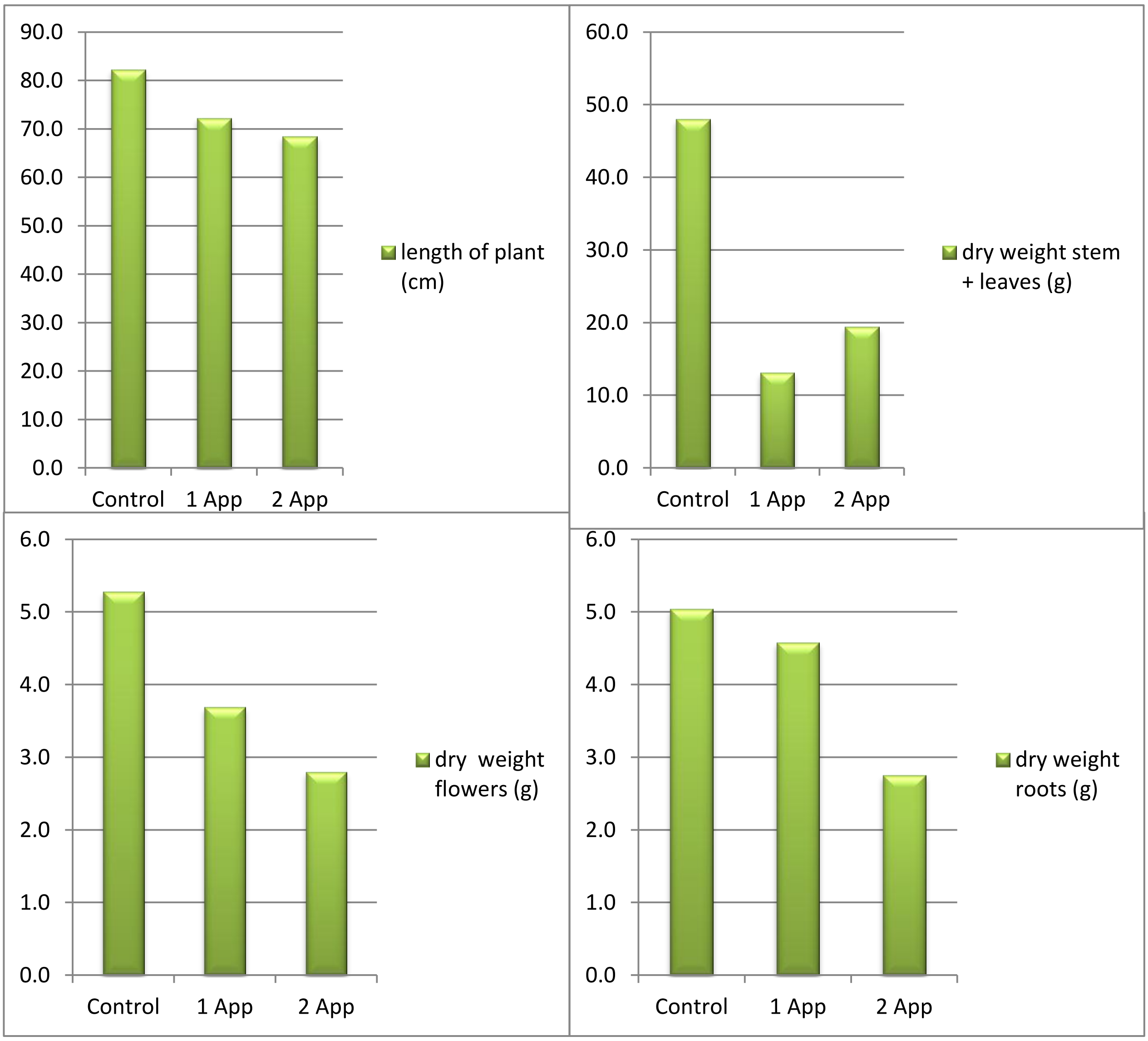


Fig 14. Mean physical parameters of basil plants

4 CONCLUSIONS AND RECOMMENDATIONS

From the results of the field trial it is evident that the direct application of sea lettuce to soil causes a significant change in the chemical properties of the soil. The dramatic increase in levels of soil sodium has most likely caused a negative impact on the growth of radish and basil plants, which had poor growth in plots receiving 2 applications of sea lettuce compared to control plots. The growth of spinach plants was not affected by sea lettuce applications and this may be due to its ability to tolerate high levels of sodium. Conversely, capsicum fruit were significantly larger in plots receiving three applications of sea lettuce, but at this application rate other vegetable plants could become negatively impacted due to the high sodium content of the soil.

Levels of some plant nutrients were elevated in plants receiving applications of sea lettuce, such as potassium, magnesium, zinc, iodine and manganese. These may in turn have nutritional benefits to consumers, although while levels in some plants were higher, for others, they were lower.

The heavy metal content of the Tauranga Harbour sea lettuce used in this trial were all below New Zealand Standard guideline levels for composts, soil conditioners and mulches and Bio-Gro Organic standards 2009. Therefore, use of sea lettuce as a soil amendment on orchards and home gardens shouldn't result in soil heavy metal concentrations exceeding the Bio-Gro standard limits. However, if frequent, long-term applications of large quantities are made then it may be advisable to periodically test soil for heavy metals which may accumulate over time.

Part of the objectives of this trial was to provide a 'worst case scenario' for applying sea lettuce to gardens or orchards. The unwashed material was applied directly to the soil in large amounts, up to three applications over a short period, to identify any detrimental effects to soil and plant growth. Although soil sodium levels increased, levels of heavy metals in the soils were all below NZ Bio-grow organic guideline levels (2009) and plant growth was not severely impacted in the garden plots. There were no differences between plants on the basis of colour or other defects and overall, the plants looked healthy, and were all perfectly edible.

The use of sea lettuce as a soil amendment in vegetable gardens and orchards may be viable. The apparent ability of sea lettuce to help suppress weed growth is an attribute that could be worthwhile investigating further. However, it would not be advisable to apply unwashed sea lettuce directly to soil immediately prior to seed sowing or seedling planting as it may physically suppress seed germination and seedling growth. It should also be applied sparingly so as to avoid excess salt accumulation in the soil. The best means by which to utilise sea lettuce in the garden would be to:

- Wash first to remove salt and sand
- Prior to planting, apply directly to soil in small amounts, leave to break down and mix in well
- Compost well with other organic material before application

It would be unadvisable to apply unwashed sea lettuce directly to orchard soils in large quantities on a regular basis due to the risk of soil salinisation. Although this study didn't assess the effects on growth of kiwifruit and avocados, potential negative impacts as a result of sea lettuce applications should be considered. Kiwifruit is a salt-sensitive plant and a study by Chartzoulakis *et al.* 1995 found that salinity affects growth through a reduction in leaf area development and decline in photosynthetic capacity. Avocados are also highly sensitive to salinity and high soil salinity and chloride toxicity causes reductions in fruit yield and tree size, lowered leaf chlorophyll content, decreased photosynthesis, poor root growth, and leaf scorching (Cuomo *et al.* 2008). If sea lettuce applied to orchards on a regular basis then it would be highly recommended to periodically send soil samples to an approved testing laboratory to ensure that soil fertility isn't being compromised. Changes in the cation exchange capacity of the soil and associated base saturation percentage levels of cations including sodium, magnesium, potassium, aluminium and hydrogen should be monitored. Levels of sodium should ideally be within the range of 0-1% and not be allowed to exceed 2.5% base saturation where salinisation and a breakdown in soil structure may result. Another parameter that should be monitored is pH which may be altered by any changes in soil chemical characteristics.

It may also be advisable to monitor levels of heavy metals in orchard soils if sea lettuce is applied over long periods, as although levels detected in Tauranga Harbour sea lettuce in this trial were low, levels of metals in sea lettuce may vary temporally and spatially and also accumulate in soil. Bioavailability of metals is also pH dependent and a lowering of pH levels may lead to an increase in metal toxicity.

