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The effects of liquid fertilisers derived from natural products on crop, pasture, and animal production: a review

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Abstract. The results from field trials measuring the effect of liquid fertilisers derived from organic materials on crop yields are summarised and reviewed. Trials comparing the efficacy of 26 specific products and 2 unnamed generic products were identified. Of these 28 products, 15 were derived from seaweed, 4 from fish waste, 5 were of vegetable origin, and 2 were from animal products. Cereals were the most frequently used test crop (328 recorded treatment effects) followed by root crops (227), legumes (88), pastures (59), and vegetables (52). Fifty-three other treatment effects were recorded on crops such as rape (15), peanuts (8), tobacco (6), and miscellaneous other crops (25). The effects of liquid fertilisers on animal performance were measured in 4 trials.

The observed effects of these products on a wide range of crops were normally distributed about zero with an equal number of positive and negative 'responses'. The frequency of statistically significant events, both positive and negative, was consistent with probability theory, assuming that the products are ineffective. The range of observed effects are also consistent with the normal variability associated with field trial experimentation, taking into account the odd intrusion of other experimental errors. There was no evidence to support the conclusion that at least some product-types or products were effective on some crop-types, crops, or cultivars. Similarly, liquid fertilisers had no effect on animal production when applied as recommended.

This conclusion, based on the field evidence, was consistent with, and could be predicted from, independent evidence showing that these products do not contain sufficient concentrations of plant nutrients, organic matter, or plant growth substances (PGSs) to elicit increases in plant growth when applied as recommended.

Additional keywords: animals, crops, fertilisers, liquid, organic, nutrients, organic matter, pastures, plant growth substances.

Introduction

Many new products have been introduced into the agricultural market in recent years as alternatives to, or to increase the effectiveness and efficiency of, traditional solid fertiliser products. This includes a group of products generally referred to as liquid fertilisers or foliar feeds. Two categories can be identified based on their constituents and stated mode of action (Iowa State University 1984). One group comprises products that are dilute solutions of soluble inorganic and, sometimes, organic compounds. They are recommended to be applied to the foliage of crops in a diluted form and at low volumes. These have been defined (Iowa State University 1984) as Mineral Nutrient Sources or Low-volume, Low-concentration products. The efficacy of these products is reviewed elsewhere (Iowa State University 1984).

A further category (Iowa State University 1984) includes liquid products derived from natural materials such as seaweed, fish, animal, and vegetable products by various chemical and biochemical processes. These products may also contain added inorganic nutrients and/or other biological materials and are recommended to be applied at low rates (2–20 L/ha). Their primary mode of action is claimed to arise from the presence of plant growth substances (PGSs, such as auxins, cytokinin, and gibberrellins), acting alone or in combination with the other components of the product (nutrients, proteins, or enzymes), which stimulate the biological processes in the plant. Some also claim to have beneficial effects on the soil.

The general claims made for this type of liquid fertiliser include: increased plant yield and quality, improved nutrient use efficiency, greater tolerance to stress (drought, cold, insect pests etc), and increased root growth or activity. Some also claim to have beneficial effects on the soil biological activity and nutrient availability. Most are recommended to be used with normal fertiliser inputs but some claim to be a complete replacement to chemical fertilisers. These products are also claimed to be organic in the sense that they are

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suitable for use in organic production systems (NZ Biological Producers and Consumers Council 1998; FAO/WHO 1999).

The efficacy of these products has been measured in many field trials on many crops and in many countries and the published literature is confusing (Verkleij 1992). For example, some researchers have reported statistically significant effects on crop yields (Blunden and Wildgoose 1977; Abetz 1980; Abetz and Young 1983; Dwelle and Hurley 1984). Others have reported that these products have no consistent statistically significant effects (Ketring and Schubert 1981; Gupta and MacLeod 1982; Feyter *et al.* 1989). However, only a small proportion of the available research is formally published. Some has been reviewed and published as compendia (Iowa State University 1984) or Technical Reports (Scottish Agricultural Colleges 1981; Miers and Perry 1986) and the conclusions from these larger collections of trial data are that these products are generally ineffective. Other comprehensive bodies of experimental results can be found in unpublished institutional reports (Wadsworth 1987).

The purpose of this paper is to critically review the international literature on these products, both published and unpublished, and to quantify their effects on the yields of common crops and pastures.

Methods

A database was established consisting of records from field trials in which the effect of one or a number of these products on crop yield had been measured relative to a control treatment. Only randomised and replicated trials for which there were also available statistical analysis of the treatment effects were included.

For each trial the following data were recorded: product name, application rate, crop, cultivar (if recorded), site, and year, together with the measured treatment effects on plant yield, expressed as a percentage of the relevant control treatment, together with an indication as to the statistical significance ($P < 0.05$) of the treatment effect. In some instances the results were reported as an average over other variables, such as rate of application, the number of cultivars, or different levels of fertiliser input. In these cases the treatment effect at the lowest level for which the given statistical information applied was reported, together with a notation to that effect.

For defined sets and subsets for which the number of observations (treatment effects) was >20, the mean and confidence interval were calculated and normal probability plots were used for descriptive purposes. In some cases the rank and distribution, and hence the cumulative distribution, of the observed responses of the sets and subsets of data were determined. This type of comparative analysis of multiple trials allows practical generalisations to be made regarding the likelihood of obtaining a beneficial effect from a product at another, untested, site.

Trials comparing the efficacy of 26 specific products and 2 unnamed generic products were identified. The product descriptions and the specific claims made for the individual products are given in Table 1. Of these 28 products, 15 were derived from seaweed, 4 from fish waste, 5 of vegetable origin, and 2 were from animal products. Cereals were the most frequently used test crop (328) followed by root crops (227), legumes (88), pastures (59), and vegetables (52). Fifty-three other treatment effects were recorded on crops such as rape (15), peanuts (8), tobacco (6), and miscellaneous other crops (25).

