Understanding biological / organic fertilisers using kelp (*Macrocystis pyrifera*) as an example

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2. Introduction

This report looks at the issues surrounding the use of biological / organic materials as fertilisers using an experiment testing the fertiliser ‘value’ of kelp (*Macrocystis pyrifera*) as an example.

The concept of using kelp and other seaweeds both as fertilisers has a long history, probably dating back many centuries and possibly many millenia. For example, in the 1940’s studies were conducted on the general use of seaweeds, their use as fertiliser, economic value and their nutrient content (Wilson & Fieldes, 1941; Marion, 1943; Rapson *et al.*, 1943; Tseng, 1947). However, with the rapid growth of mined potassium fertilisers in the middle of the 20th century, interest in natural materials, such as seaweed, for fertiliser declined to very low levels. With the increasing understanding of the limited amounts of mineable lithospheric fertilisers, the problems they can cause, such as nutrient leaching there is renewed interest in materials, such as seaweed, to supply nutrients.

This experiment builds on a previous trial, that compared different rates of kelp on the growth of crop plants in artificial growth media (‘potting mix’), conducted in 2011 by students studying BIOS 0273, examined by Dr Roddy Hale, at Lincoln University, Canterbury, New Zealand.

This experiment compared the effect of a single rate of kelp on pea and ryecorn growth among five soils of the same type but with differing nutrient status and histories.

2.1. Method

Five soil samples were collected from Iverson Research Field and the Biological Husbandry Unit (BHU) at Lincoln University New Zealand (Table 1). The samples were chosen based on previous soil test reports to give soils with a range of nutrient statuses from ‘low’ to ‘high’. The soil sample sites were within a distance of 900 m of each other and have the same soil classification of mottled immature pallic, family Wakanui, dominant texture: silty (Source http://smap.landcareresearch.co.nz/ accessed 2012-05-02).

Table 1. Five soil sample sites at Lincoln University

Field	**Location**
BHU Crowder Tunnel 1	43°38'59.82" S 172°27'21.58" E
BHU Low input	43°38'59.88" S 172°27'25.96" E
Iverson 3	43°38'57.24" S 172°28'02.52" E
Iverson 10	43°38'54.33" S 172°28'01.40" E
Iverson 12	43°38'54.52" S 172°27'51.62" E

Samples were manually removed with a spade from the top 20 cm of the soil profile. The each soil sample was then sieved through a 1 cm mesh and then thoroughly mixed in a cement mixer for five minutes. A 500 g sample was then removed for soil analysis. Then eight, approx 4,300 cm^3 sub samples of soil were withdrawn into 20×17×17 cm (H×W×D) white pots. Four randomly selected sub-samples, were then returned to the empty cement mixer and 60 g of ground kelp was added to the soil an then again thoroughly mixed before being returned to the four pots. This produced, for each soil, four pots / replicates of untreated soil (control) and four pots / replicates of soil treated with kelp at a rate of 15 g of kelp per pot. This equates to a rate of 5.19 tonnes/hectare of kelp.

Soil analysis was undertaken by Hill laboratories (101c Waterloo road, Hornby, Christchurch 8042, New Zealand) using the “Basic Soil Test” suite which includes: pH, Olsen phosphorus, potassium, calcium, magnesium, sodium, cation exchange capacity, base saturation, and volume weight. In addition a resin phosphorus test was also completed.

The pots were then placed in a glasshouse with 30°C maximum and 15°C minimum set points. The pots were bottom watered (to minimise soil slumping) via individual trays 3 cm deep that were kept filled with water. Pots were left for four weeks to:

- allow weed seeds present in the soil to germinate and the seedlings to be removed;
- for soil processes to start the decomposition and mineralisation of the kelp;
- and for the soil to 'settle' after mixing.

After four weeks pots were sown with field pea (*Pisum sativum*) and rye corn (*Secale cereale*), with plants thinned to one plant of each species per pot. The plants were grown for 80 days, then the aerial parts were harvested, oven dried and weighed.

Results were analysed by ANOVA.

2.2. Results

The results of the students of BIOS 0273, found that kelp added to potting mix at a rate of 1% w/w gave increased growth in pak-choi, radish and basil plants but concentrations of 5% and above decreased growth to the point of completely killing the plants. Similar effects were found on seed germination.

The soil analysis results are presented in Table 2 and Figure 1, Figure 2 and Figure 3.

