Taylor & Francis
Taylor & Francis Group

Effects of Algal Fibre and Perlite on Physical Properties of Various Soils and on Potato Nutrition and Quality on a Gravelly Loam Soil in Southern Norway

Riley, H. (Norwegian Crop Research Institute, Apelsvoll Research Centre, Division Kise, NO-2350 Nes på Hedmark, Norway). Effects of algal fibre and perlite on physical properties of various soils and on potato nutrition and quality on a gravelly loam soil in southern Norway. Received April 10, 2002. Accepted June 4, 2002. Acta Agric. Scand., Sect. B, Soil and Plant Sci. 52: 86–95, 2002.
© 2002 Taylor & Francis.

Large quantities of seaweed are harvested world-wide for industrial processing, but significant amounts of by-product remain unused and may cause environmental pollution if returned to the sea. Its potential for use in agriculture is therefore of interest. Algal fibre waste from a large alginate extraction plant in Norway was studied with respect to its potential both for soil physical amelioration and as a nutrient source for potatoes. The material contained perlite, itself a well-known growth substrate, as this was used to filter the fibre in the factory. The effects on soil moisture retention and aeration properties of incorporating up to 80% fibre waste or pure perlite were studied on five widely contrasting soil types. The algal fibre waste had similar effects to pure perlite on soil aeration and on the proportion of water held at low soil moisture tension. It had, however, a far greater effect on moisture retention at higher tension levels. Plant-available water increased by 3.6 vol.% when 10% by volume of fibre was incorporated, as against 1.2 vol.% with the same volume of pure perlite. The effects were similar in all soils. The effect on potato growth and quality of spreading 20 or 40 Mg ha^{-1} of algal fibre was studied by comparison with the use of various amounts of compound nitrogen–phosphorus–potassium (NPK) fertilizer. The algal fibre contained large amounts of plant nutrients. In the absence of fertilizer, potato yield increased by 30% and 70% with the use of 20 and 40 Mg ha^{-1}, respectively. These increases declined to 7% and 17% at the highest rate of fertilizer application (120 kg N, 55 kg P and 187 kg K ha^{-1}). The effect of 10 Mg ha^{-1} algal fibre was equivalent to that of 20–25 kg N in compound fertilizer. Algal fibre had little effect on soil contents of available P, K, calcium and magnesium, but the level of sodium rose sharply. Electrical conductivity did not, however, rise excessively. A considerable amount of mineral N remained in the soil after harvest, but most was lost to leaching before the following year's ryegrass crop could make use of it.

Hugh Riley
Norwegian Crop Research Institute, Apelsvoll Research Centre, Division Kise, NO-2350 Nes på Hedmark, Norway

Key words: crop yield and quality, soil aeration, soil moisture retention, soil nutrients.

Introduction

The use of seaweed as manure has a long tradition in many parts of the world (Booth, 1966; Blunden, 1991), but is today seldom considered as a commercially viable practice. Seaweed harvesting is, however, an important and widespread activity for the extraction of alginate for use in pharmaceuticals and as food additives (Chapman & Chapman, 1980), and large quantities of algal fibre are derived as a by-product. This fibre was previously disposed of at sea, but this practice is now restricted and the fibre is instead collected on filter-beds of perlite. Some 10 000 t of dry matter (DM) per year are produced at FMC Biopolymer's plant in south-west Norway. The use of this material for soil amelioration may be an attractive option in the future.

Studies on the effects of algal fibre on the germination and growth of barley, on the plant availability of the macronutrients that it contains and on its potential for improving soil aggregate stability were performed by Kolden (1995). These studies showed that the material has favourable effects on both chemical and physical soil properties.

This paper presents the results of a laboratory study performed to evaluate the effects of the algal fibre by-product, which contains approximately 40% perlite, on the physical properties of some common soil types, and of a field trial aimed at evaluating its effects on potato yield and soil nutrient status. The studies were performed under contract at Apelsvoll Research Centre, Division Kise.

Material and methods

Studies on soil physical properties

Samples of soil types with widely varying physical properties were collected from the subsoil at five locations in south-east Norway. Details of their texture, organic matter status and aggregate stability to artificial rain (Njøs, 1967) are given in Table 1.

The soils were air-dried, crushed and sieved (< 2 mm). Dry bulk densities of the sieved, vibrated material were 1.67 g cm^{-3} for the sandy soil (1), 1.47 g cm^{-3} for the silty (2) and loam (3) soils and 1.27 g cm^{-3} for the medium clay (4) and heavy clay (5) soils. Bulk densities of the algal fibre by-product (at 83% DM) and pure perlite material, when loosely packed, were 0.33 g cm^{-3} and 0.12 g cm^{-3}, respectively. On the basis of these values, weights of soil and fibre/perlite were calculated to give a range of up to 75% by volume of the two materials when mixed with soil. Samples of about 300 ml total volume were mixed thoroughly and placed in 5 cm deep aluminium trays. Water was added in 50 ml aliquots over a number of days until the soil mixtures were uniformly wetted, but not saturated. Two 100 ml cylinder samples were taken from each mixture, making 110 samples in total.