Theoretical considerations

The power of an experiment to detect treatment differences depends on (*a*) the size of the difference measured, (*b*) the variability in the quantities that are measured, and (*c*) the number of replicates of each treatment (Johnstone and Sinclair 1991). Typically, the variability (CV) of pasture and crop yields is between 5 and 10% (see, for example, Scottish Agricultural Colleges 1981; Sinclair *et al.* 1994), and as Johnstone and Sinclair (1991) have shown, 9–28 treatment replications would be required to detect a 10% difference in yield at a 95% level of probability.

Most field experiments do not meet this standard, and furthermore, the reported effects of some products, such as liquid fertilisers, on plant yields are generally small (<10%, see Results). It is not surprising, therefore, that the effects of these products, as measured in individual field experiments, are frequently not statistically significant. The interpretation of such results is problematic: is the product having an effect but the experiment is not sufficiently accurate to detect it, or, is the product having no effect and the observed treatment effect due to the background biological variation? The converse situation also arises when an individual result is statistically significant: is the effect due to the treatment, or is it due to the small but finite probability that the product is having no effect and the observed effect is due to the background variability? These possibilities give rise to the classic Type I and II errors associated with statistical testing (Snedecor and Cochran 1967). These interpretive difficulties are possibly the reason why comparatively few experiments with liquid fertilisers are reported in the formal literature.

Reynolds (1987) has suggested a pragmatic solution to this problem. It arises when a given product is tested many times. This enables the frequency distribution of the measured treatment effects to be examined and compared with a normal distribution with a mean of zero. For convenience this is achieved by converting the distribution frequency and plotting the cumulative distribution function. Any displacement of the distribution, either positive or negative, can be taken to indicate a real treatment effect. For example, the data in Fig. 1 are from a set of experiments conducted by Wadsworth (1987) in which the effect of a small application of water (225 L/ha) on crop yields was measured relative to a nil treatment (no water). Such an input of water would not be expected to have a sustained or substantial effect on crop yield. This is indicated by the fact that the observed effects of water are distributed normally around a mean of –0.6% with a confidence interval of 2.3%. The range in the observations is –22% to 32%, consistent with the variability normally associated with experiments of this nature allowing for the odd intrusion of other experimental errors.

If a product is having a real, and sufficiently large, effect, the distribution of responses relative to the control is expected to move to the right. This is observed in Fig. 2, for a set of data derived from field experiments in which the effects of applying a phosphate fertiliser, at 2 rates, on pasture yields, on a series of P-deficient soils, were measured. Although the population of results was not large enough to clearly define the expected S-shaped cumulative distribution, the positive shift in the population of results on the *x*-axis is apparent.

The advantage of this approach is that it is easy to visualise large sets of data. Also the statistical significance of particular trial results can be seen in the context of the total population of results. It also obviates the difficulty that arises when formally averaging trial results from trials of many different designs.

Results and discussion

Field evidence

Some of the reported trials measured the effects of liquid fertilisers on both plant yields and crop quality, the latter being measured as either plant nutrient concentration, plant

Table 1. Descriptions and claims of liquid fertilisers derived from organic materials

Product	Manufacturer's description[A]	Manufacturer's claims
Ascophyllum nodosum	Foliar spray prepared from soluble powder of the seaweed *Ascophyllum nodosum*	Not given
Agriblend	Foliar spray derived from seaweed with macro and micronutrients. Contains at least 100 μg/g cytokinin	Beneficial effects on plant root systems, increases root efficiency and hence higher yields and quality
Agroplus	Foliar spray derived from an extract of bacteria, yeast, and fungi. Contains PGSs[B] (auxins, gibberellins, and adenine)	Stimulates root growth, increases efficiency of fertiliser use, increases the availability of nutrients, improves environments for roots and micro flora
Algistim	Foliar spray derived from a seaweed extract containing natural and synthetic cytokinin (175 mg/L kinetin) plus 33 ingredients including trace elements	Not given
Burst	Foliar spray comprising marine algae extract (4%), microbial extract (5%), and acetic acid preservative	Promotes root growth and vigour and increases yields, assists germination
Crop booster	Foliar spray derived from hydrolysed fish products with possible addition of other organic materials and inorganic nutrients	Not given
Culbac	Culture of *Lactobacillus* in whey and Norwegian kelp extract. Claimed to contain PGSs. Can be applied to soil or plant	Increases root development, stress tolerance, emergence, and yields. Improves fertiliser use efficiency
Cytex	Foliar spray derived from seaweed extract containing natural cytokinins (100 μg/g)	Increases size and yield of fruit
Cytozyme	Derived from marine algae and contains cytokinins with various micronutrients. Can be applied to soil and plant	Activates soil enzymes, increases nutrient retention, enhances decomposition, improves stress resistance, increases yields
Goemar (also known as Seagrow)	Foliar spray from seaweed containing auxins, cytokinins, and gibberellins plus 18 amino acids, 18 trace elements, and 7 vitamins	Not given
Grozyme (also known as Agroplus)	Fermented mixture of molasses, sugar, malt, yeast, and kelp plus micronutrients. Can be applied to soil and plant	Increases soil microbial activity, mobilises soil organic N, increases root growth, plant yields, and reduces the need for fertiliser N
Kelpac	Foliar spray derived from South African seaweed (*Ecklonia maxima*)	Not given
Maxicrop	Foliar spray derived from hydrolised seaweed containing nutrients, trace elements, auxins, cytokinins, and other biologically active materials	Higher yields and quality of crops, unlocks soil nutrients, more efficient nutrients use, enhanced soil biological activity, enhanced root growth
Moana Fish Fertiliser	Foliar spray derived from hydrolysed fish waste to which inorganic nutrients may be added	Higher yields and quality crops, improved animal health, more organic activity and release of soil nutrients, more earthworms and better soil structure
Nitrosol	Foliar spray derived from blood and bone containing gibberellic acid (0.01 μg/g) and tricontanol plus major and minor nutrients	Higher yields and quality crops, improved animal health, more organic activity and release of soil nutrients, more earthworms and better soil structure
PGS-10	Plant growth activator extracted from shale containing carboxyl, phenolic, and polyhydric acids	Stimulates seed germination, enhances soil and foliar nutritional activity, promotes soil microorganisms, reduces soil compaction
Plant Plasma	Foliar spray derived from fish and vegetable extracts plus a humic soil conditioner and macro and minor trace elements	Increased production, less disease in plants and stock, improved soil structure and deeper root development, improved pasture and fruit quality
Polverdol	A mixture of N, P, K, and 11 trace elements plus vitamin B and hormones	Not given
Response	Foliar spray derived from seaweed boosted with macro and micro nutrients	Increased yields and healthier plants and stock
Seaborn (also Seaborn Plus and Seaborn F)	Foliar spray derived from seaweed extract with urea, phosphoric acid, and KOH. Seaborn F also contains a fish extract	Source of nutrients, activates soil bacteria, enhances N-fixing bacteria, releases soil nutrients
Seacrop 16	Seaweed extract made from a blend of seaweeds from Maine, USA. Active ingredient is cytokinins	Improves growth processes and protein content and plant vigour
Seamac.	Seaweed extract containing cytokinin activity and trace elements (66 mg/L of kinetin equivalents)	Not given
Seasol	Foliar spray derived from Tasmanian bull kelp (*Durillaea potatorum*) containing natural growth stimulants	Soil conditioner and helps release bound soil nutrients and stimulate their uptake by the plant
Siapton	Foliar feed containing protein and amino acids (18) extracted from animal offal. Minimum of 700 g/L of polypeptides and amino acids and N, P, K, and 19 other nutrients	Not given
SM3	Foliar feed derived from 2 seaweeds, *Laminareaceae* and *Fucaceae*. 125 μg/g of kinetin equivalents	Not given
Stimufol	A mixture of amino acids derived from vegetable sources with trace elements (10) and N, P, K	Not given
10.8.8	Foliar spray derived from hydrolysed fish products with possible addition of other organic materials and inorganic nutrients	Not given
Triggr	Blend of fermentation products, marine algae extracts, plant extracts, natural saponins, and micronutrients	Increases plant yields