Table 2. Soil analysis results for the five test soils. CEC = cation exchange capacity, TBS = total base saturation, Vol. Wt. = volume weight.

Soil	**pH**	**Resin P**	**Olsen P**	**K**	**Ca**	**Mg**	**Na**	**CEC**	**TBS**	**Vol. Wt.**
		mg/kg	mg/L	me/ 100g	me/ 100g	me/ 100g	me/ 100g	me/ 100g	%	g/mL
BHU tunnel	7.2	407	137	1.75	24.8	4.33	0.44	31	100	0.81
BHU low input	6.0	17	7	0.47	7.0	1.02	0.13	14	62	1.05
Iverson 3	5.8	28	18	0.30	6.6	0.90	0.13	13	62	1.13
Iverson 12	6.0	35	20	0.57	8.7	0.93	0.13	15	67	1.06
Iverson 10	5.6	24	15	0.86	6.7	1.05	0.15	14	61	0.98

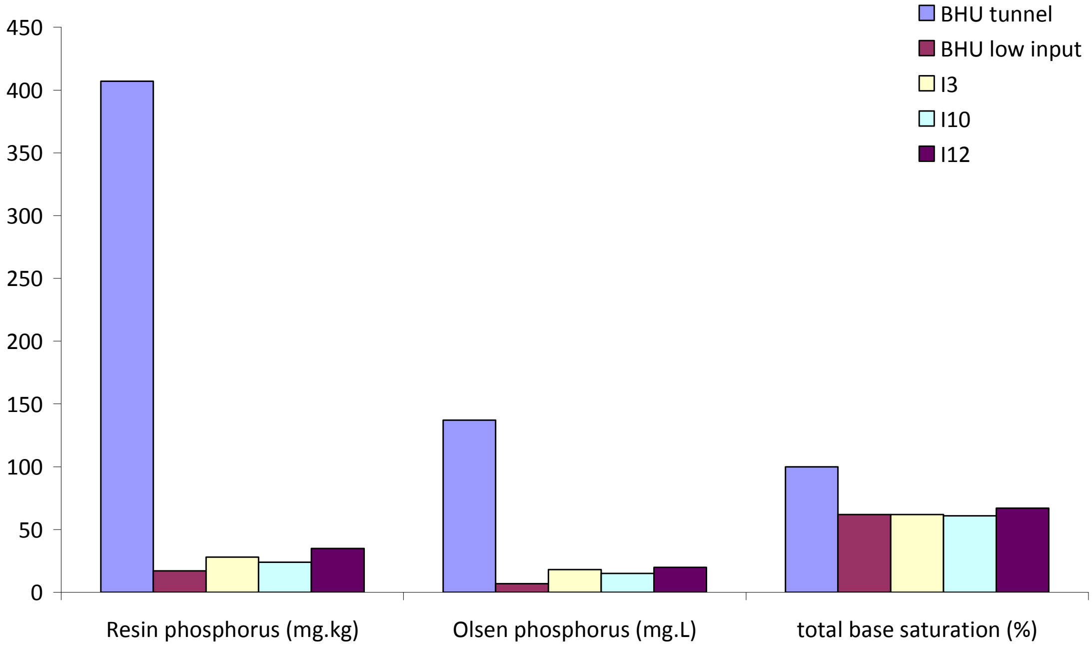

Figure 1. Soil analysis results for the five test soils, phosphorous and total base saturation.