The cylinders were first placed in a freezer at -20°C to obtain a natural pore structure through the effect of freezing. They were then saturated from below for 4 days, weighed and placed on ceramic plates in pressure apparatus (Soil Moisture Inc.) and equilibrated at a matric tension of -10 kPa for 28 days and thereafter at -100 kPa for 54 days. Air permeability was measured after equilibration at -10 kPa using a constant-head permeameter. Finally, sieved subsamples were placed in pressure membrane apparatus at a tension of -1500 kPa for 1 week. Calculations were made of volumetric water contents at saturation and at the three matric tensions mentioned above, from which values for total porosity, air capacity (0 to -10 kPa), readily plant-available water (-10 to -100 kPa) and total plant-available water (-10 to -1500 kPa) were derived. Mean values of each cylinder pair were used in analyses of variance, in which soil type and material type were treated as main factors and the amount of material added was treated as a split-plot factor.

Field trial with algal fibre/perlite mixture

The trial was performed on a gravelly loam soil overlying gravel alluvium at Nes på Hedmark (60°47′ N, 10°49′ E, 125 m asl). The stone and gravel content of the topsoil was about 15%, while that of the

Table 1. Texture, organic matter and aggregate stability of the soils in the laboratory study

Location of sampling site	Sand 6–2000 µm (%)	Silt 2–6 µm (%)	Clay <2 µm (%)	Organic matter (%)	Aggregate stability (%)
1. Tjølling, Vestfold	89	8	3	2.1	na
2. Roverud, Solør	6	83	11	0.8	33
3. Nes på Hedmark	35	43	22	1.1	56
4. Nes på Romerike	1	52	47	0.2	26
5. Skjeberg, Østfold	8	36	55	0.4	61

na: not applicable.

subsoil was over 40%. The fine material (<2 mm) was comprised of 65% sand, 25% silt and 10% clay. The topsoil had a relatively high humus content (6%), which is typical for the region. This soil is considered to be extremely drought prone, with a plant-available moisture capacity in the upper 25 cm of only 25–30 mm. Root growth in the subsoil is restricted owing to a lack of moisture.

The main objective was to investigate whether the use of algal fibre in moderate amounts has any beneficial or harmful effects on potato yield and quality, compared with conventional fertilizer practice. The trial had a two-factor split-plot design, with algal fibre on main plots and conventional fertilizer on split plots. There were four randomized replications. Each factor had three levels:

- *level of algal fibre*: 0, 20 and 40 Mg ha^{-1} of DM. The two amounts of algal fibre contained approximately 240/480 kg nitrogen (N), 12/24 kg phosphorus (P) and 185/375 kg potassium (K) ha^{-1}, respectively, most of which was in organic form. The levels were chosen on the basis of limits set by Norway's regulations on the use of organic waste products in agriculture. The main plot size was 54 m^2 (8 × 6.75 m), separated by 1 m borders;
- *level of mineral fertilizer*: 0, 550 and 1100 kg ha^{-1} of 11:5:17 NPK compound fertilizer (Norsk Hydro). The two fertilizer levels thus supplied 60/120 kg N, 27.5/55 kg P and 93.5/187 kg K ha^{-1}, respectively. The highest level represented the normal fertilizer level for main-crop potatoes in Norway. The split-plot size was 18 m^2 (8 × 2.25 m).

Typical chemical analyses of the algal fibre, together with some actual values for the material used in the trial, are shown in Table 2. The N and P contents were within the normal range, but the K content was higher. There was little inorganic N, but the normal carbon/nitrogen (C/N) ratio of the material (12–15) suggests that relatively rapid mineralization may be expected. In addition to N, P and K, the algal fibre contains substantial amounts of bases as well as sulfur (S) and smaller quantities of many trace elements. The heavy metal content of the algal fibre is normally low. The material used in the trial had a slightly higher than normal ash content, and had not been dried as much as usual.

Herb crops were grown on the site in the previous year. These had received only a low level of fertilizer, and most plant residues were removed. Therefore, no residual effect was likely. The soil was harrowed lightly on 30 April. After a prolonged period of rain, the algal fibre was spread evenly on 19 May and mixed to a depth of 5 cm using a rotating harrow. Nine potato drills were formed with 75 cm spacing on each main plot (three per split plot), and one guard drill was included between each main plot. Potatoes, cv. Laila, were set at 30 cm spacing, and the mineral fertilizer was spread by hand along the drills. The drills were then ridged in such a way that the fertilizer was incorporated around the seed potatoes. Emergence occurred around 15 June and initial plant development was slow. Weeds were controlled by pre-emergence spraying with Metribuzin and later by hand-hoeing. Insects were sprayed with Alfacypermetrin. Some damage was nevertheless caused by leafhoppers (cicada). Potato blight was controlled by spraying twice with Mankozeb + metalaxyl.