Future studies of the changes that occur to sea lettuce when composted could identify a practical methodology for local orchardists to process and gain value from the product, while minimising any possible detrimental effects.

The limited number of replicates in this small trial makes it difficult to draw firm conclusions from the data due to the wide range in measurement values obtained. However, the study has highlighted issues that will need to be considered if formulating a 'best practice' protocol for the use of sea lettuce as a soil amendment.

REFERENCES

Chartzoulakis, K. S., Therios, I. N. Misopolinos, N. D., Noitsakis, B. I. (1995). Growth, ion content and photosynthetic performance of salt-stressed kiwifruit plants. Irrigation Science 16(1): 23-28.

Cuomo, V., Perretti, I., Palomba, A., Verde, A., Cuomo, A. (1995). Utilisation of *Ulva rigida* biomass in the Venice Lagoon (Italy): biotransformation in compost. *Journal of Applied Phycology* 7, 479-485.

Crowley, D. (2008). Salinity management in avocado orchards. *California Avocado Society 2008 Yearbook* 91, 83-104.

Eyras, M.C., Rostagno, C.M., Defosse, E. (1998). Biological evaluation of seaweed composting. *Compost Science and Utilisation* 6(4), 74-81.

Eyras, M.C., Defosse, G.E., Dellatore, F. (2008). Seaweed compost as an amendment for horticultural soils in Patagonia, Argentina. *Compost Science and Utilisation* 16(2), 119-124

Hamza, M.A., Anderson, S.H., Aylmore, L.A.G. (2007). Computed tomographic evaluation of osmotica on shrinkage and recovery of lupin (*Lupinus angustifolius* L.) and radish (*Raphanus sativus* L.) roots. *Environmental and Experimental Botany* 59, 334-339.

Moore, K. (2004). Using seaweed compost to grow bedding plants. *Biocycle* 45(6), 43-44.

APPENDIX A – Soil Results

kg/ha

BROOKSIDE LABORATORIES, INC.

48582-158

SOIL AUDIT AND INVENTORY REPORT

Name Bio Soil & Crop NZ Ltd. City Tauranga State NZL

Independent Consultant Bio Soil & Crop NZ Ltd. Date 11/27/2012

Sample Location SEA LETTUCE TRIAL		BEFORE A	BEFORE A	BEFORE A		
Sample Identification		KIWIFRUI	VEGETABL	AVOCADO		
Lab Number		1471-1	1472-1	1473-1		
Total Exchange Capacity (ME/100 g)		15.22	18.03	11.07		
pH	Buffer (SMP/Sikora)	6.8	6.8	6.6		
	H_2O (1:1)	6.3	6.4	6.3		
Organic Matter (humus) %		10.41	13.89	10.83		
ANIONS – SOLUBLE SULFUR*	ppm	27	13	14		
PHOSPHORUS – MEHLICH III	kg/ha P as P_2O_5	703	503	180		
	ppm of P	137	98	35		
PHOSPHORUS – BRAY II	kg/ha P as P_2O_5	2319	1954	549		
	ppm of P	452	381	107		
PHOSPHORUS – OLSEN	kg/ha P as P_2O_5	410	226	144		
	ppm of P	80	44	28		
EXCHANGEABLE CATIONS – CALCIUM*	kg/ha	4865	6301	3286		
	ppm	2172	2813	1467		
MAGNESIUM*	kg/ha	540	408	508		
	ppm	241	182	227		
POTASSIUM*	kg/ha	544	589	452		
	ppm	243	263	202		
SODIUM*	kg/ha	63	65	74		
	ppm	28	29	33		
ALUMINUM (KCl Ext.)	kg/ha	2	4	4		
	ppm	< 1	2	2		
BASE SATURATION PERCENT						
Calcium	%	71.35	78.01	66.26		
Magnesium	%	13.20	8.41	17.09		
Potassium	%	4.09	3.74	4.68		
Sodium	%	0.80	0.70	1.30		
Aluminum	%	0.07	0.12	0.20		
Hydrogen	%	10.50	9.00	10.50		
EXTRACTABLE MINORS						
Boron* (ppm)		0.81	0.83	0.54		
Iron* (ppm)		47	48	51		
Manganese* (ppm)		18	28	19		
Copper* (ppm)		24.76	18.06	4.56		
Zinc* (ppm)		16.44	15.51	7.48		
Aluminum* (ppm)		1307	1220	1432		
OTHER TESTS – Soluble Salts (mmhos/cm)						
Chlorides (ppm)						
NO_3-N (ppm)		12.1	8.2	6.9		
NH_4-N (ppm)		8.1	3.0	1.1		
Total Acidity (ME/100 g)		1.676	1.676	4.112		
Carbon (%)		5.25	6.84	4.79		

* Mehlich III Extractable

kg/ha

BROOKSIDE LABORATORIES, INC.

48582-168

SOIL AUDIT AND INVENTORY REPORT

Name Bio Soil & Crop NZ Ltd. City Tauranga State NZL

Independent Consultant Bio Soil & Crop NZ Ltd. Date 06/04/2013

Sample Location			PLUS GROUP	VEGETABL	VEGETABL	VEGETABL	VEGETABL	AVOCADO
Sample Identification				CONTROL	1 APP	2 APP	3 APP	CONTROL
Lab Number				0709-1	0710-1	0711-1	0712-1	0713-1
Total Exchange Capacity (ME/100 g)				20.50	19.22	20.55	22.50	12.38
pH			Buffer (SMP/Sikora)	6.6	6.6	6.6	6.7	6.2
pH			H_2O (1:1)	6.4	6.3	6.3	6.2	6.0
Organic Matter (humus) %				12.50	11.64	11.72	11.51	10.25
ANIONS	SOLUBLE SULFUR*		ppm	16	39	61	76	30
ANIONS	PHOSPHORUS MEHLICH III	kg/ha	P as P_2O_5	482	549	503	410	185
ANIONS	PHOSPHORUS MEHLICH III		ppm of P	94	107	98	80	36
ANIONS	PHOSPHORUS BRAY II	kg/ha	P as P_2O_5	318	246	231	841	467
ANIONS	PHOSPHORUS BRAY II		ppm of P	62	48	45	164	91
ANIONS	PHOSPHORUS OLSEN	kg/ha	P as P_2O_5					
ANIONS	PHOSPHORUS OLSEN		ppm of P					
EXCHANGEABLE CATIONS	CALCIUM*		kg/ha	7240	6315	6801	7114	3438
EXCHANGEABLE CATIONS	CALCIUM*		ppm	3232	2819	3036	3176	1535
EXCHANGEABLE CATIONS	MAGNESIUM*		kg/ha	432	544	556	618	578
EXCHANGEABLE CATIONS	MAGNESIUM*		ppm	193	243	248	276	258
EXCHANGEABLE CATIONS	POTASSIUM*		kg/ha	464	414	419	650	376
EXCHANGEABLE CATIONS	POTASSIUM*		ppm	207	185	187	290	168
EXCHANGEABLE CATIONS	SODIUM*		kg/ha	161	282	318	428	114
EXCHANGEABLE CATIONS	SODIUM*		ppm	72	126	142	191	51
EXCHANGEABLE CATIONS	ALUMINUM (KCl Ext.)		kg/ha	9	11	9	9	9
EXCHANGEABLE CATIONS	ALUMINUM (KCl Ext.)		ppm	4	5	4	4	4
BASE SATURATION PERCENT								
Calcium %				78.83	73.34	73.87	70.58	62.00
Magnesium %				7.85	10.54	10.06	10.22	17.37
Potassium %				2.59	2.47	2.33	3.30	3.48
Sodium %				1.53	2.85	3.00	3.69	1.79
Aluminum %				0.22	0.29	0.22	0.20	0.36
Hydrogen %				9.00	10.50	10.50	12.00	15.00
EXTRACTABLE MINORS								
Boron* (ppm)				0.69	0.79	0.82	0.76	0.59
Iron* (ppm)				66	73	63	69	66
Manganese* (ppm)				31	38	37	34	27
Copper* (ppm)				22.40	23.27	22.51	19.68	4.81
Zinc* (ppm)				16.53	15.16	13.38	14.09	6.47
Aluminum* (ppm)				1498	1612	1583	1373	1831
OTHER TESTS	Soluble Salts (mmhos/cm)							
OTHER TESTS	Chlorides (ppm)							
OTHER TESTS	NO_3-N (ppm)			4.9	3.6	4.0	5.4	3.7
OTHER TESTS	NH_4-N (ppm)			5.9	5.0	5.0	4.3	4.3
OTHER TESTS	Total Acidity (ME/100 g)			4.112	4.112	4.112	2.894	8.984

* Mehlich III Extractable

kg/ha

BROOKSIDE LABORATORIES, INC.