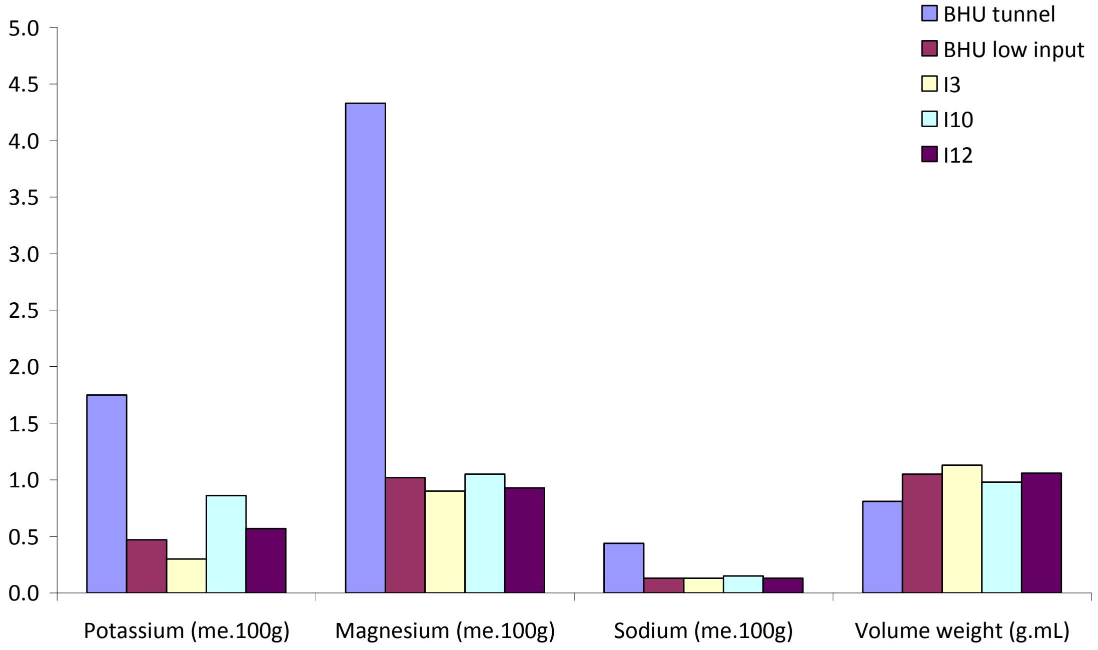

Figure 2. Soil analysis results for the five test soils, potassium, magnesium, sodium and volume weight.

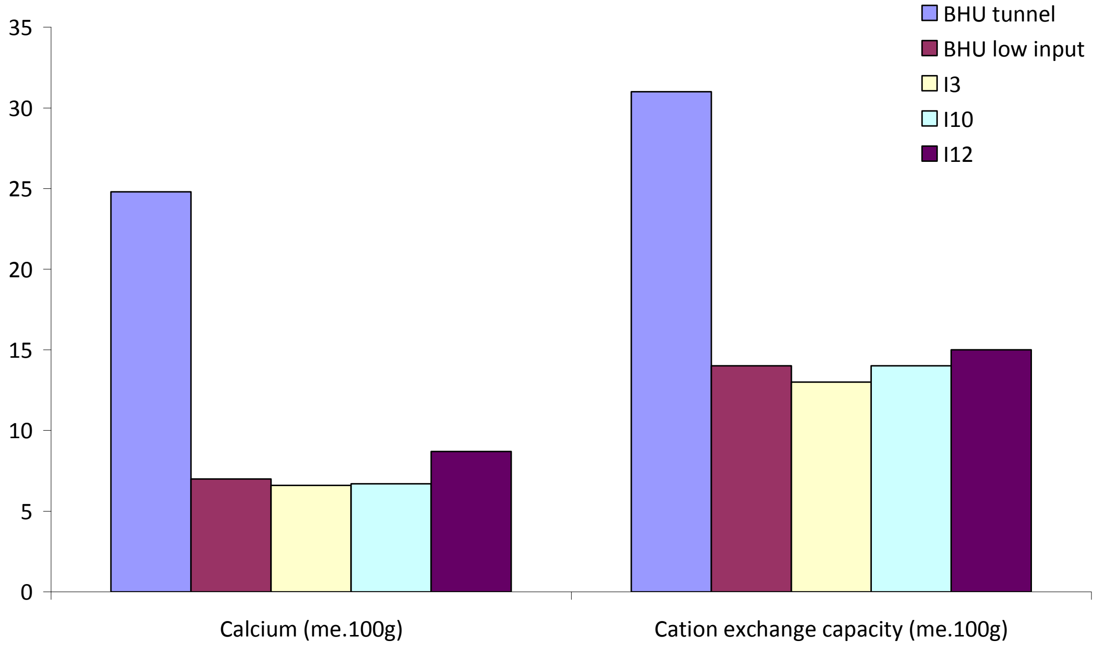

Figure 3. Soil analysis results for the five test soils, calcium and cation exchange capacity.

The average dry matter weight of the aerial parts of the pea and rye plants, the percentage change in weight due to the addition of kelp and statistical significance are presented in Table 3.

Table 3. The average dry matter weight in grams (n=4) of pea and rye plants grown in five soils with different nutrient statuses with and without the addition of kelp fertiliser. ns = not significant, * significant, ** highly significant.