Monthly values of air temperature, rainfall and open-water evaporation at Kise in 1997 are given in Table 3, together with the long-term normal values (1961–1990). The early period was somewhat cooler and much wetter than usual. No irrigation was required before 23 June. Thereafter, the whole trial was sprinkler irrigated once or twice a week until mid-

Table 2. Chemical analyses of algal fibre/perlite mixture

Plant nutrients	Range (%)	Actual (%)	Heavy metals	Range (mg kg^{-1})	Actual (mg kg^{-1})
Nitrogen (total)	0.5–1.5	1.19	Cadmium	<1	nd
Nitrate-N	<0.004	<0.001	Lead	<5	nd
Ammonium-N	<0.001	0.016	Mercury	<0.25	nd
Phosphorus	0.04–0.08	0.06	Nickel	0–80	nd
Potassium	0.2–0.3	0.94	Zinc	4–15	nd
Calcium	0.3–0.7	0.60	Copper	1–6	nd
Magnesium	0.08–0.17	0.16	Chromium	3–110	nd
Sodium	1.0–1.8	1.20	General properties	Range (%)	Actual (%)
Sulfur	0.3–0.6	nd	Ash content	55–65	68
Boron	<0.02	nd	Dry matter content	>80	44

All data are given on a dry weight basis. Typical values (obtained from FMC Biopolymer) are shown as ranges. Actual values refer to material used in the trial at Kise.
nd: no data.

Table 3. Weather conditions at Kise in the growing season 1997, compared with the 30 year normal

	May		June		July		August	
	1997	Normal	1997	Normal	1997	Normal	1997	Normal
Mean air temperature (°C)	8.0	8.5	14.7	13.6	18.6	15.2	19.1	14.0
Rainfall sum (mm)	106	44	61	59	50	66	37	76
Evaporation sum (mm)	58	64	79	85	97	82	72	66

August, with about 15 mm each time. Most of the May rainfall fell before the potatoes were planted, but some nutrient leaching may have occurred in late June when heavy rain followed the first irrigation. The remainder of the growing season was considerably warmer than usual, slightly drier than normal in July and much drier in August. The warm weather caused the crop to mature early despite slow early development. Haulm senescence started on plots with least fertilizer around 20 August, and was almost complete on all plots when the potatoes were lifted on 8 September.

Samples of potato haulm were taken from all plots at the end of August to measure nutrient status. After the potatoes had been size-graded, tuber samples of size 35–45 mm were used for assessing the incidence of the skin disorder common scab (*Streptomyces scabies*), measurement of DM content and analysis of nutrient content.

Soil samples were taken in the topsoil of zero-fertilizer plots at planting to measure the amount of mineralized N present in the soil in spring (average 27 kg ha^{-1}). All plots were sampled after harvest to a depth of 0–25 cm to analyse mineral N and available nutrients. Soil mineral N was also measured in the following spring. A crop of Westerwold ryegrass was grown in 1998 to assess possible residual effects.

Soil mineral N (nitrate + ammonium) was analysed after extraction of frozen material in 1 *M* KCl, using a Tecator Aquatec autoanalyser. Plant nutrient contents were analysed after sulfuric/hypochloric acid digestion, using a Skalar autoanalyser for N and P, flame photometry for K and sodium (Na) and atomic absorption spectrophotometry for calcium (Ca) and magnesium (Mg).

Chemical soil analyses were performed after extraction with a mixture of lactic acid and ammonium acetate (Égner et al., 1960) in the case of plant-available (-AL) P, K, Mg, Ca and Na, and after extraction with 1 *N* HCl in the case of acid-soluble potassium. Soil reaction (pH) was measured in water.

Split-plot factorial analyses of variance were performed using the MSTAT package for statistical analysis (Nissen & Mosleth, 1985), using standard practice for *F*-testing.

Results

Laboratory study of soil physical properties

A summary of the analyses of variance for all variables is given in Table 4, and mean treatment values for individual soils are shown in Table 5 for the most important properties.

The use of both the algal fibre by-product and pure perlite had highly significant effects on most of the soil physical properties measured. The direction of the effects was in nearly all cases similar on different soils, despite the large differences between soils in the initial levels of the measured properties. The follow-

Table 4. Levels of significance for factors tested in the study of soil physical properties

Soil physical parameter	Soil type	Material type	Quantity used	Mat. × Quant.
Saturation porosity	*	**	***	***
Vol.% water at −10 kPa	**	**	***	***
Vol.% water at −100 kPa	**	***	ns	***
Vol.% water at −1500 kPa	ns	ns	*	ns
Dry bulk density	**	ns	***	ns
Air capacity	*	ns	***	ns
Air permeability	†	**	***	*
Readily available water	**	ns	***	*
Strongly held available water	†	†	ns	***
Total plant-available water	†	ns	***	***

*** $P<0.001$, ** $P<0.01$, * $P<0.05$, † $P<0.1$; ns: not significant.

Table 5. Effect on soil physical properties of adding increasing amounts of algal fibre or perlite to five typical Norwegian soil types, compared with an untreated control