48582-168

SOIL AUDIT AND INVENTORY REPORT

Name Bio Soil & Crop NZ Ltd. City Tauranga State NZL

Independent Consultant Bio Soil & Crop NZ Ltd. Date 06/04/2013

Sample Location		PLUS GROUP	AVOCADO	AVOCADO	AVOCADO	KIWIFRUI	KIWIFRUI
Sample Identification			1 APP	2 APP	3 APP	CONTROL	1 APP
Lab Number			0714-1	0715-1	0716-1	0717-1	0718-1
Total Exchange Capacity (ME/100 g)			14.38	17.30	15.92	18.21	17.76
pH		Buffer (SMP/Sikora)	6.4	6.5	6.7	6.6	6.7
		H_2O (1:1)	6.1	6.2	6.3	6.4	6.5
Organic Matter (humus) %			9.54	10.52	10.05	12.56	11.28
ANIONS	SOLUBLE SULFUR*	ppm	51	36	65	13	19
	PHOSPHORUS MEHLICH III	kg/ha P as P_2O_5	185	287	256	775	852
		ppm of P	36	56	50	151	166
	BRAY II	kg/ha P as P_2O_5	487	821	713	1811	1703
		ppm of P	95	160	139	353	332
	OLSEN	kg/ha P as P_2O_5					
		ppm of P					
EXCHANGEABLE CATIONS	CALCIUM*	kg/ha	3718	4617	4041	6030	5376
		ppm	1660	2061	1804	2692	2400
	MAGNESIUM*	kg/ha	822	995	995	578	712
		ppm	367	444	444	258	318
	POTASSIUM*	kg/ha	553	594	627	692	694
		ppm	247	265	280	309	310
	SODIUM*	kg/ha	220	244	408	60	477
		ppm	98	109	182	27	213
	ALUMINUM (KCl Ext.)	kg/ha	4	13	4	11	11
		ppm	2	6	2	5	5
BASE SATURATION PERCENT							
	Calcium	%	57.72	59.57	56.66	73.92	67.57
	Magnesium	%	21.27	21.39	23.24	11.81	14.92
	Potassium	%	4.40	3.93	4.51	4.35	4.48
	Sodium	%	2.96	2.74	4.97	0.64	5.21
	Aluminum	%	0.15	0.39	0.14	0.31	0.31
	Hydrogen	%	13.50	12.00	10.50	9.00	7.50
EXTRACTABLE MINORS							
	Boron* (ppm)		0.62	0.79	0.73	0.76	0.97
	Iron* (ppm)		68	75	65	62	59
	Manganese* (ppm)		28	33	30	25	24
	Copper* (ppm)		5.57	5.97	5.43	32.01	31.31
	Zinc* (ppm)		7.43	11.82	9.81	17.02	18.48
	Aluminum* (ppm)		1807	1651	1667	1649	1486
OTHER TESTS	Soluble Salts (mmhos/cm)						
	Chlorides (ppm)						
	NO_3-N (ppm)		7.7	10.8	9.4	7.2	9.4
	NH_4-N (ppm)		4.5	5.5	7.2	3.4	3.6
	Total Acidity (ME/100 g)		6.548	5.33	2.894	4.112	2.894

* Mehlich III Extractable

kg/ha 48582-168

BROOKSIDE LABORATORIES, INC.

SOIL AUDIT AND INVENTORY REPORT

Name Bio Soil & Crop NZ Ltd. City Tauranga State NZL

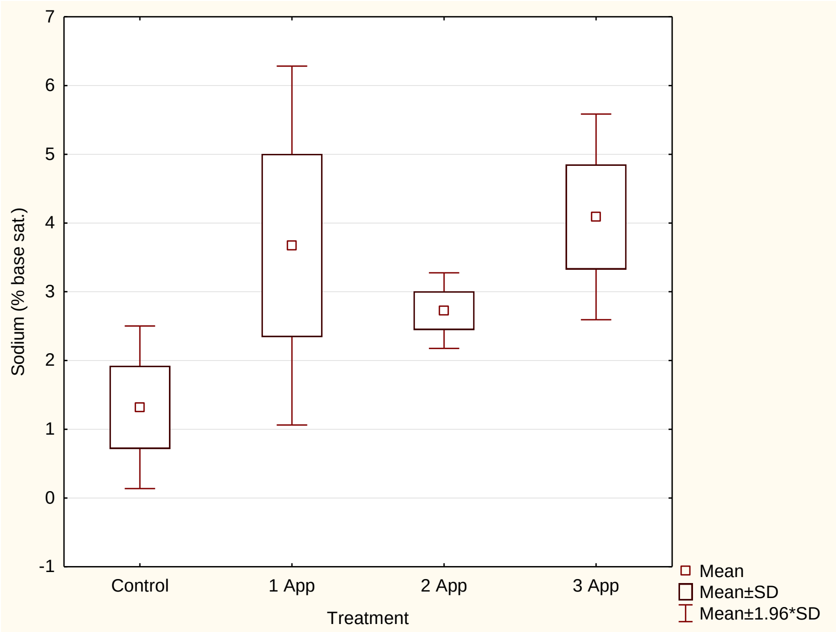
Independent Consultant Bio Soil & Crop NZ Ltd. Date 06/04/2013