Soil	Crop	Weight g no kelp	Weight g with kelp	% change	P value	Significance
BHU tunnel	**Peas**	15.0	8.7	-42%	0.145	ns
	Rye	9.6	7.0	-27%	0.271	ns
BHU low input	**Peas**	4.0	3.4	-16%	0.591	ns
	Rye	4.2	3.8	-9%	0.766	ns
Iverson 3	**Peas**	5.9	2.8	-53%	0.240	ns
	Rye	2.7	5.3	94%	0.012	*
Iverson 10	**Peas**	10.8	2.4	-78%	0.007	**
	Rye	4.1	0.4	-90%	0.004	**
Iverson 12	**Peas**	2.9	4.0	37%	0.325	ns
	Rye	5.0	6.5	30%	0.098	ns

2.3. Discussion

The soil test results from the collected soils had lower variation in nutrient status that the soil tests used to select the sample sites (data not presented), however, there was still a significant variation in the amount of nutrients among the samples, especially the BHU polytunnel which had very high levels of nutrients.

There was considerable variability in plant growth among the replicates of each soil sample, probably due to interplant competition. This is considered to be a key reason for the reduced level of statistical significance despite large biological differences in yields. However, the results overall also show considerable variability among the different soils, with the addition of kelp both increasing and decreasing plant growth, and in the case of the Iverson 3 soil it decreasing the growth of peas and increased the growth of rye, though the lack of significance of the pea result means that this result must be treated with caution. This may appear to be a confusing result, but it is consistent with crop responses to fertilisation. The results of the BIOS 0273 students is also consistent with expectations, with 1% rates of kelp boosting growth while higher rates dramatically decreased growth, to the point of killing the plants.

The explanation to these apparently contradictory results is that there is **NOT** a direct relationship between a materials fertiliser ‘value’ and the response of a crop, contrary to the widespread belief that it is a fertilisers ‘nutrient value’ that determines crop growth. The response of a crop to the addition of a fertiliser is primarily dependent on the level of nutrients already in the soil (or growing medium) and the crop’s nutrient requirements.

All plant species have an individual response curve for every nutrient and pH Figure 4. Where there are low levels of a particular nutrient the crop grows poorly (section a). As nutrient levels increase an inflection point is reached where the addition of an extra unit of nutrient creates a large growth response (section b). Then a second inflection point is reached where the curve levels off as the addition of more nutrients results in no further increase in growth (section c), due to the crop becoming satiated with that nutrient. Most nutrient response graphs only show this section of the curve, i.e., to the middle of section c. making a sigmoid shaped curve. However, if the level of nutrient continues to be increased, in most cases, and especially where the nutrients are applied in inorganic forms (minerals / ‘salts’) a third inflection point is reached where the nutrient addition causes a decrease in plant growth, i.e., the levels of nutrient start to become harmful (section d). If nutrient levels continue to increase, a final inflection point is reached, after which the nutrient levels become toxic and will kill the plant (section e) and Figure 5.

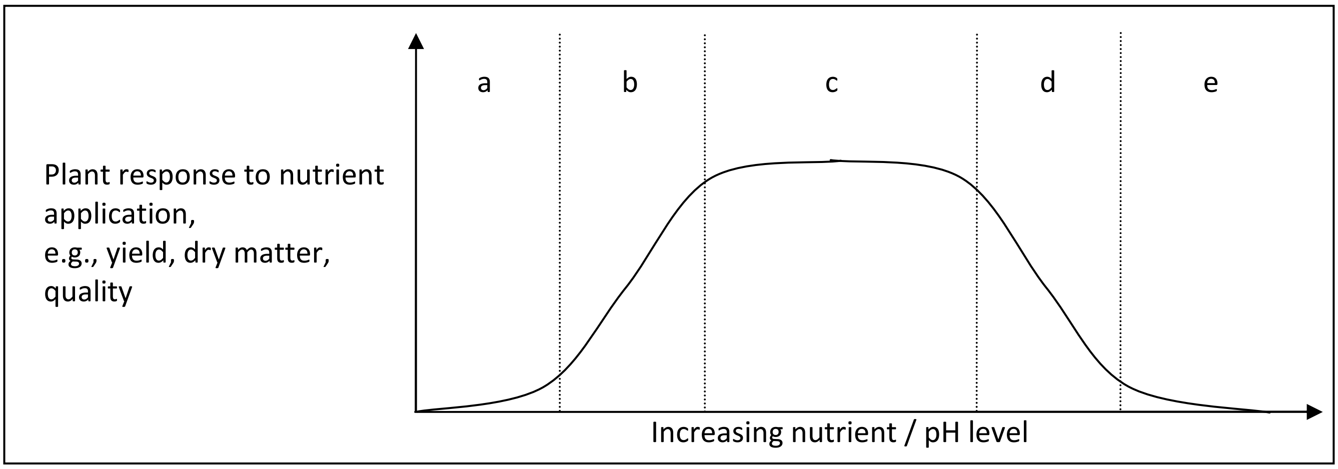

Figure 4. Generalised plant response curve to nutrient and pH levels.