		Algal fibre (vol.%)					Perlite (vol.%)				
	Control	5	20	35	50	75	5	20	35	50	75
Porosity (%)											
Sandy soil	41.1	43.5	50.9	57.5	65.7	78.6	41.8	46.1	52.1	53.9	67.3
Silty soil	44.9	46.9	52.4	58.4	66.9	81.8	44.1	47.3	50.0	51.4	66.8
Loam soil	40.2	42.6	49.0	58.3	66.6	79.5	42.0	45.8	55.7	54.6	64.8
Silty medium clay	55.2	51.0	58.8	65.1	69.4	79.2	53.7	56.2	61.8	63.9	70.5
Heavy clay	49.6	52.8	58.6	65.9	72.5	80.9	59.2	59.8	58.1	63.5	70.0
Mean	46.2	47.3	53.9	61.0	68.2	80.0	48.1	51.0	55.5	57.4	67.9
Air capacity (%)											
Sandy soil	22.4	24.4	26.6	26.3	28.1	33.3	21.3	27.4	29.3	29.1	38.9
Silty soil	9.2	10.2	14.2	16.9	20.1	25.3	9.4	11.3	12.6	13.7	28.1
Loam soil	10.9	13.4	14.8	19.2	22.4	26.5	13.1	16.7	25.0	23.3	31.1
Silty medium clay	17.4	12.2	17.6	21.8	21.9	25.5	15.8	17.6	24.6	21.7	25.5
Heavy clay	12.7	14.2	18.1	20.5	23.7	29.2	25.1	25.7	20.6	27.3	32.9
Mean	14.5	14.9	18.2	20.9	23.2	27.9	16.9	19.7	22.4	23.0	31.3
Air permeability (μm^2)											
Sandy soil	20.9	28.5	32.5	52.8	58.3	>65	26.4	24.8	34.7	36.3	47.9
Silty soil	0.2	0.0	11.9	49.5	>65	>65	0.0	0.0	0.1	9.8	23.3
Loam soil	1.1	1.7	4.0	16.5	>65	>65	5.3	4.0	9.4	14.6	42.9
Silty medium clay	0.4	44.0	20.9	36.9	49.5	>65	9.9	19.3	3.5	55.0	38.0
Heavy clay	29.2	39.6	13.4	55.0	>65	>65	5.4	18.1	36.8	42.4	31.9
Mean	10.4	22.7	16.5	42.1	61.2	>65	9.4	13.2	16.9	31.6	36.8
Plant-available water (%)											
Sandy soil	15.2	15.8	20.3	27.3	33.4	40.6	17.2	15.9	20.4	22.7	26.8
Silty soil	30.4	31.8	33.4	36.8	42.0	50.5	29.7	31.5	34.1	35.1	36.7
Loam soil	19.1	18.4	24.4	30.7	37.6	47.7	19.1	20.7	23.6	25.6	31.1
Silty medium clay	17.2	18.4	23.7	28.9	46.6	52.9	36.4	37.2	36.1	41.3	44.6
Heavy clay	34.0	36.0	38.3	43.5	47.3	50.7	31.5	31.6	35.2	34.6	36.5
Mean	23.2	24.1	28.0	33.4	41.3	48.4	26.8	27.4	29.8	31.9	35.1
Dry bulk density ($kg\ l^{-1}$)											
Sandy soil	1.54	1.44	1.27	1.07	0.90	0.56	1.45	1.32	1.06	0.94	0.57
Silty soil	1.42	1.36	1.21	1.05	0.88	0.57	1.36	1.21	1.04	0.84	0.53
Loam soil	1.58	1.50	1.34	1.14	0.93	0.59	1.49	1.29	1.12	0.92	0.54
Silty medium clay	1.28	1.23	1.11	0.95	0.81	0.53	1.24	1.10	0.93	0.80	0.51
Heavy clay	1.29	1.26	1.06	0.94	0.78	0.52	1.18	1.04	0.98	0.78	0.48
Mean	1.42	1.36	1.20	1.03	0.86	0.55	1.35	1.19	1.03	0.85	0.53

ing presentation refers therefore mainly to mean values for all soils.

Mean effects of the algal fibre by-product and of pure perlite on soil moisture contents at different tensions, and on air- and plant-available water capacities, are shown in Figs. 1 and 2, respectively. Both materials gave linear increases in the soil's total porosity and moisture retention at −10 kPa (field capacity). The increases were greater with the algal fibre by-product than with pure perlite. The use of algal fibre also increased moisture retention at −100 kPa tension, whereas addition of pure perlite lowered the amount of water held at that level. Both materials caused slight declines in the amount of water held at −1500 kPa (wilting point).

Both air capacity and the capacity for readily plant-available water increased linearly in an almost identical fashion with increasing additions of algal fibre and perlite. However, the use of perlite had a negative effect on the capacity for more strongly bound water (that held at −100 to −1500 kPa). Therefore, the total amount of plant-available water increased much more with the use of the algal fibre by-product than it did with pure perlite. The mean increases in soil porosity, air capacity and total plant-available water capacity per unit volume of algal fibre

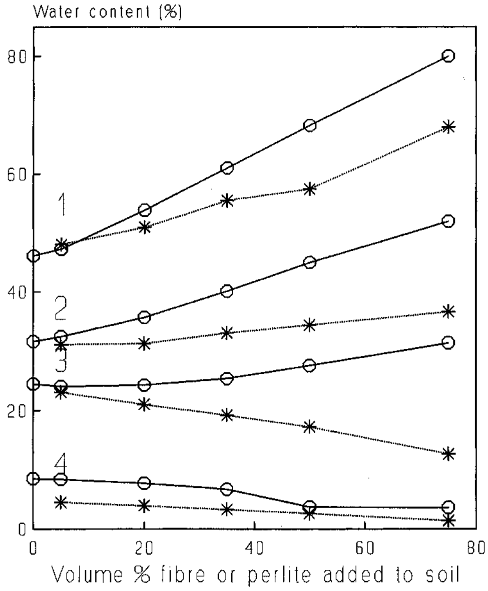

Fig. 1. Mean effects of algal fibre (○) and perlite (∗) on soil water-holding capacity (vol.%) at various matrix tensions (1: 0 kPa; 2: − 10 kPa; 3: − 100 kPa; 4: − 1500 kPa).