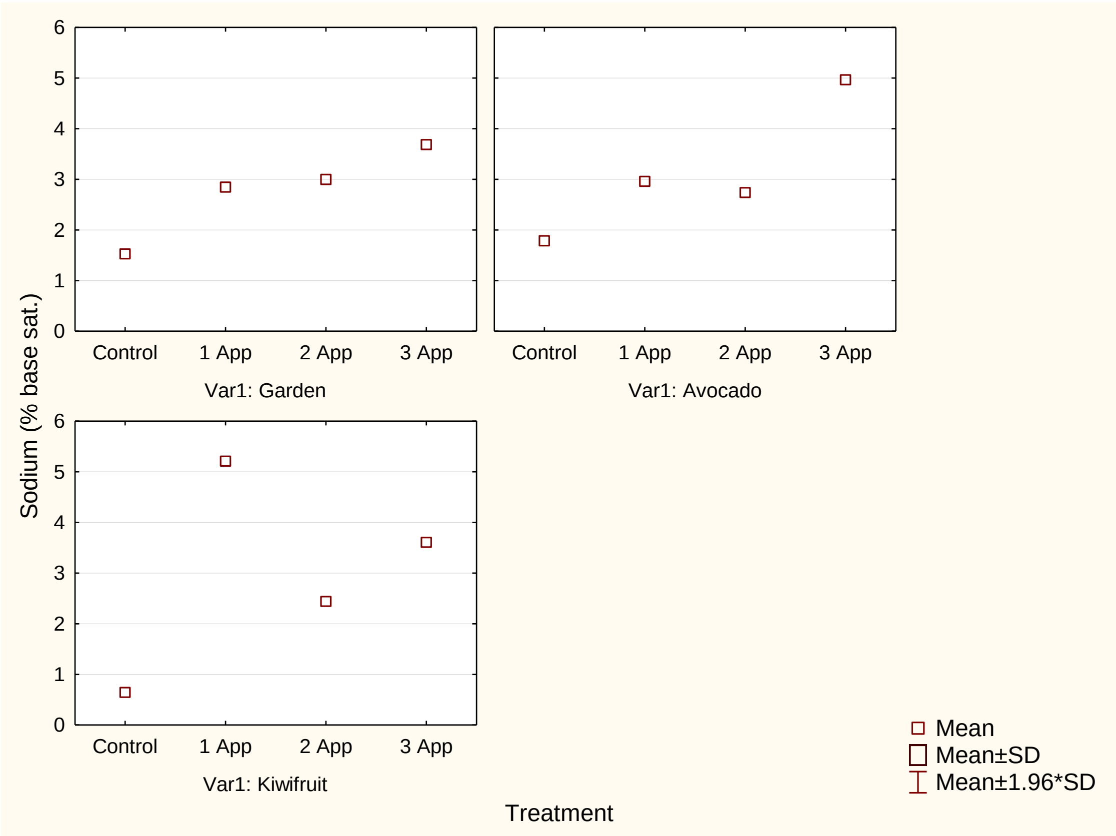
Sample Location	PLUS GROUP	KIWIFRUI	KIWIFRUI			
Sample Identification		2 APP	3 APP			
Lab Number		0719-1	0720-1			
Total Exchange Capacity (ME/100 g)		17.29	16.25			
pH	Buffer (SMP/Sikora)	6.7	6.6			
	H_2O (1:1)	6.5	6.3			
Organic Matter (humus) %		10.09	14.12			
ANIONS: SOLUBLE SULFUR*	ppm	30	37			
PHOSPHORUS: MEHLICH III	kg/ha P as P_2O_5	651	734			
	ppm of P	127	143			
PHOSPHORUS: BRAY II	kg/ha P as P_2O_5	1790	1559			
	ppm of P	349	304			
PHOSPHORUS: OLSEN	kg/ha P as P_2O_5					
	ppm of P					
EXCHANGEABLE CATIONS: CALCIUM*	kg/ha	5006	4310			
	ppm	2235	1924			
MAGNESIUM*	kg/ha	894	948			
	ppm	399	423			
POTASSIUM*	kg/ha	878	672			
	ppm	392	300			
SODIUM*	kg/ha	217	302			
	ppm	97	135			
ALUMINUM (KCl Ext.)	kg/ha	13	9			
	ppm	6	4			
BASE SATURATION PERCENT						
Calcium	%	64.63	59.20			
Magnesium	%	19.23	21.69			
Potassium	%	5.81	4.73			
Sodium	%	2.44	3.61			
Aluminum	%	0.39	0.27			
Hydrogen	%	7.50	10.50			
EXTRACTABLE MINORS						
Boron* (ppm)		1.04	1.00			
Iron* (ppm)		61	60			
Manganese* (ppm)		24	25			
Copper* (ppm)		33.27	31.46			
Zinc* (ppm)		16.62	22.45			
Aluminum* (ppm)		1580	1575			
OTHER TESTS: Soluble Salts (mmhos/cm)						
Chlorides (ppm)						
NO_3-N (ppm)		9.9	17.0			
NH_4-N (ppm)		4.7	4.7			
Total Acidity (ME/100 g)		2.894	4.112			

* Mehlich III Extractable

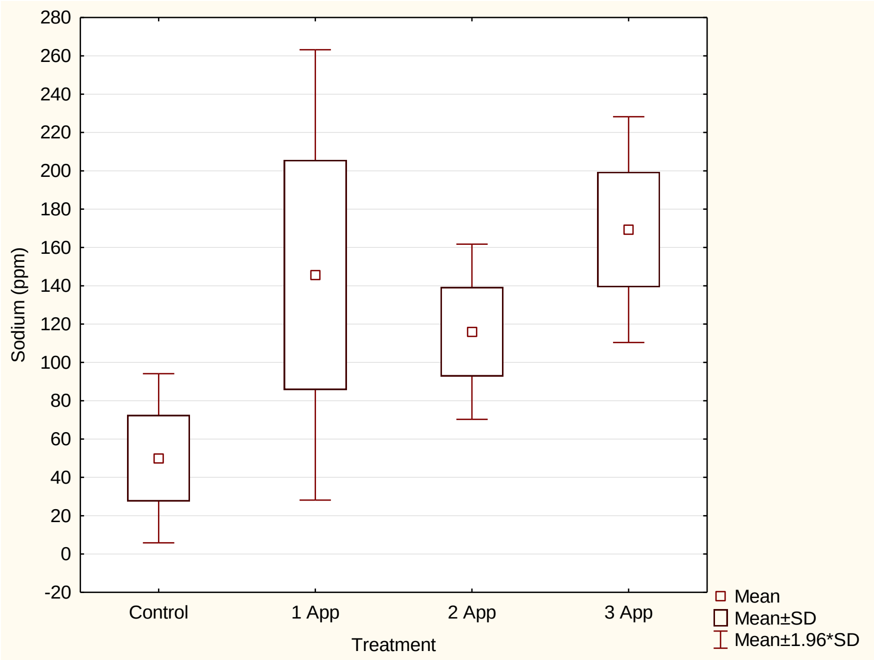
APPENDIX B – Box and Whisker Plots

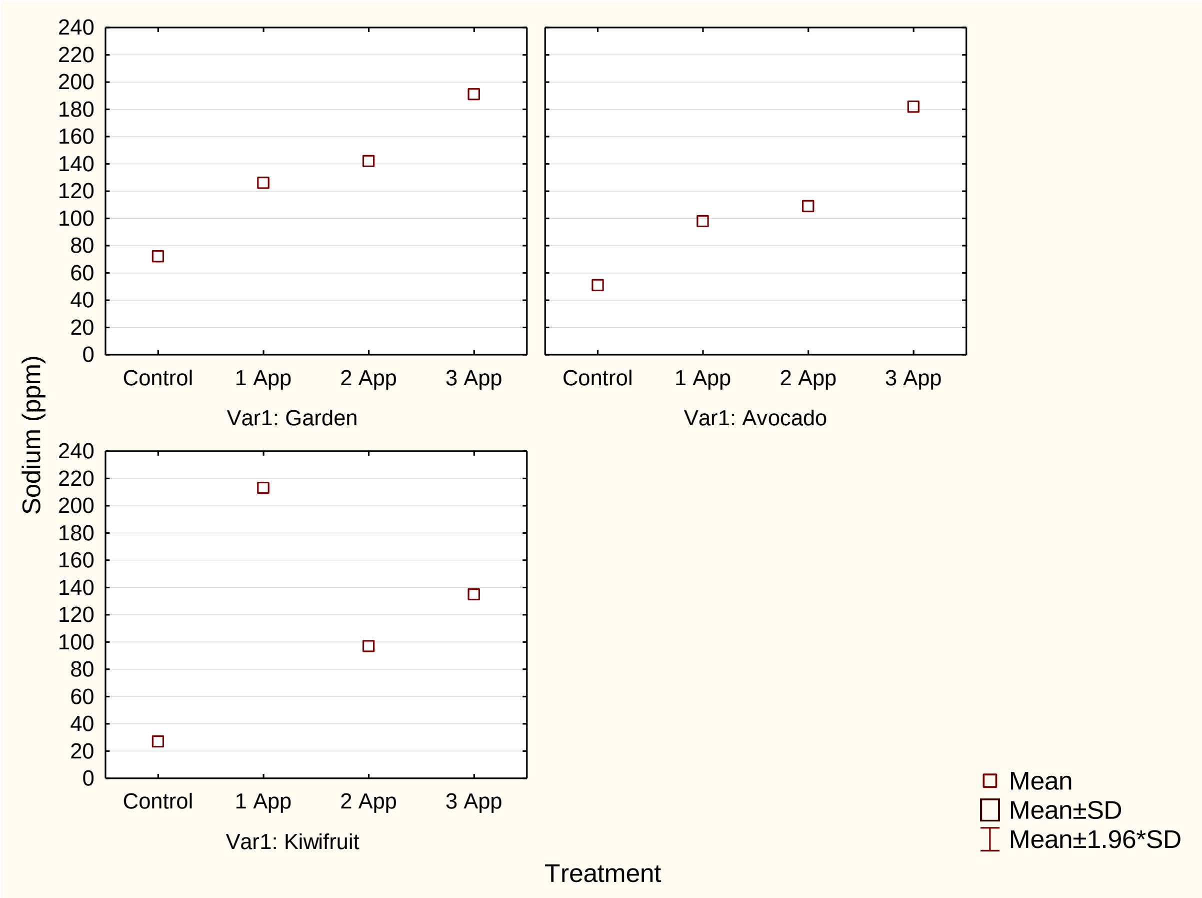
Soil Sodium (base saturation %)