[A]Most of these products are sold in a liquid form for application to plant foliage but some are recommended for both plant and soil application. Also some are sold as a wettable powder to be applied directly to the soil or sprayed onto the plant or soil. Such details are not always available. The terms 'foliar feed' or 'foliar spray' are used where the manufacturer has specified this in the product description.

[B]Plant growth substances.

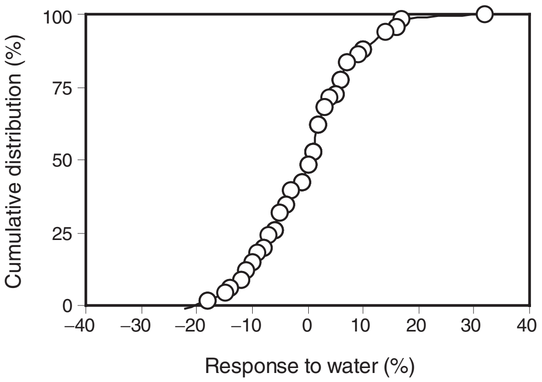

Fig. 1. Frequency distribution of crop responses to water (225 L/ha) expressed as the increase or decrease (%) relative to control (data from Wadsworth 1987).

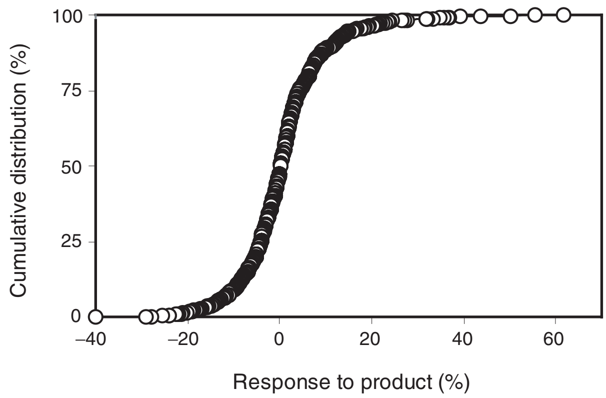

Fig. 3. Frequency distribution of crop and pasture responses ($N = 810$) to all liquid fertilisers expressed as the increase or decrease (%) relative to control (no liquid fertiliser).

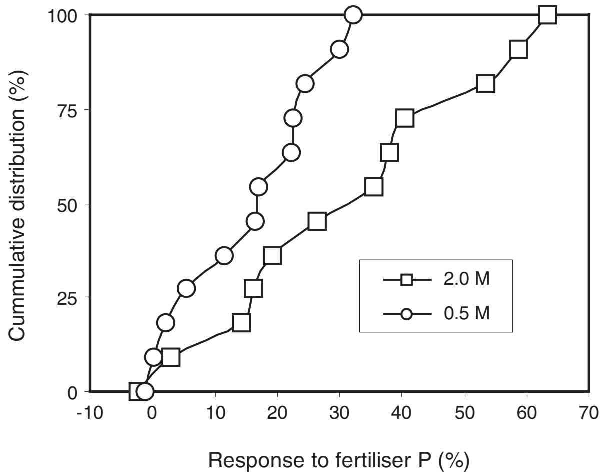

Fig. 2. Frequency distribution of pasture responses to triple superphosphate applied at 2 rates (0.5 and 2.0 times maintenance, M) expressed as the increase or decrease (%) relative to control (no fertiliser) (data from Sinclair *et al.* 1994).

size, plant size distribution, shelf life, resistance to pests and diseases, or storage quality. Because of the volume of information, this review is restricted to the effects of liquid fertilisers on plant yields. A total of 810 treatment effects on plant yields was recorded, including all products and crops. These were normally distributed around zero (Fig. 3) with a mean of 0.64 [confidence interval ± 0.67 ($P = 0.05$)] and a range from –40% to +61%. The 25%, 50%, and 75% quartiles were –4.1, 0.1, and 4.3, respectively. Of the total observations, 51 (6%) were statistically significant ($P < 0.05$) and of these, 28 (3%) were positive and 23 (3%) were negative.