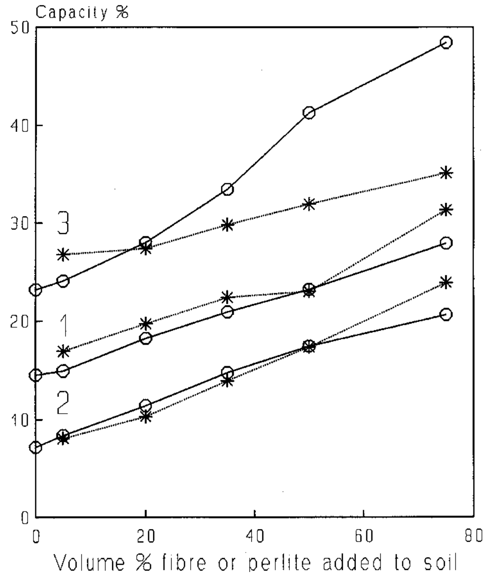

Fig. 2. Mean effects of algal fibre (○) and perlite (∗) on soil capacities (vol.%) for air and water (1: air; 2: readily plant-available water; 3: total plant-available water). DM: dry matter.

(AF) or pure perlite (PP) in the soil followed in all cases a closely linear pattern, and the following regression equations accounted for 97–100% of the variation in the mean data:

Increase in total porosity $= -1.5 + 0.47 \times$ vol.% AF and $-0.4 + 0.28 \times$ vol.% PP

Increase in air capacity $= -0.2 + 0.18 \times$ vol.% AF and $0.0 + 0.19 \times$ vol.% PP

Increase in available water $= -1.6 + 0.36 \times$ vol.% AF and $2.6 + 0.12 \times$ vol.% PP

The equations show that the increase in air capacity was similar for both materials, whereas the increase in total porosity was almost twice as large with the use of algal fibre as that with pure perlite, and the increase in available water was three times as great with algal fibre.

The effects of algal fibre and perlite on soil air permeability were somewhat variable, which is not unusual for this property, as transport processes in soil are themselves highly variable. However, for both materials there was a general trend towards increased permeability with increasing amounts used. The increases were higher with algal fibre than with pure perlite, probably because the former material caused more shrinkage and cracking of the soil than did perlite.

Potato yield and quality in field trial

Total tuber yield was significantly increased by the use of both algal fibre ($P < 0.02$) and mineral fertilizer ($P < 0.001$). In both cases the increases were linear up to the highest level of fibre/fertilizer used. The interaction term between these two factors was not statistically significant, which implies that positive effects of either factor can be expected irrespective of the level of the other factor. There was nevertheless a clear trend towards higher responses to algal fibre at lower levels of mineral fertilizer, and vice versa (Fig. 3). The increase in total yield with the use of 40 Mg ha^{-1} of fibre was thus 70% when no

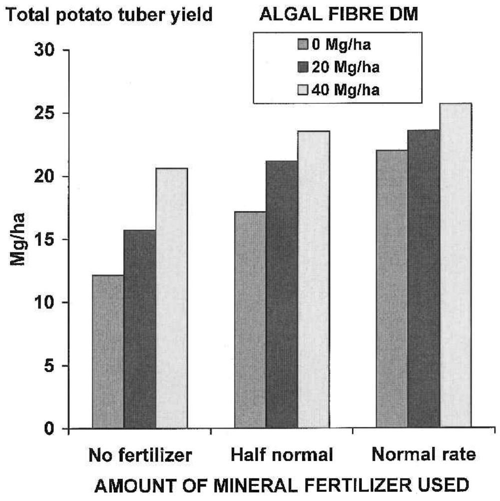

Fig. 3. Effect of algal fibre on potato yield at different levels of mineral fertilizer input. DM: dry matter.

fertilizer was used, 37% at half the normal fertilizer rate and only 17% when the normal fertilizer rate was used. This suggests that the effect of the algal fibre was mainly connected with nutrient supply. There may, however, also have been a slight positive effect of soil structure improvement.

The effects of algal fibre and fertilizer on individual tuber size fractions were similar to those for total yield (data not shown). Saleable yield was more than doubled by algal fibre at the zero-fertilizer level. There was a significant interaction ($P < 0.01$) between algal fibre and fertilizer level on tuber DM concentration (Table 6). When a low level of either fibre or fertilizer was used, an increase in the other factor increased tuber DM, probably owing to more rapid growth and plant maturation. When both fibre and fertilizer were applied at high levels, however, the tuber DM concentration declined. This commonly happens when the nutrient supply is high, as a result of prolonged growth and delayed maturation. The effect of algal fibre on total DM yield was thus even more than that on tuber yield at low fertilizer levels, but was somewhat less when the normal fertilizer level was used.