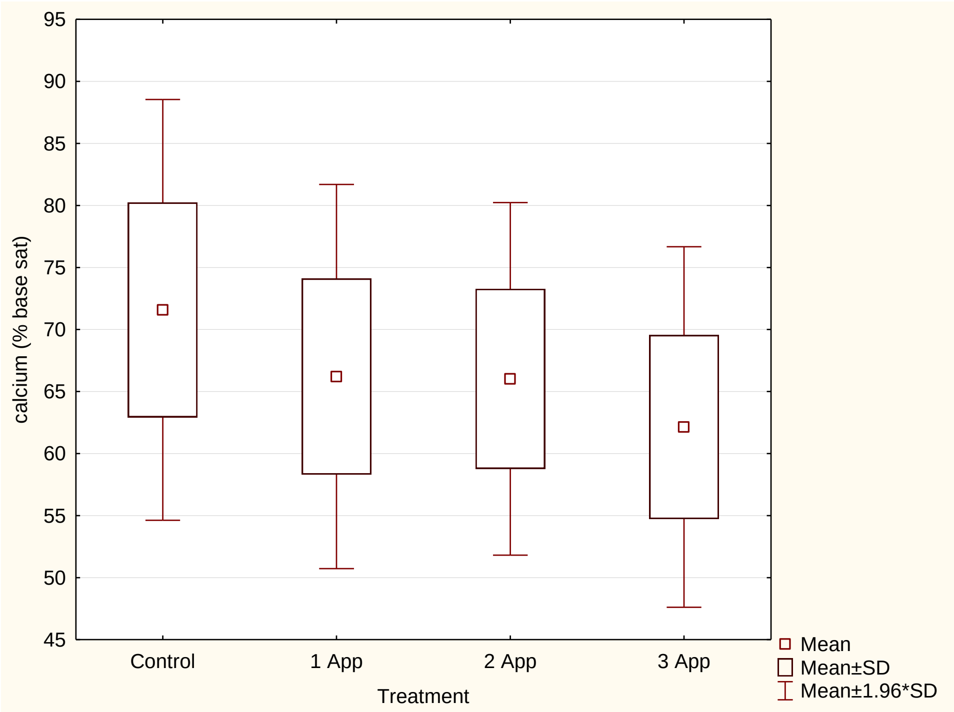


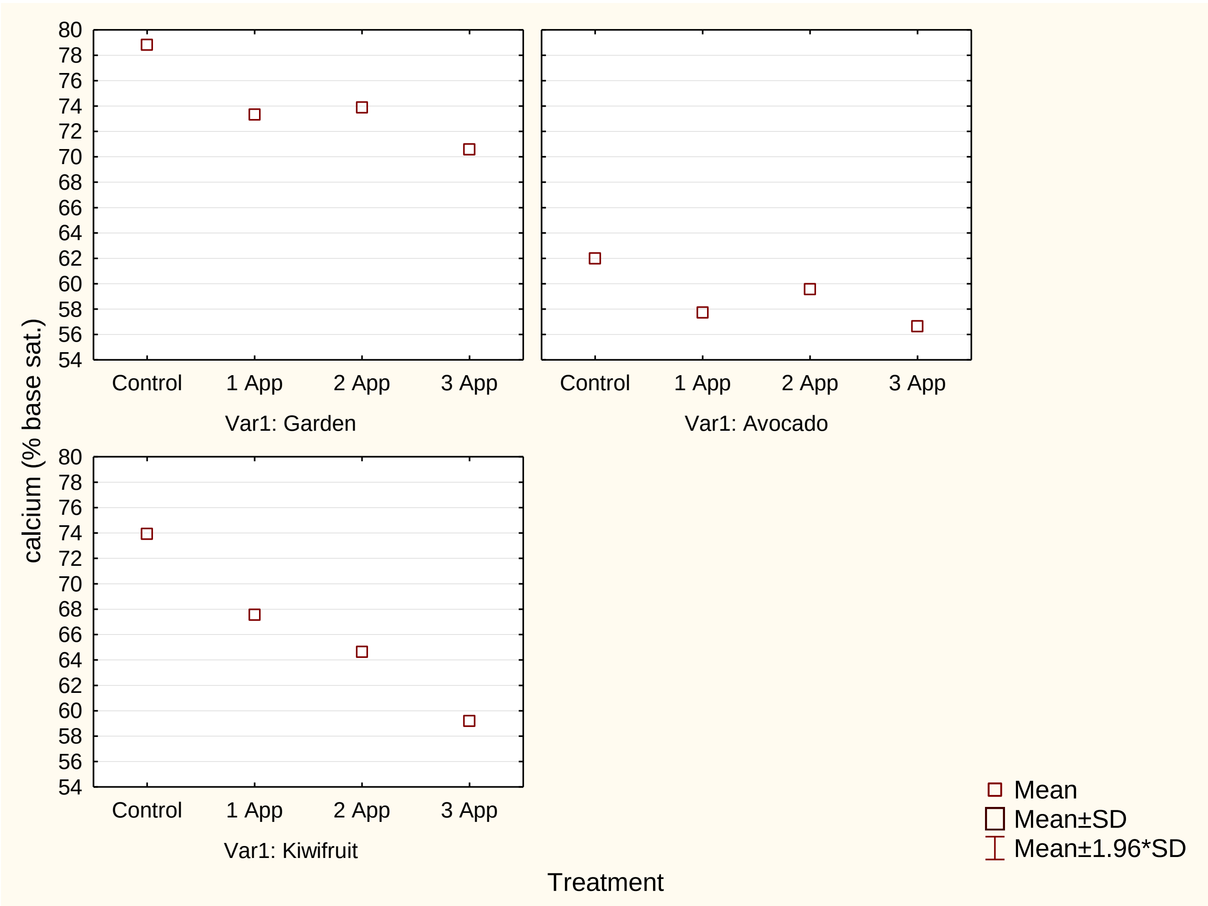
Soil Sodium (ppm)