Figure 5. Example of pasture killed from a spill of undiluted fish fertiliser, demonstrating that at sufficient concentrations fertilisers, even organic / biological materials, become toxic.

For each plant nutrient, the shape of the curve differs, often considerably, especially between the major and micro nutrients. The major nutrients generally have a much longer and flatter curve, especially the middle section ‘c’ (Figure 4) as plants can cope with large variations in nutrient status, while the micro nutrients, such as zinc, selenium and copper, generally have a much sharper peak due to plants only tolerating a small range of values between deficiency and toxicity. The curves’ shapes also varies among different plant species, and for some crops, it can even vary considerably among cultivars. The curves are also effected by soil type, soil structure and climate, and there are complex interactions among the nutrients and soil pH, e.g., a change in the pH or levels of one nutrient can change the shape, often considerably, of other nutrient curves.

The result of this is that the response of a crop to the addition of a fertiliser / nutrient will result in:

- A large increase in growth;
- No response at all;
- A large decrease in growth, even plant death.

I.e., adding exactly the same fertiliser in different situation, e.g., to a different soil or a different crop, will result in contrary results. This is what is seen in the results from this experiment.

To work out the value of a material as a fertiliser (fertiliser used in the broad meaning to include biological / organic materials), the three equally critical factors are:

- The amount of plant available nutrients in the fertiliser;
- The amounts of plant available nutrients in the soil, and;
- The nutrient requirements of the crop in question.
- The plant availability aspect is critical: for example, soils typically contain 10-15 tonnes of potassium in the top 30 cm per ha, but only a few kg or few 100 grams may be available to plants, the rest being tied up in the rock particles that make up the bulk of the soil. Water soluble mineral salt fertilisers are effectively 100% available, while less soluble materials such as reactive phosphate rock (RPR) becomes available about ⅓ per year, while insoluble minerals, e.g., elemental sulphur, need to be converted into soluble forms by soil microbes so may take many years, even decades to become available. In the same vein, biological fertilisers, e.g., compost, seaweed, manure, etc., vary in how rapidly the nutrients they contain become plant available, with a rough rule of thumb being the higher the carbon content, especially in the form of wood (lignin) the slower the release of nutrients and the higher the proportion of 'green' material, i.e. sugars, starches, proteins, the quicker the release. Kelp decomposes quite quickly as it lacks lignin being a seaweed, so most of the nutrients it contains can therefore be assumed to be readily plant available. Table 4 lists the typical nutrient content of green plants, compost and kelp.

Table 4. Comparison of the typical nutrient content of green land plants, compost and kelp. Multiple sources used. Grey rows highlight nutrients where kelp has considerably higher nutrient content than land plants and compost.

Nutrient		Plants		Compost		Kelp	Units
		Low	High	Low	High		
Nitrogen	N	2.0	4.0	0.5	4	1.2	%
Phosphorus	P	0.1	0.5	0.1	3	0.2	%
Potassium	K	0.7	2.0	0.5	3	8.8	%
Sulphur	S	0.1	0.3	0.5	2	1.0	%
Calcium	Ca	0.2	2.0	0.5	4	1.5	%
Magnesium	Mg	0.2	0.8	0.2	1	0.7	%
Sodium	Na	0.0	0.3	0.01	0.1	3.5	%
Iodine	I	1	30			2,063	mg/kg
Iron	Fe	50	250	200	4000	71	mg/kg
Manganese	Mn	20	300	100	600	6.5	mg/kg
Copper	Cu	5	20	40	600	1.5	mg/kg
Zinc	Zn	20	100	50	800	7.9	mg/kg
Boron	B	10	100			170	mg/kg
Cobalt	Co	0.2	0.5			0.17	mg/kg
Selenium	Se	25	100			0.07	mg/kg
Molybdenum	Mo	0.1	0.5			0.28	mg/kg

The table shows that kelp mostly has a similar nutrient profile compared with land plants and compost, however, for potassium sodium and iodine kelp has a nutrient content several or many times higher. Taking a mineral fertiliser ‘perspective’ i.e., its ‘NPK’ values kelp is a 1:0:9 fertiliser, while fresh green plants are a 3:0:1 and compost 2:2:2 (though the exact amounts vary widely). This means that for the major nutrients, kelp is **not** a balanced fertiliser. Even compost, which is widely considered to be a balanced fertiliser, is not when it is used as a nitrogen source - in such situations excessive levels of P, K and most other nutrients will be added to the soil if compost is used over the long term.