It was feared that the use of algal fibre might affect the incidence of common scab on potato tubers, owing to its high base content, since this form of scab is more usual at high soil pH, but no such effect was found. There was, however, a significant reduction ($P < 0.001$) in the level of scab occurrence with increasing levels of fertilizer use. This may have been due to the acidifying effect of ammonium in the compound fertilizer.

Plant nutrient concentrations in field trial

The use of algal fibre increased the nitrogen concentrations of both tubers and haulm ($P < 0.05$) at all levels of fertilizer use. Both factors acted in a similar manner (Table 6). On plots with 40 Mg ha^{-1} of algal fibre, the tuber N uptake was increased by 30, 18 or 12 kg ha^{-1} with the use of zero, half-normal or normal fertilizer rates, respectively. In the absence of algal fibre, the uptakes were increased by 15 and 32 kg ha^{-1} with half-normal and normal fertilizer rates. It may thus be concluded that the higher rate of algal fibre had approximately the same N-supplying power as the normal fertilizer rate.

There was a significant interaction ($P < 0.05$) between algal fibre and fertilizer use on the concentration of S in potato tubers. The fertilizer compound used contained 9% S, which increased the S concentration of tubers when no algal fibre was applied. The use of algal fibre masked this response, giving uniformly high values irrespective of fertilizer use. It may therefore be concluded that the algal fibre supplies some S to plants.

Algal fibre had no significant effect on the concentrations of P, K or Ca in either tubers or haulm, but it led to large increases in the Na concentration of tubers ($P < 0.001$) and a small increase in Mg concentration of haulm ($P < 0.01$). The concentrations of all

Table 6. Effect of algal fibre (AF) on some quality traits of potatoes grown at different levels of fertilizer input (zero, half and normal rates, where normal rate = 121:55:187 kg ha^{-1} N:P:K)

		Fertilizer rate				
		Zero	Half	Normal	Mean	Significance
Tuber DM (%)	0 Mg DM ha^{-1} AF	18.9	20.0	20.4	19.7	Interaction $P<0.01$
	20 Mg DM ha^{-1} AF	19.3	19.0	19.6	19.3	
	40 Mg DM ha^{-1} AF	20.1	19.4	18.9	19.5	
	Mean	19.5	19.4	19.6		
Tuber N (g kg^{-1} DM)	0 Mg DM ha^{-1} AF	10.0	11.0	12.4	11.2	AF $P<0.05$
	20 Mg DM ha^{-1} AF	10.2	11.6	12.0	11.3	Fert. $P<0.01$
	40 Mg DM ha^{-1} AF	12.9	12.5	14.0	13.1	
	Mean	11.0	11.7	12.8		
Haulm N (g kg^{-1} DM)	0 Mg DM ha^{-1} AF	33.0	29.1	32.9	31.6	AF $P<0.05$
	20 Mg DM ha^{-1} AF	32.8	30.8	31.1	31.5	Fert. ns
	40 Mg DM ha^{-1} AF	34.5	35.7	35.9	35.4	
	Mean	33.4	31.9	33.3		
Tuber S (g kg^{-1} DM)	0 Mg DM ha^{-1} AF	1.5	1.6	1.9	1.7	Interaction $P<0.05$
	20 Mg DM ha^{-1} AF	1.8	1.9	1.9	1.8	
	40 Mg DM ha^{-1} AF	1.7	1.8	1.8	1.8	
	Mean	1.7	1.8	1.8		

N: nitrogen; P: phosphorus; K: potassium; DM: dry matter; S: sulfur; ns: not significant.

of these nutrients were considered to be sufficient for good plant growth, even in the absence of algal fibre. It was therefore concluded that the major determinant of plant response to the latter was its effect on N supply.

Soil nutrient status and residual effects in field trial

Algal fibre had no significant effect on the reserves of plant-available P, K or Ca in the topsoil at harvest, but fertilizer application increased the reserves of both P and K (data not shown). Algal fibre gave a small increase in plant-available Mg and a large increase in available Na, as expected (Table 7).

Soil reaction was low on the control plots without fertilizer or fibre (pH 5.0). The use of algal fibre led to marked increases ($P < 0.001$) of up to 0.6 pH units. Fertilizer use had a slightly acidifying effect, owing to the ammonium content in the compound fertilizer. The electrical conductivity of the soil was more than doubled by the use of algal fibre, owing to its high Na content, but it was nevertheless well below the level at which adverse effects on plant growth occur (2–3 mS cm^{-1}). Fertilizer use also increased electrical conductivity slightly.

Residual levels of soil mineral N (both nitrate and ammonium) were markedly increased after harvest with the use of both fertilizer and algal fibre. The highest level of algal fibre used gave about 35 kg ha^{-1} more mineral N at harvest when no fertilizer had been used, while the highest rate of fertilizer gave an increase of 48 kg ha^{-1} when no algal fibre was used. When both fibre and fertilizer were applied at the highest rate, the residual N increased by 66 kg ha^{-1}, relative to the control plots. Most of this N was, however, lost to leaching before it could be utilized by the next year's crop (Fig. 4). The ryegrass crop grown in 1998 showed a DM yield increase of 14% on the plots that had received most algal fibre in 1997, but this was not statistically significant. There was, however, a significant reduction in DM concentration in the grass ($P < 0.002$), which suggests that nutrient release from the fibre was still occurring during the second growing season.