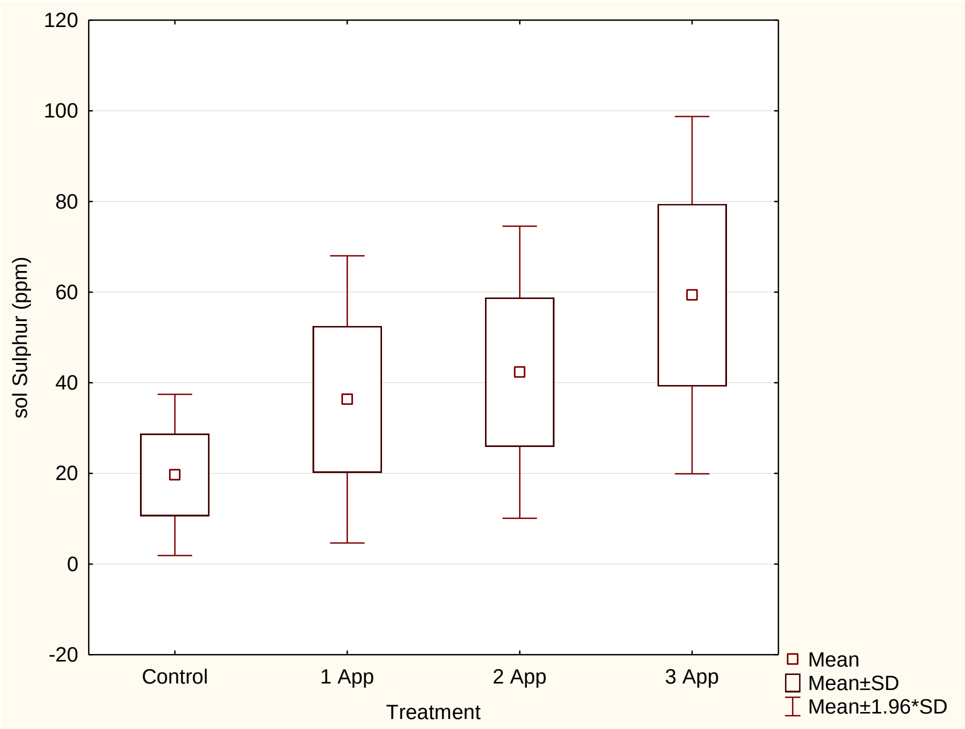


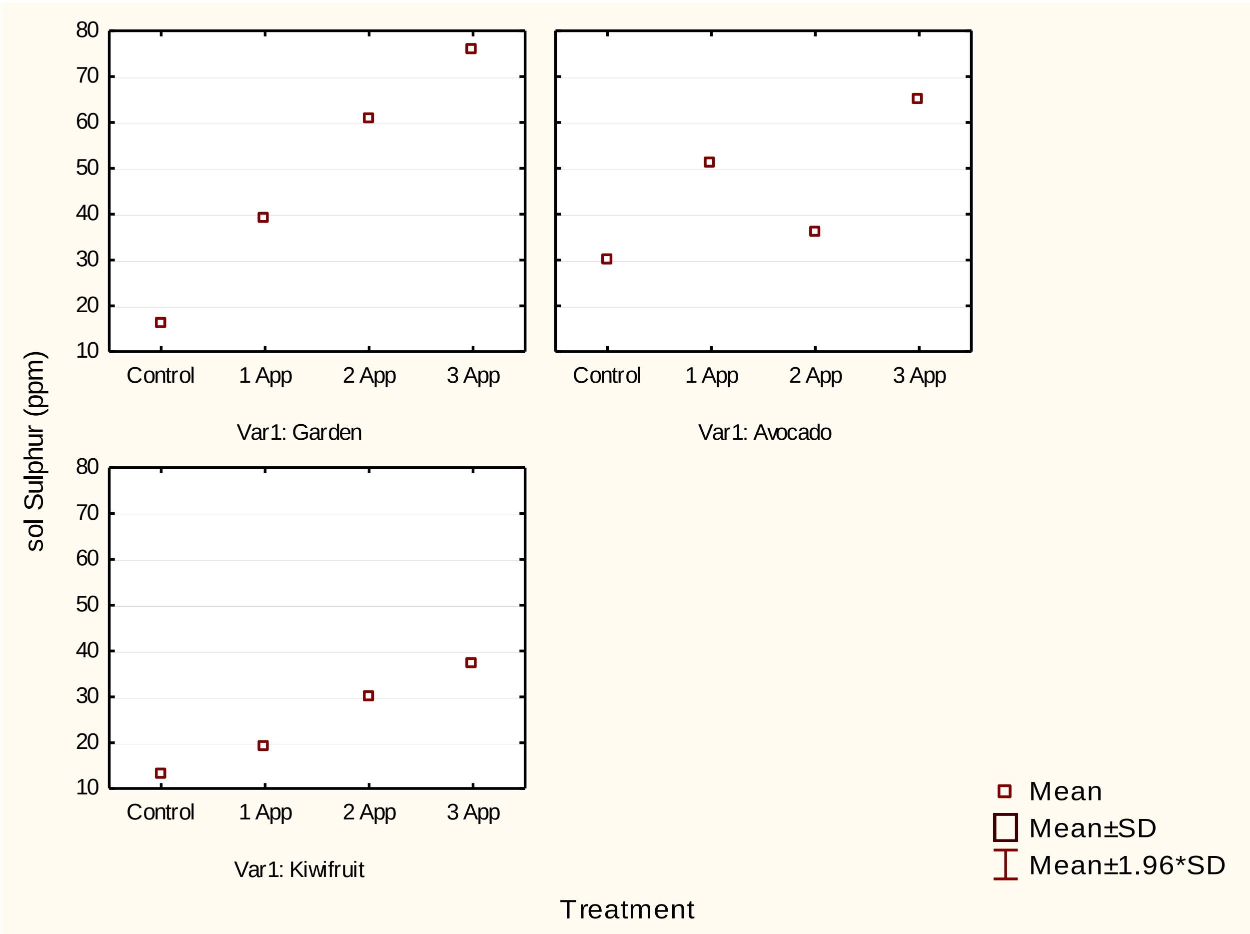
Soil Calcium (% base saturation)



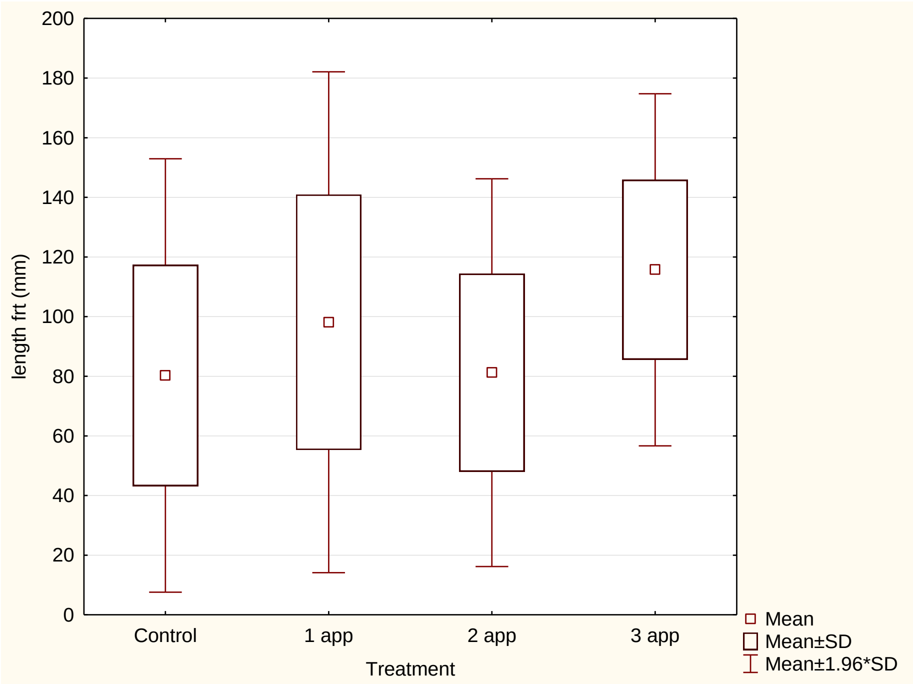


Soil Sulphur (ppm)