These overall results are consistent with the hypothesis that liquid fertilisers generally have no effect on the plant yields over a wide range of crops, when applied as recommended. The range in the observations is generally consistent with the background biological variation normally encountered in such experiments, allowing for the odd intrusion of other experimental errors. Similarly, the frequency of statistically significant events is consistent with the theoretical frequency of Type II errors. However, it is possible that these general results mask some effects that may occur at the product-type, product, crop-type, or crop level.

Effect of product-type and product

The cumulative distributions of the observed crop yield responses to the 4 types of liquid fertilisers (viz. seaweed, vegetable, animal, or fish-based) are shown in Fig. 4 *a–d* and the relevant descriptive statistics for each subset of data are given in Table 2. For the fish-, animal-, and vegetable-based products, the observed effects are approximately normally distributed about zero, consistent also with the hypothesis that these product-types are having no effect on crop yields. There is some evidence, however, suggesting that the seaweed-based products are having some small effect on average (1.5%).

There were 8 specific products for which the number of measured effects exceeded 20. Four of these were seaweed-based (Maxicrop, SM3, Seasol, Kelpak), 2 were fish-based (Crop Booster and 10.8.8), one animal-based (Siapton), and one of vegetable origin (Stimufol). The distribution of observed effects for each product, across all crop-types and crops, is described in Table 2. In all cases the confidence interval included zero with approximately an equal distribution of positive and negative results, once again consistent with the null hypothesis.

The product Kelpak has been reported to increase the growth of a number of crop species when grown in the glasshouse (Fentonby-Smith and Van Staden 1983*a*, 1983*b*, 1984; Nelson and Van Staden 1984*a*, 1984*b*) and these effects were attributed to the presence of cytokinins. These results are inconsistent with those reported above from field trials. The likely explanation for this discrepancy is that the rates of application of Kelpak in these pot experiments were

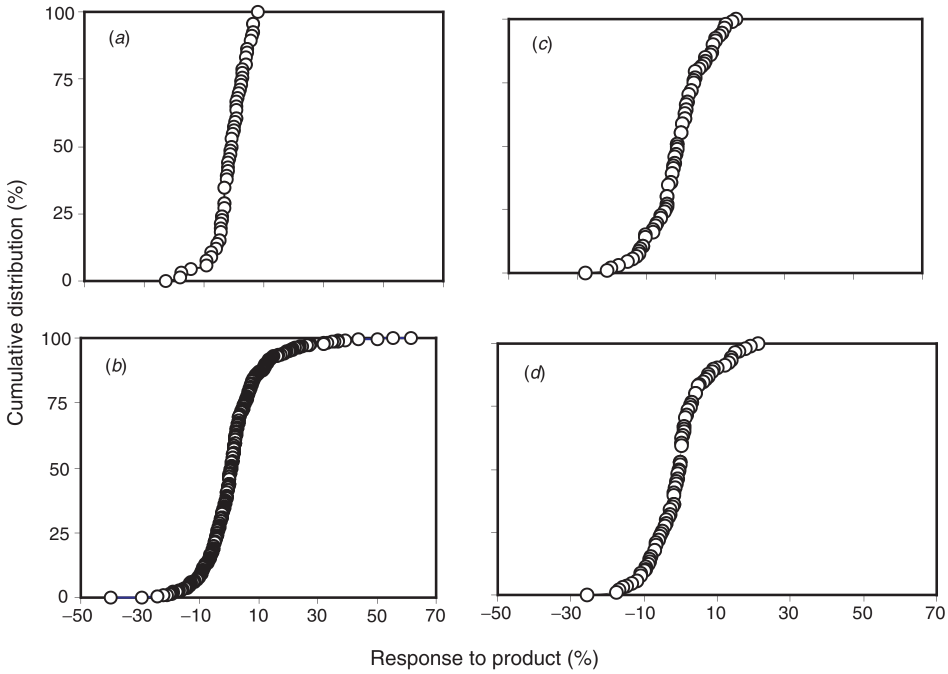

Fig. 4. Frequency distribution of crop and pasture responses to (*a*) fish-based (*N* = 67), (*b*) seaweed-based (*N* = 543), (*c*) animal-based (*N* = 93), and (*d*) vegetable-based (*N* = 107) liquid fertilisers expressed as the increase or decrease (%) relative to control (no liquid fertiliser).

Table 2. Descriptive statistics of the population of observed effects of the 4 product-types and 8 specific products where *N* > 20 on the production of all crops and pastures expressed as the percentage increase or decrease in production relative to the control

	N	Mean	Confidence interval (95%)	Distribution by quartile 25	50	75
			Product type			
Fish-based	67	–1.4	1.44	–3.9	–0.9	2.6
Seaweed-based	543	1.48	0.88	–4.0	0.8	5.4
Animal-based	93	–1.24	1.69	–4.1	–1.1	3.6
Vegetable-based	107	–0.72	1.52	–5.1	0.4	2.6
			Product			
Maxicrop	302	1.68	1.39	–4.5	1.2	6.3
Siapton	91	–1.46	1.70	–4.7	–1.2	3.0
Stimufol	85	–0.69	1.90	–6.0	–0.8	4
SM3	46	1.46	2.47	–3.8	1.0	5.8
Seasol[A]	30	1.8	2.82	–2.2	–0.1	3.4
Kelpak[A]	30	–0.76	1.48	–4.2	–0.7	2.0
Crop Booster[A]	29	–0.89	1.83	–3.2	–0.7	2.8
10.8.8[A]	26	–2.86	2.96	–4.5	–1.9	0.9

[A]All on a single crop (wheat).

several orders of magnitude greater than that recommended for use in the field and, in addition, the fertility of the growing media used (peat moss, sand : soil mixture, compost) was not given, but was likely to be low. Thus, the observed effects could have resulted from the elimination of nutrient deficiencies. This is supported by the evidence from 2 of these pot trials that demonstrated large responses to the application of fertiliser, which were decreased by the addition of Kelpak.