Table 7. Effect of algal fibre (AF) on some chemical topsoil properties (0–20 cm) after potatoes grown at different levels of fertilizer input (zero, half and normal rates, where normal rate = 121:55:187 kg ha^{-1} N:P:K)

		Fertilizer rate				
		Zero	Half	Normal	Mean	Significance
Mg-AL (mg kg^{-1})	0 Mg DM ha^{-1} AF	61	62	63	62	Alg. $P<0.01$
	20 Mg DM ha^{-1} AF	68	74	71	71	Fert. $P<0.05$
	40 Mg DM ha^{-1} AF	73	73	82	76	Interaction
	Mean	6.7	7.0	72		$P<0.07$
Na-AL (mg kg^{-1})	0 Mg DM ha^{-1} AF	2.2	2.5	3.3	2.6	Alg. $P<0.001$
	20 Mg DM ha^{-1} AF	27.4	23.7	19.6	23.6	Fert. ns
	40 Mg DM ha^{-1} AF	40.5	36.1	44.1	40.3	
	Mean	23.3	20.8	22.3		
pH in water	0 Mg DM ha^{-1} AF	5.0	5.0	4.9	5.0	Alg. $P<0.001$
	20 Mg DM ha^{-1} AF	5.4	5.4	5.3	5.4	Fert. $P<0.05$
	40 Mg DM ha^{-1} AF	5.7	5.5	5.5	5.6	
	Mean	5.4	5.3	5.2		
Electrical conductivity (mS cm^{-1})	0 Mg DM ha^{-1} AF	0.043	0.055	0.079	0.059	Alg. $P<0.001$
	20 Mg DM ha^{-1} AF	0.068	0.081	0.087	0.079	Fert. $P<0.02$
	40 Mg DM ha^{-1} AF	0.133	0.111	0.147	0.130	
	Mean	0.081	0.082	0.104		
NO_3-N (mg kg^{-1})	0 Mg DM ha^{-1} AF	3.3	4.6	8.7	5.5	Alg. $P<0.01$
	20 Mg DM ha^{-1} AF	5.7	8.3	10.0	8.0	Fert. $P<0.01$
	40 Mg DM ha^{-1} AF	11.2	11.8	17.2	13.4	
	Mean	6.7	8.2	12.0		
NH_4-N (mg kg^{-1})	0 Mg DM ha^{-1} AF	12.1	12.1	22.3	15.5	Alg. ns
	20 Mg DM ha^{-1} AF	13.3	14.6	22.1	16.7	Fert. $P<0.001$
	40 Mg DM ha^{-1} AF	15.5	18.6	19.2	17.8	Interaction
	Mean	13.6	15.1	21.2		$P<0.11$

Plant-available nutrients are denoted by -AL (ammonium acetate/lactic acid extraction).
N: nitrogen; P: phosphorus; K: potassium; Mg: magnesium; Na: sodium; NO_3: nitrate; NH_4: ammonia; DM: dry matter; ns: not significant.

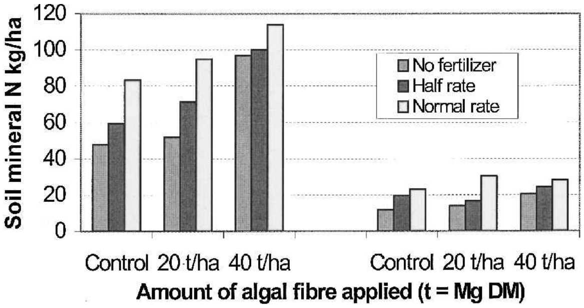

Fig. 4. Effect of algal fibre and fertilizer use on the amounts of mineral nitrogen (N) in topsoil (0–25 cm) after harvest in 1997 (left) and in April of the following year (right).

Discussion

Studies on soil physical properties

The by-product that remains after alginate extraction from seaweed and perlite beads, which are used to filter fibre material from effluent water, are both potential soil ameliorators which may be expected to improve soil porosity and thereby moisture storage and aeration.

This study showed that both materials improved soil porosity and most of the other properties measured in five widely contrasting soil types. The algal fibre by-product was superior to pure perlite with respect to its effect on both total porosity and available moisture-holding capacity, while both materials had approximately the same effect on air capacity. Soil air permeability was also greatly increased by the use of these materials, particularly by the algal fibre by-product, probably owing to cracking which occurred as a result of shrinkage. The same response patterns were observed on all soils, regardless of their initial status.

The effects of these materials, especially those of the algal fibre by-product, may be expected to be beneficial to plant growth, through improved moisture availability and/or better aeration, providing that they do not have any undesirable effect on plant nutrition. Their practical importance is, however, governed by the amount of material that it is permitted to apply, and by the economics of making such applications. Present legislation in Norway limits the application to 40 Mg ha^{-1} of DM. This is equivalent to approximately 150 m^3 ha^{-1}.