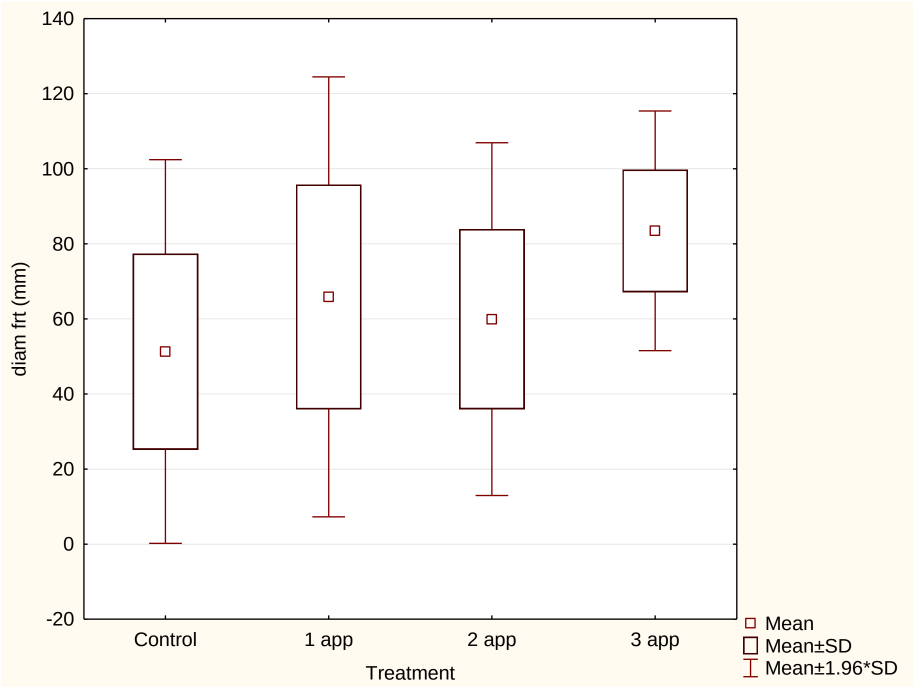




Capsicum

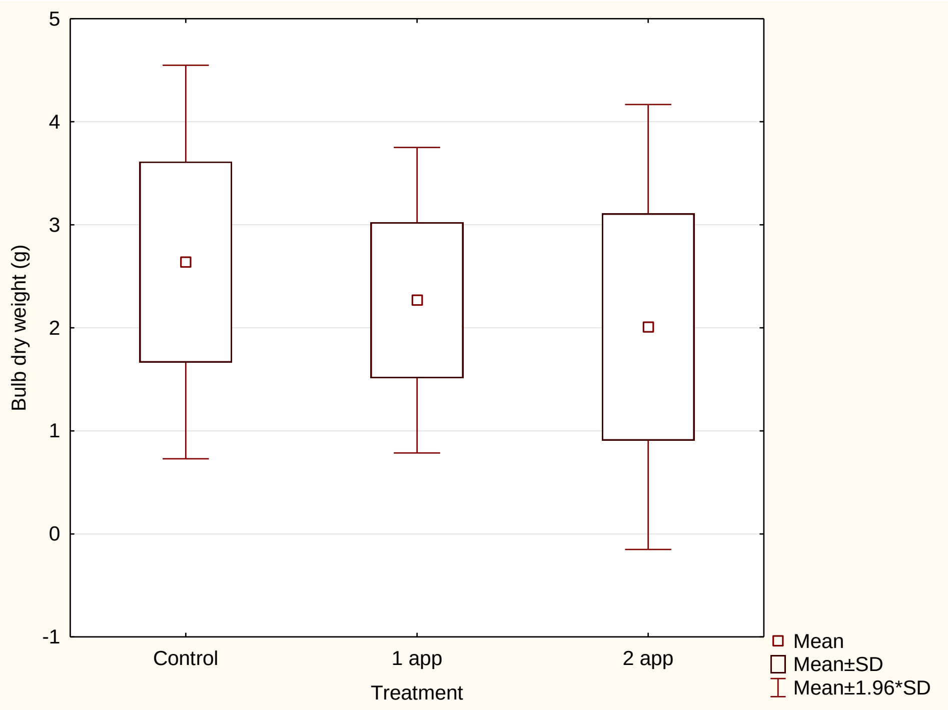


200
180
160
140
120
100
80
60
40
20
0
length frt (mm)
Control
1 app
2 app
3 app
Treatment
Mean
Mean±SD
Mean±1.96*SD

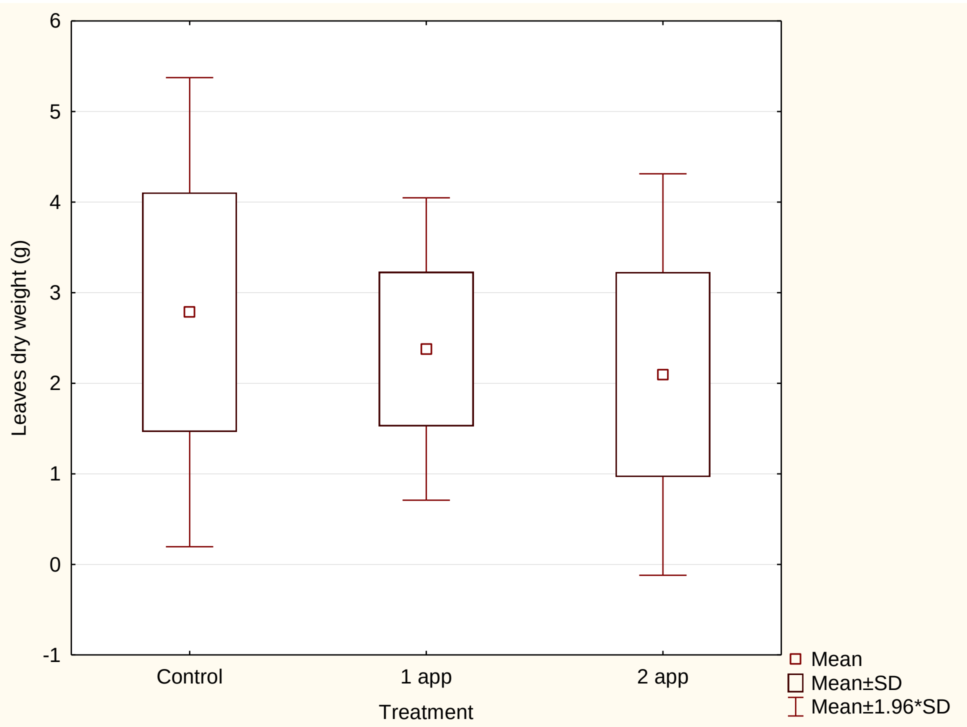


140
120
100
80
60
40
20
0
-20
diam frt (mm)
Control
1 app
2 app
3 app
Treatment
Mean
Mean±SD
Mean±1.96*SD

Radish

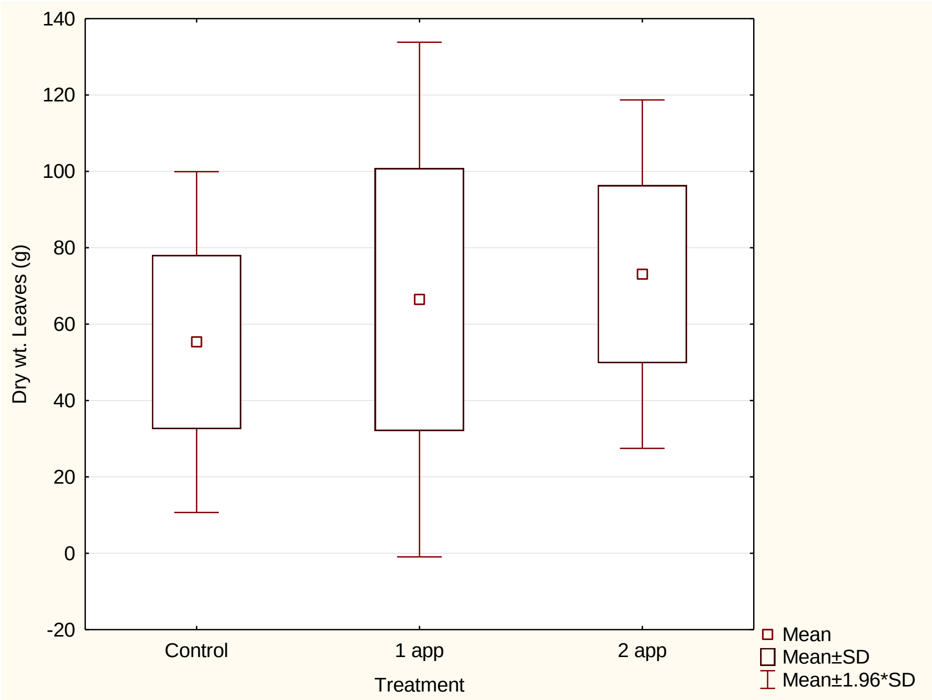


5
4
3
2
1
0
-1
Bulb dry weight (g)
Control
1 app
2 app
Treatment
Mean
Mean±SD
Mean±1.96*SD