Effect on crop-type and crop

Five types of crops were represented: cereals, root crops, vegetables, pasture, and legumes. All other crops were treated as one group. The relevant statistics for each population of results are given in Table 3. Except for the legumes, the confidence intervals contained zero with an equal distribution of positive and negative observed effects, consistent with the conclusion that these liquid fertilisers

Table 3. Descriptive statistics of the population of observed effects of all products on specific crop-types or specific crops where *N* > 20, expressed as the percentage increase or decrease in production relative to the control

	N	Mean	Confidence interval (95%)	Distribution by quartile 25	50	75
Crop type						
Cereals	328	–0.06	0.80	–3.4	0.0	2.8
Roots	227	–0.47	1.07	–5.0	–0.7	3.0
Vegetables	52	0.11	3.38	–8.7	2.2	7.1
Pasture	59	1.19	1.75	–3.9	1.8	6.1
Legumes	93	4.54	2.94	–2.7	2.3	9.6
Others[A]	50	3.23	4.47	–7.1	2.1	11.8
Crop						
Barley	102	0.93	1.55	–2.3	0.0	3.0
Corn	152	–0.47	0.95	–3.4	–0.6	2.6
Wheat	23	–0.35	1.77	–2.5	0.4	1.4
Potatoes	188	–0.72	1.14	–5.2	–1.0	2.0
Lettuce	22	2.22	3.61	–1.75	2.0	7.5
Soybean	20	2.76	2.73	–0.2	1.44	5.75
Lupins	20[B]	6.86	9.48	–3.9	1.3	21.6

[A] Includes cotton, grapes, peanuts, apples, lentils, rape, saflower, linseed, and tobacco.
[B] All with the product Maxicrop.

Table 4. Descriptive statistics of the population of observed effects of specific products on specific crops where *N* > 20, expressed as the percentage increase or decrease in production relative to the control

Product	Crop	*N*	Mean	Confidence interval (95%)	Distribution by quartile 25	50	75
Maxicrop	Barley	42	1.9	3.33	–1.7	0.1	3.7
	Wheat	25	1.64	2.38	–1.6	1.7	3.7
	Potato	35	–0.18	3.14	–4.1	–1.1	3.4
	Vegetables	25	0.28	3.80	–8.4	4	6.3
	Pastures	34	1.49	2.25	–3.1	2.4	6.4
	Lupins	20	4.53	9.48	–3.9	1.3	21.6
	Other legumes[A]	33	4.97	5.83	–4.6	4.7	13.4
Siapton	Barley	20	0.17	2.36	–2.0	0.0	1.7
	Potato	46	–2.06	2.46	–6.7	–2.4	2.8
Stimufol	Potato	42	–1.5	2.68	–7.0	–2.4	2.8
	Barley	19	1.11	2.68	–2.0	0.0	3.5
SM3	Potato	30	1.48	3.06	–3.0	1.0	6.5

[A] Chickpea, field beans, fababeans, lucerne, and vetch.

have no effect on these crops. For the legumes, the results suggest that liquid fertilisers may have small beneficial effects (~4%) on yields.

There were 7 specific crops for which the number of observations was greater than 20 (Table 3). For these specific crops, including 2 legumes, the observed effects were approximately normally distributed about zero. Similarly, the distributions for the observed effects at the specifc product and crop level (Table 4) provide no evidence to suggest that these specific products are effective at the specific crop level.

The results for the legume crops (Tables 3 and 4) indicate that there was greater variability in this set of trial results. The reason for this is not known but most of these trials were from experiments conducted in South Australia with the seaweed product Maxicrop on lupins. It is possible that this subset of results is the reason for the apparently favourable result for seaweed-based products across all crop-types (Table 2) and for legumes across all products (Table 3). Given that the specific effect of Maxicrop on lupins is not statistically significant, it is suggested that these results do not contradict the overall conclusion.

Blunden and Wildgoose (1977) reported a statistically significant effect of the seaweed product SM3 on the potato cultivar King Edward but not on Pentland Dell. Similarly, Dwelle and Hurley (1984) recorded responses to Cytex (seaweed extract) with the cultivar Lemhi Russet, but not with Russet Burbank. These results suggest that some liquid

Table 5. Effect of various liquid fertilisers on the yield (t/ha) of potato cv. King Edward (Wadsworth 1987)

Treatment	1976	1977
Control	50.2	35.8
Stimufol	52.5	40.2
Siapton	53.8	35.1
Maxicrop	50.7	33.5
l.s.d. (*P* = 0.05)	4	6

Table 6. Effect of rate and placement of Agroplus on the relative yield of corn and soybean (Iowa State University 1984, Report B 1.3.1)

Treatment	Corn	Soybean
Control	100	100
Soil applied (11.2 L/ha)	103	101
Foliar application (0.1 L/ha)	101	99
Foliar application (1 L/ha)	97	101
Foliar application (10 L/ha)	98	101
l.s.d. (*P* = 0.1)	7	5

Table 7. Effect of time and rate of application (L/ha) of Kelpak on wheat yields (Miers and Perry 1986)
There were no statistically significant treatment effects

Time of application	Rate of application	Relative yield
Five-leaf stage	0	100
	1	103
	2	106
	3	101
Five leaf + extended stem	2	103
	3	103
	4	101
	6	103
CV		7%

fertiliser may have some effects, at least on some cultivars of some crops.