To further illustrate this point, the fertiliser recommendations that were calculated by R. McLenaghen at Lincoln University for this experiment showed that to supply sufficient P to bring the average soil nutrient status of the five soils up to recommended levels (P being the major limiting nutrient for these soils) it would of required 33 g of kelp per pot (11.4 tonne/ha) (compared with the 15 g that was applied(5.2 tonne/ha). However, at that rate, the K in the kelp would of induced Ca and Mg deficiencies in the crop plants. If kelp was applied to match the average K demand of the soils only 6 g of kelp (2.1 tonne/ha) should have been applied per pot.

As the NPK values shows (1:0:9), kelp is almost a straight K fertiliser. This is why Rapson *et al* (1943) during the second world war period were interested in kelp “as a source of potash in New Zealand”.

Similar potential issues arise with the high sodium (from ‘salt’ i.e. sodium chloride) and iodine levels in kelp. While in many situations the amount of these nutrients being added to land at kelp application rates up to, say, 10 tonne/ha, are unlikely to cause problems, higher rates or regular application of kelp at rates greater than 5 tonnes/ha/year may, depending on soil type and climate, cause toxicity or other problems. If the kelp is used in artificial potting mixes, i.e. without any soil, then the potential for kelp to cause negative growth could be much higher, as demonstrated by the results of the BIOS 0273 students.

3. Conclusions / recommendations

While kelp can be a valuable fertiliser and increase the growth of crops were K is below optimum levels, kelp is not a general purpose or balanced fertiliser (a nonsensical concept), and if it is used where K is not deficient and/or Ca and/or Mg levels are low the use of kelp as a fertiliser may cause a reduction in crop yield and/or other reductions in quality.

However, where soil K levels are low and Ca and Mg levels are sufficient or addressed through other fertilisers, then kelp (as do all biological / 'organic' materials) provides additional soil quality benefits through the addition of organic matter (carbon compounds) to the soil and also useful amounts of micro-nutrients. The long term effect of kelp or other seaweeds on soil, is more open to debate as kelp lacks lignin, which is the primary source of soil humus, so its effects on the soil are expected to be short lived, i.e. it will not build soil organic matter over the longer term, however, it contains alginates and other materials that can help bind soil particles and may increase soil organic matter via other routes.

Therefore if kelp is to be used as a fertiliser it must not used as a general purpose fertiliser, rather that it should be principally used as a potassium fertiliser and that it should only be applied according to soil nutrient tests.

While the use of kelp, and other seaweeds, as fertilisers is not as straightforward as it may initially appear, they represent one of the few practical and viable ways of closing the lithospheric nutrient cycles once nutrients have entered the oceans, i.e. returning soil nutrients such as P, K, Mg, etc. that are currently lost to the oceans via rivers and sewerage systems, back to the soil. While this is a valuable activity, the amounts currently being lost are many orders of magnitude greater than current and foreseeable seaweed for fertiliser harvesting programs, so it cannot be considered a full solution to the problem of lithospheric nutrient loss. However, following the idiom of 'every little bit helps' the use of seaweeds as fertilisers should be strongly welcomed in terms of helping to close lithospheric nutrient cycles.

This research also illustrates the need for a more fundamental ('under the hood') understanding of using biological / organic materials, such as kelp, within agriculture. Kelp clearly can be a valuable fertiliser, and has been used so for many years, probably all the way back to the dawn of agriculture, but uninformed use can result in worse not better crop performance. Therefore, while kelp and many other organic / biological materials have as real a fertilisers 'value' as mineral fertilisers have, it is not possible to make general claims about their, or mineral fertilises, value, e.g., 'that product 'X' will increase yields by 15%'. Such claims are not supported by science, even though it is very easy to set up a perfectly valid experiment where the results of using product 'X' do show a 15% increase in yield. In agriculture, unlike chemistry and physics, one experiment does NOT prove a theory, anymore than one swallow makes a summer.

4. Acknowledgements

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