The approximate average effects on key soil physical properties, which may be expected from incorporating 150 m^3 ha^{-1} of algal fibre to different soil depths, are shown in Table 8.

Table 8. Approximate average effects of algal fibre on soil physical properties

	Soil depth (cm)			
Property	5	10	15	30
Total porosity (%)	+14.1	+7.0	+3.5	+2.4
Air capacity (%)	+5.4	+2.7	+1.3	+0.9
Available water (%)	+10.8	+5.4	+2.7	+1.8

The greatest benefits are obtained when the material is incorporated within a shallow surface layer. This is likely to improve conditions for germination of most crops grown from seed. Such use would also improve the stability of the surface layer and reduce erosion risk. Soil types that may benefit from such treatment include in particular silts and silty clays with low organic matter reserves. Some drought-prone sandy soils may also benefit, but it is unlikely that the increase in moisture-holding capacity on these soils would be large enough to sustain good growth over long periods without irrigation.

Field trial with algal fibre/perlite mixture

Algal fibre contains substantial amounts of plant nutrients, including N, K, S and some P, as well as Na, Mg and Ca. This study investigated its effects on the yield and quality of potatoes and on the nutrient status of the soil at the end of the growing season, in comparison to the effects of mineral fertilizer.

The algal fibre had a large, positive effect on the yield of potatoes. In the absence of mineral fertilizer, this amounted to increases in total tuber yield of 30% and 70% with the use of 20 and 40 t of DM ha^{-1}, respectively. The responses were smaller when mineral fertilizer was used, declining to 7% and 17% at the highest fertilizer level. This suggests that the effect of algal fibre was mainly due to improved nutrient supply. Assuming that the effect of algal fibre was attributable mainly to its supply of N, its fertilizer value per Mg of DM may be interpolated as being equivalent to the use of 2–2.5 kg N in compound fertilizer. This suggests that about 20% of the N contained in the algal fibre had become available during the first growing season. Lopez-Mosquera & Pazos (1997), in a study with seaweed at rates of 80 t fresh weight ha^{-1}, also reported large yield increases in potatoes, but they attributed these primarily to effects on soil pH and the availability of other nutrients.

Algal fibre had a positive effect on tuber DM concentration when used alone, but had a negative effect when used in conjunction with a high level of mineral fertilizer. The latter effect may be attributed to a delay in maturation due to over-optimum nutrient supply.

Despite its high base content, the algal fibre had no adverse effect on the level of common scab in tubers, a disorder normally associated with high soil pH on light soils. Mineral fertilization, in contrast, gave a reduction in its occurrence.

The use of algal fibre considerably increased N concentrations in both haulm and tubers. Effects on other mineral concentrations were slight, with the exception of Na. The latter increased markedly, but this was not thought likely to reduce tuber eating quality. Soil reserves of plant-available P, K and Ca at harvest were not affected by the use of algal fibre, which is in contrast to the findings of Lopez-Mosquera & Pazos (1997). The soil Mg level increased slightly and that of Na rose sharply. This led to higher electrical conductivity in the soil. The values measured were nevertheless well below the limit at which plant growth is likely to be impaired. Soil pH increased significantly, by about 0.015 units per Mg DM ha^{-1} used.

Residual levels of soil mineral N in autumn were raised by the use of both algal fibre and mineral fertilizer. Most of the increase was, however, lost by leaching during the following winter, and the residual effect of algal fibre on the next year's ryegrass crop was small. This suggests that catch crops should be grown after the first year's crop when algal fibre is applied at rates similar to those used in the present case.

References

Blunden, G. 1991. Agricultural uses of seaweeds and seaweed products. In: Guiry, M. D. & Blunden, G. (eds.) European Seaweed Resources: Uses and Potential. John Wiley and Sons, Chichester, pp. 65–81.

Booth, E. 1966. Some properties of seaweed manures. In: Proceedings of the 5th International Seaweed Symposium. Pergamon Press, Oxford, pp. 349–357.

Chapman, V. J. & Chapman, D. J. 1980. Seaweeds and Their Uses. Chapman & Hall, London, pp. 30–42.

Égner, H., Riehm, H. & Domingo, W. R. 1960. Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Boden. II. Chemische Extraktionsmetoden zur Phosphor und Kaliumbestimmung. Kung. Lantbr. Högsk. Ann. 26, 199–215.

Kolden, F. M. 1995. Growth trials using residues from alginate production. Research Report, Institute of Soil and Water Sciences, Agric. Univ. Norway, Ås, 13 pp + Appendix. (In Norwegian.)

Lopez-Mosquera, M. E. & Pazos, P. 1997. Effects of seaweed on potato yields and soil chemistry. Biol. Hort. Agric. 14, 199–205.

Nissen, Ø. & Mosleth, E. 1985. User Manual for the MSTAT Statistics Program for Microcomputers. Landbruksbokhandelen, Ås. ISBN 82-557-0225-3.

Njøs, A. 1967. Aggregate stability using artificial rainfall. West European Methods for Soil Structure Determination VI, 53. University of Ghent, Belgium.

Copyright of Acta Agriculturae Scandinavica: Section B, Soil & Plant Science is the property of Taylor & Francis Ltd and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.