The general results for the product SM3 (Tables 2 and 4) suggest that this product is ineffective on crops generally and on potatoes specifically. For the product Cytex there where 15 recorded treatment effects with a mean of 1.19 (confidence interval 3.49). Half of these results were from Dwelle and Hurley's (1984) potato experiments. This suggests that Cytex is no more effective than the other seaweed-based products. Furthermore, other results with the potato cultivar King Edward indicate that it is not uniquely sensitive to the application of liquid fertilisers generally and to seaweed-based products specifically (Table 5). Taken together, these results suggest that the observations of Blunden and Wildgoose (1977) and Dwelle and Hurley (1984) are likely to be due to background biological variation, or to the other sources of experimental error, and are not treatment effects due to the action of specific products on specific cultivars.

Table 8. Effect of application rate of Plant Plasma on pasture production (Feyter *et al.* 1989)

Treatment	Relative yield (mean 2 years)
Control	100
Plant Plasma (recommended rate)	104
Plant Plasma (10 times recommended)	101
Nutrients equivalent to 10 times recommended	108
l.s.d. (*P* = 0.05)	9

Table 9. Effect of application rate of Maxicrop on pasture production in the presence and absence of applied fertiliser phosphorus (P) (McDonald 1987)

Treatment	Relative yield	
	No P	Plus P
Control	100	109
5 L/ha	97	123
10 L/ha	100	120
25 L/ha	106	116
50 L/ha	96	121
100 L/ha	97	114
5 L/ha, 5 times	95	112
Nutrients equivalent to 100 L/ha	98	117
l.s.d. (*P* = 0.05)	Vertical 14, horizontal 4	

Table 10. Effect of rate and time of application of Cytex on the yield (kg pod/ha) of 3 peanut cultivars (Ketring and Schubert 1981)
There were no statistically significant treatments effects

Treatment	Cultivar 1	Cultivar 2	Cultivar 3
Control	3450	2650	2710
Cytex (12 L/ha)			
Early flowering	3540	3030	2880
Late flowering	3540	2460	2900
Both stages	3660	2620	2960

Effect of rate and time of application of product

In most of the experiments recorded on the database, the products were applied at the rate and time recommended by the proprietor. However, a number of researchers have examined the effect of rate and timing of application of various products, often in conjunction with other factors. Some representative results are given in (Tables 6–10). Collectively, these results indicate that the efficacy of liquid fertiliser is not affected by the rate or timing of application.

Effect of soil fertility

Similarly, most of the experiments examined the efficacy of liquid fertilisers either on fertile soils or soils to which adequate fertiliser was applied. Under these circumstances it is likely that any possible nutritional effects of the liquid fertilisers would be eliminated and that any plant responses

Table 11. Effect of Maxicrop on pasture and animal production at three sites in New Zealand (Metherell 1987)
Pasture production in kg DM/ha over 3 years; animal production in lamb growth rate (g/day) over 3 years

Site	Measurement	Control	Observed effect	Confidence interval (95%)
Site A	Pasture	29 063	762	–3579 to 5103
	Animal	94.6	–3.2	–12.0 to 5.6
Site B	Pasture	46 566	1270	–3071 to 5611
	Animal	128.7	–10.6	–19.0 to 1.4
Site C	Pasture	44 099	–676	–5017 to 3665
	Animal	133.8	9.3	0.5 to 18.1

Table 12. Effect of the product 'Response' on pasture and animal production at Te Kuiti (Feyter *et al*. 1989)

Measurement	Control	'Response'	l.s.d. (P = 0.05)
Pasture production[A]	40 378	37 770	4026
Ewe liveweight gain (kg)	–0.04	–0.04	0.008
Ewe wool weight (kg)	4.47	4.20	0.23
Lamb liveweight (kg/ha)	505	438	32
Lamb wool weight (kg/ha)	19.0	15.6	1.6

would be due to the addition of organic matter or PGS. However, in some trials the products were tested on nutrient-deficient soil, both in the presence and absence of fertiliser. This is demonstrated by the example in Table 9 in which there was a large response to applied P on this P-deficient soil but there were no consistent effects of the product in either the presence or absence of fertiliser P.

Effects on animal production

It is claimed for some of these products that they have beneficial effects on animal production. It is possible that such effects could occur in the absence of any effects on pasture production; for example, by affecting the palatability or quality of the forage. This possibility has been tested in 4 trials (Tables 11 and 12). In these trials, many measurements were made on the nutrient content, legume content, and digestibility of the pasture (data not shown). No consistent treatment effects due to liquid fertiliser were found (Feyter *et al.* 1989; A. K. Metherell, pers. comm.), consistent with their lack of effect on animal production.

Laboratory evidence

The nutrient concentrations of some representative liquid fertilisers are given in Table 13. These must be treated as indicative only, because many of these products are sold as the basic organic extract to which various amounts of other nutrients, particularly N, P, and K and trace elements, are added. The product 'Response' is one of the more enriched. The amounts of nutrients applied, using this product at the recommended rate of 20 L/ha are, respectively, 2, 0.8, 1, 0.1, and >0.01 kg/ha for N, P, K, S, and Na. Such inputs are much smaller than the amounts of these nutrient present in fertile soils, or the amounts applied as fertilisers to correct nutrient deficiencies. It is most unlikely therefore that these types of products could affect plant growth by relieving nutrient stress, except perhaps in unusual circumstances where the products are applied well above the recommended rate. This conclusion is supported by the many results in the database (see Table 9 for example) which show that they are ineffective both in the absence and presence of fertiliser inputs on infertile soils.

Similarly, although it is undoubtedly true that these products contain organic matter, the amounts present are small. For example, Maxicrop contains about 10% C. When applied at 4 L/ha, the recommended rate, 400 g/ha of organic C would be applied. Such an input is insignificant in relation to the amounts of organic matter present in most fertile soils or the amounts required to elicit an effect on soil properties and hence plant growth. It is possible that such small amounts of organic matter may stimulate soil microbial activity in soils but it must be noted that these products are normally sterilised to prevent fermentation during transport and storage.

Many of these products are claimed to contain either natural or synthetic PGSs and in particular cytokinins, or to exhibit cytokinin-like activity (Abetz 1980; Verkleij 1992). To the extent that many of these products are derived from plant material it is likely that they do contain some of these chemicals or properties (Verkleij 1992). The practical issue is: what concentrations of the PGSs are present and are they sufficient to elicit growth response in intact plants in the field?