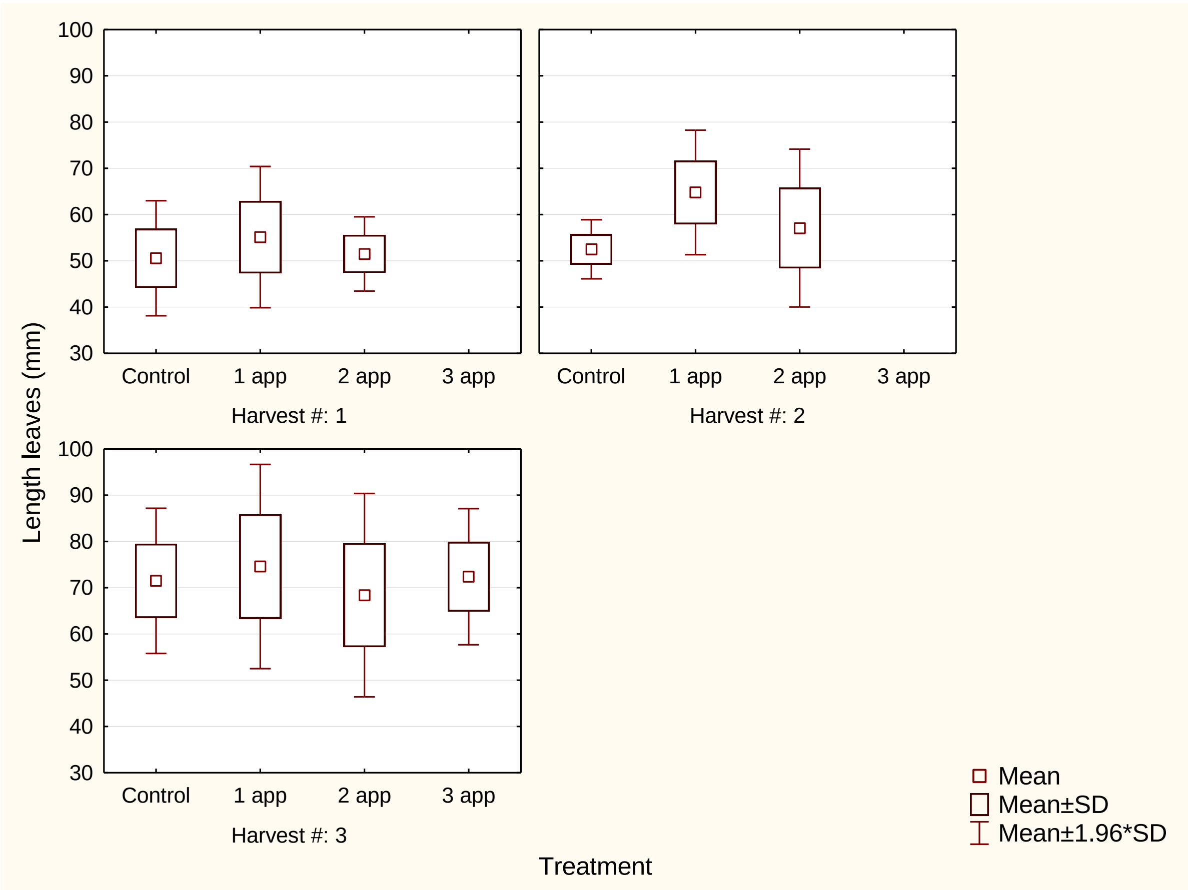


6
5
4
3
2
1
0
-1
Leaves dry weight (g)
Control
1 app
2 app
Treatment
Mean
Mean±SD
Mean±1.96*SD

Spinach

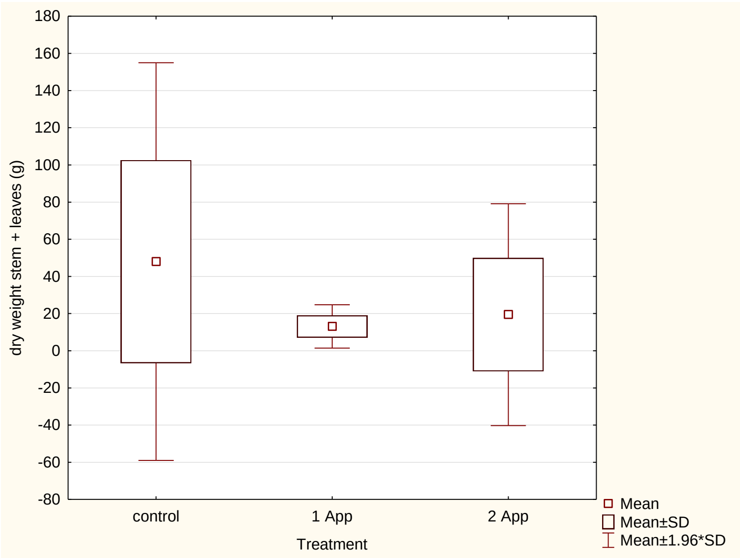


140
120
100
80
60
40
20
0
-20
Dry wt. Leaves (g)
Control
1 app
2 app
Treatment
Mean
Mean±SD
Mean±1.96*SD



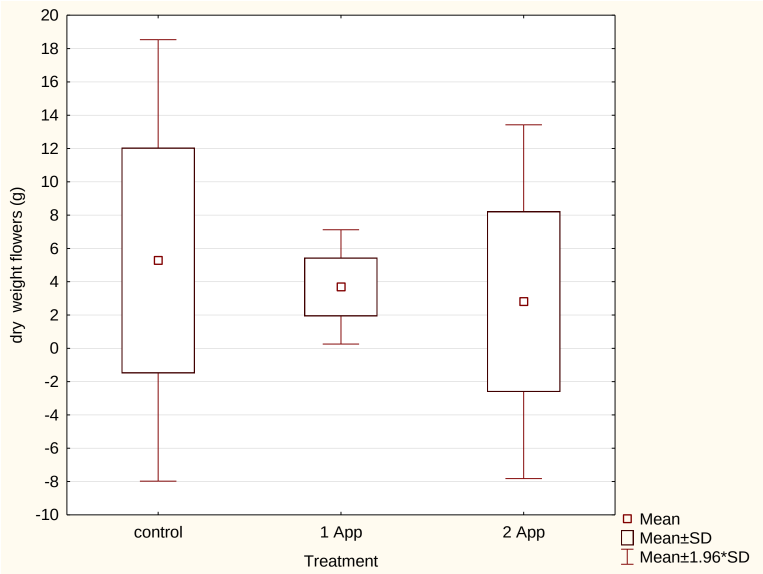
Length leaves (mm)
100
90
80
70
60
50
40
30
Control
1 app
2 app
3 app
Harvest #: 1
Harvest #: 2
Harvest #: 3
Treatment
Mean
Mean±SD
Mean±1.96*SD

Basil



dry weight stem + leaves (g)
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
control
1 App
2 App
Treatment
Mean
Mean±SD
Mean±1.96*SD

dry weight roots (g)
16
14
12
10
8
6
4
2
0
-2
-4
-6
control
1 App
2 App
Treatment
Mean
Mean±SD
Mean±1.96*SD


20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
dry weight flowers (g)
control
1 App
2 App
Treatment
Mean
Mean±SD
Mean±1.96*SD