Williams *et al.* (1976) examined 3 seaweed-based liquid fertilisers and reported that there was no significant auxin

Table 13. Nutrient concentrations in a range of liquid fertilisers

Product	Specific gravity	Concentration (%) N	P	K	S	Na	Concentration (µg/g) Mg	Ca	Fe	Mn	Cu	Zn	Mo	B
Maxicrop	1.08	0.14	0.02	3.4	0.5	0.7	170	220	80	5	5	5	5	30
Seasol	1.09	1.6	0.1	1.3	–[A]	–	0.21	300	108	4	5	24	–	–
Kelpak	1.06	8.8	0.8	0.7	–	–	0.02	40	14	1	3	17	–	–
Response	1.23	10.3	3.9	5.2	0.3	0.07	100	130	160	90	70	45	5	80
Goemar (Seagrow)	1.01	0.04	–	0.04	0.06	0.1	155	490	20	5	5	2	2	2

[A]Not given or available.

Table 14. Effect of two liquid fertilisers of stated kinetin content and the synthetic product Kinetin on the relative yields of potatoes (Scottish Agricultural Colleges 1981)

Application rates are for Year 1 and Year 2, respectively

Treatment	Rate (g/ha of kinetin equivalents)	Relative yield Year 1	Year 2
Control	0, 0	100	100
Kinetin	0.5, 0.7	100	106
	1, 1.4	106	109
	2, 2.8	93	103
Algistem	1.7, 2.6	100	108
Seamac	0.7, 0.7	99	90
l.s.d. (P = 0.05)		8	7

Table 15. Effect of two liquid fertilisers of stated kinetin content and the synthetic product Kinetin on the relative grain yields of barley (Scottish Agricultural Colleges 1981)

Treatment	Rate (g/ha of kinetin equivalents)	Relative yield Year 1	Year 2
Control	0	100	100
Kinetin	0.25	103	97
	1.2	103	99
	2.2	102	100
Algistem	1.7	100	96
Seamac	0.4	109	98
l.s.d. (P = 0.05)		4	4

activity and that the initial activity of gibberrellic acid declined rapidly to zero in 4 months following storage. They did, however, report significant cytokinin activity and estimated the concentrations to be about 25–200 mg kinetin equivalents (KE)/L. Elsewhere, Maxicrop has been reported to contain 1.3 mg KE/L (Jameson 1987). However, all of these estimates were made using bioassays. The only unequivocal identification of a PGS in a liquid fertiliser has been reported by Tay *et al.* (1985), who identified a number of cytokinin derivatives in the product Seasol using mass spectrometry. The highest concentration was 0.04 mg/L. Given the interpretative difficulties that arise from bioassays it is more likely than not that the cytokinin concentrations in these products are in the parts per billion range, which according to Field (1987) and Witham (1987) is too low by several orders of magnitude to affect the growth of intact plants in the field.

For some products the actual concentration of cytokinin is stated, although it is not clear whether this results from the addition of synthetic cytokinins. These range up to 100–175 mg/L of KE (Table 1). Several authors (Blunden and Wildgoose 1977; Scottish Agricultural Colleges 1981) have compared the efficacy of liquid fertiliser of known, or claimed, cytokinin concentration with equivalent applications of the synthetic cytokinin, Kinetin. Some typical results are given in Tables 14 and 15, from which it can be inferred that these inputs of cytokinin are insufficient to affect plant growth.

It is reasonable, therefore, to predict that liquid fertilisers will have no practical effect on plant growth in the field when used as recommended, simply because they do not provide sufficient quantities of nutrients, organic matter, or PGSs to elicit plant growth responses. Indeed it is likely that the recommended application rates would need to be increased by possibly 3–4 orders of magnitude before practical benefits could result from their application.

The suggestion that these products contain insufficient amounts of any substance likely to enhance plant growth is reinforced by a unique set of trials conducted by Wadsworth (1987). He conducted many trials with a variety of liquid fertilisers on a variety of crops. The experimental design included a control, a treatment of liquid fertiliser applied as recommended, and a further treatment of water applied at the same rate as the water used to apply the liquid fertilisers. The distribution functions derived from his results are shown in Fig. 5*a–d*. These results are consistent with the conclusion that these liquid fertilisers do not contain sufficient quantities of any ingredients that may affect plant growth.

Overall conclusion

The results from the field trials and the laboratory evidence reviewed in this paper lead to the conclusion that liquid fertilisers, as defined, have no practical effects on crop and pasture yields. This appears to contradict the conclusions reached in two previous reviews. Verkleij (1992), echoing the earlier review by Abetz (1980), concluded that seaweed extracts can be beneficial for the growth and yield of crops, at least for some crops and under some conditions. How can this apparent contradiction be resolved, especially given that the results they relied upon are included in the present review, and given the qualification that the trials were adequately designed (see methodology)?

The reviews by Abetz (1980) and Verkleij (1992) fairly reflected the published literature on liquid fertilisers at the time they were published. However, there is normally little motivation for researchers to publish negative results in the formal literature. This is especially so when the motivation for the original research was to meet a local need that was satisfied once the results were reported to the local growers or merchants. It is possible that, only where the need for information about such products becomes more regional, or national, that collections of trials are summarised or series of trials covering a range of products, crops, and conditions are undertaken. This is the likely motivation for the Compendia of Non-Traditional Products (Iowa State University 1984), the Technical Report from the Scottish Agricultural Colleges (1981), and the comprehensive studies by Miers and Perry (1986) and Wadsworth (1987). Indeed the motivation for the current review arose initially because of a legal challenge against the conclusions reached by scientists in the New

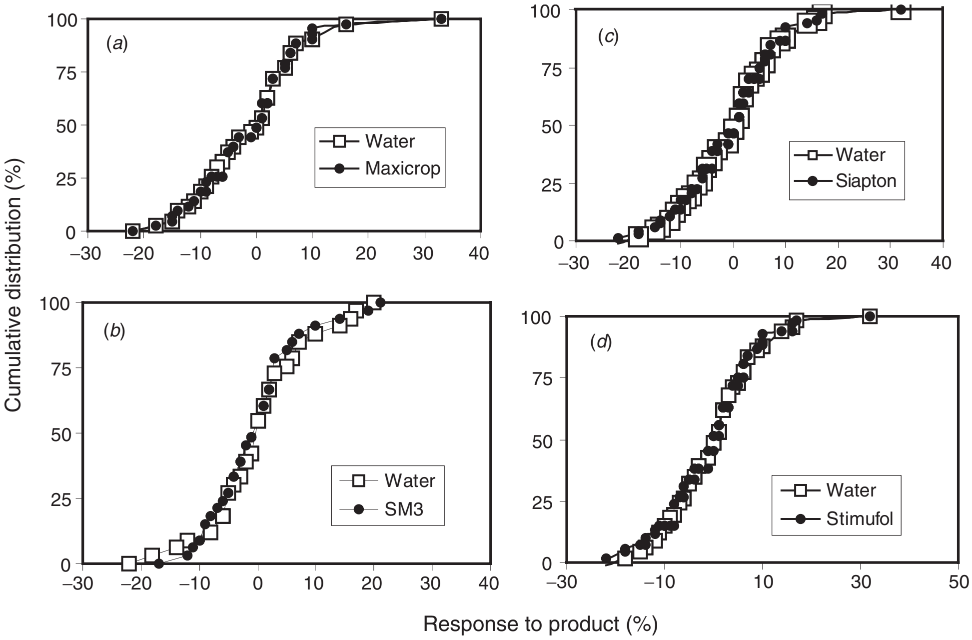

Fig. 5. Frequency distribution of crop responses to 4 liquid fertilisers: (*a*) Maxicrop (*N* = 44), (*b*) SM3 (*N* = 34), (*c*) Siapton (*N* = 66), and (*d*) Stimufol (*N* = 67), compared with the same rate of application of water, expressed as the increase or decrease (%) relative to control (no liquid fertiliser or water).

Zealand Ministry of Agriculture and Fisheries (Edmeades 2000). But even under these circumstances, these reviews do not become published in the formal scientific literature. Thus, the published scientific literature on these products has been biased to this extent, and furthermore, this bias is not apparent until all the available data, both published and unpublished, are viewed together in a quantitative manner, as in this review.

Both Abetz (1980) and Verkleij (1992) acknowledged that liquid fertilisers are not always effective. Verkleij (1992) suggested several reasons for this. Firstly, he suggested that seaweed extracts [note he only reviewed this one type of product] 'are most beneficial when plants are coping with adverse environmental conditions, such as nutritional stress or pest and diseases.' Specific trials, such as that summarised in Table 9, do not support this conclusion. Furthermore, it is unlikely that 'adverse environmental conditions' did not apply to at least some, and perhaps many, of the 810 yield observations reported in this review. Verkleij (1992) also suggested that variable product quality, soil type, crop type, and growth stage may affect the efficacy of these liquid fertilisers. The evidence presented earlier does not support these suggestions.

The most likely explanation for the conclusions of Abetz (1980) and Verkleij (1992) is that they were examining a published subset of the total information, which was biased to the extent that negative results are not normally published in the formal scientific literature. Their suggestions for the lack of effectiveness of liquid fertiliser in some situations, while plausible, do not appear to be supported by the total information now available. It is more likely than not, that the range of effects they reported is simply a reflection of the underlying biological variation that occurs in all fieldwork of this type and not attributable to any specific effect of liquid fertilisers (*viz*. Type II errors).

The present review is restricted to the effects of liquid fertiliser on plant yields. Both Abetz (1980) and Verkleij (1992) considered also their effects on plant quality and reported some beneficial effects. However, such observations must also be treated cautiously given the comments above.

The problem highlighted by this review, in relation to the two earlier reviews, arises because of a combination of circumstances: the lack of motivation to publish all results, including results that are not statistically significant or are negative, and the difficulty of measuring the effects of some treatments against a background of biological variation. It is likely that there are many agricultural products and practices which owe their ongoing existence to this dilemma. However, the statistical approach suggested by Reynolds (1987) appears to be a useful technique for summarising and reviewing results where such products and practices have been tested many times under a variety of circumstances. This approach lends itself particularly to all research on fertilisers and lime.

Finally, when viewed retrospectively, the results of this study highlight several issues against which agricultural science and scientists must remain vigilant, working as they do with a background of biological variation. These include:

(*1*) the importance of trial design and the difficulties of data interpretation when measuring treatment effects that are likely to be of a similar magnitude to the background biological variation;
(*2*) the need to publish all results, both positive and negative, so that the literature does not develop an inherent bias; and
(*3*) the danger of basing conclusions on a subset of the total information available.

Conclusions

The results summarised in this review show that liquid fertilisers derived from natural products have no practical effect on crop yields when applied as recommended. It is possible that such products when applied at many times their recommended application rates may increase plant growth due to either the addition of nutrients, organic matter, or plant growth hormones. However, the evidence suggests that this would require increasing the application rate by at least several orders of magnitude. It is most unlikely that such high rates would be economically viable.

This conclusion is based on two independent components of evidence. Firstly, the observed effects of these products on the yield of a wide range of crops are normally distributed about zero with approximately equal numbers of positive and negative 'responses'. The frequency of statistically significant events, both positive and negative, is consistent with probability theory assuming that the products are ineffective. The range of observed effects is also consistent with the normal variability associated with field trial experimentation, taking into account the odd intrusion of other experimental errors. Furthermore, this conclusion is consistent with, and can be predicted from, independent evidence showing that these products do not contain sufficient concentrations of either plant nutrients, organic matter, or PGSs to elicit increases in plant growth when applied as recommended.

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