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Physical and biological effects of kelp (seaweed) added to soil

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Abstract

The effects of chopped pieces of the fronds of the brown seaweed, *Laminaria digitata* (a kelp), on the pore volume and pore size distribution, aggregate stability, soil microbial biomass and biological activity (respiration and N mineralization) of a sandy soil have been investigated. Ninety days after addition of either 8.2 or 16.4 g kelp kg^{-1} soil, the total pore volume of the soil had increased significantly. Most of the additional volume was present in pores ranging from 75 to 150 μm in diameter in the whole soil, and in pores of less than 60 μm diameter in aggregates of 4–7 mm diameter. The aggregate stability of both the whole soil and the 4–7 mm aggregates was also increased significantly by kelp addition compared with the unamended control. The soil microbial biomass content and the soil respiration rate were both significantly greater, relative to the control, following addition of either 8.2 or 16.4 g kelp kg^{-1} soil. However, the soil respiration rate was lower in the soil amended with 16.4 g kelp kg^{-1} soil compared with that amended with only 8.2 g kelp kg^{-1} soil. The rate of potential N mineralization were also increased by amendment with the kelp at 8.2 g kg^{-1} compared with the rates in the unamended soil.

Keywords: Aggregation; Algae; Microbial biomass; N mineralization; Pores; Respiration; Seaweed; Soil structure

1. Introduction

The use of seaweeds as soil conditioners has a long history in coastal regions with sandy soils of low organic matter content where access to the seaweed is easy (Darling, 1945; Chapman, 1970). The improved productivity and nutrient availability in soils to which seaweed has been added are associated with biological mineralization of the seaweed and the interaction between soil particles and organic compounds derived either directly or indirectly from the seaweed (Stephenson, 1968).

Both bacteria and fungi promote soil aggregation (Lynch, 1981; Molope et al., 1987; Forster, 1979). Microorganisms contribute to aggregation of soil particles by the binding action of filamentous organisms, and the production of adhesive extracellular polysaccharides (Martin, 1971; Lynch, 1981). Seaweeds are rich sources of polysaccharides which may affect soil aggregation directly or indirectly after decomposition by soil microorganisms.

Much of the information about agriculturally beneficial effects of seaweed added to soil is qualitative and/or anecdotal. Here we quantify some of the effects of seaweed addition to a sandy soil on the soil aggregate stability, pore size distribution and the soil microbial biomass and activity.

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2. Materials and methods

2.1. Soil and seaweed amendment

An arable soil collected from Muirdrum near Arbroath, Angus near the East coast of Scotland (National Grid Reference NO 565367) was used. The soil was weakly structured and had a sandy loam texture, 1.13% organic matter content and pH 6.8. The soil was sieved (7 mm) in the field-moist state (0.3 g H_2O g^{-1} (dry weight) soil) and stored for 14 days at 15°C prior to kelp addition.

Fronds of kelp (*Laminaria digitata*, a brown seaweed) were collected from the intertidal zone of the beach at East Haven, Angus, Scotland (National Grid Reference NO 592358). The kelp was chopped into pieces approximately 10 mm × 5 mm pieces and washed with distilled water to remove surface deposits of salt. The kelp was added to the soil at the rate of either 8.2 or 16.4 g (wet weight) kelp kg^{-1} (dry weight) soil, and there was an unamended control soil. A total of 16 kg (dry weight) soil was amended with kelp at each rate. The soil and kelp were mixed by hand in plastic containers (43 cm × 33 cm × 23 cm (deep)) and then left at a bulk density of between 1.2 and 1.3 g cm^{-3}, uncovered for 90 days at a temperature of 15°C and adjusted to the equivalent of approximately 50% of the water-holding capacity for the unamended soil every 7 days. The amounts of kelp corresponded to those required to cover a 15 cm depth of soil with either 0.5 or 1.0 cm of kelp. The kelp-amended and the control soils were then divided into two parts, one comprising of whole soil, the other comprising of 4–7 mm diameter range aggregates obtained by gently sieving the moist soil. Sieving removed large pieces of kelp and non-aggregated soil particles.

2.2. Pore size distribution and water holding capacity

The moisture release curves of the whole soil and the 4–7 mm aggregates were determined using duplicate, 50 g (dry weight) samples of moist soil and porous plate tensiometers, as shown by White (1979). The maximum pore diameter drained at a particular matric potential was calculated from the equation: Matric potential (− kPa) = 300/pore diameter (μm) (Marshall and Holmes, 1979).

2.3. Aggregate stability

The aggregate stability was assessed using two methods. In the first method, the reduction in soil volume as a result of aggregate breakdown on saturation with water was measured; the percentage reduction in volume was inversely proportional to aggregate stability. Five 20 g (dry weight) samples of moist soil were added to 50 cm^3 measuring cylinders (25 mm internal diameter) and distilled water was added until it reached the top of the soil. The decreases in soil volume after 1 h at 20°C were recorded. The second method was an adaptation of that of Lynch (1981), in which soil dispersion was measured from the turbidity of a soil suspension; turbidity was inversely proportional to aggregate stability. Five 3.5 g (dry weight) samples of moist soil were mixed with 20 cm^3 of distilled water in 50 cm^3 boiling tubes. The suspensions were inverted 20 times in 1 minute and then allowed to settle for 2 min. The turbidity of a ten-fold dilution of the final soil suspension was determined by measuring its absorbance at 540 nm. The turbidity measurements were expressed as the absorbance of the soil suspensions divided by that of the suspensions of soil which had been completely dispersed by 1 min of high energy ultrasonication from an ultrasonic probe (MSE Soniprep 150).

2.4. Soil microbial biomass and respiration

The soil microbial biomass was determined using the glucose induced respiration method of Anderson and Domsch (1978) with modifications to the incubation conditions and CO_2 determination described by Hopkins and Ferguson (1994), such that CO_2 accumulation at 22°C at 0 and 6 h after glucose addition were determined by gas chromatography (Varian 90-P with TCD detector). Glucose was added to triplicate 20 g (dry weight) samples of moist soil at the rates of 0, 0.5, 1.0, 2.0, 4.0 or 8.0 mg glucose g^{-1} (dry weight) soil. Prior to its addition to soil, the glucose was mixed intimately with 0.5 g of an inert carrier, talc. CO_2 evolution from glucose amended soils followed Michaelis–Menten kinetics for both

treatments and the control and zero-order kinetics were achieved at the higher rates of glucose addition. The maximum rate of CO_2 evolution was determined from Woolf plots (added glucose concentration divided by rate of CO_2 evolution plotted against added glucose concentration to give a straight line the slope of which is equivalent to the reciprocal of the maximum rate of CO_2 evolution) as described by Hopkins and Shiel (1996). Basal soil respiration was determined as the rate of CO_2 evolution from soils to which no glucose had been added.

2.5. Net and potential nitrogen mineralization

Duplicate 100 g (dry weight) samples of moist soil from each treatment were amended with L-glutamine mixed with 0.5 g talc (as above) to give a soil solution concentration of 100 mmol dm^{-3}, or were unamended. The soils were incubated in covered, but not sealed, glass jars at 22°C. After 0 and 48 h, inorganic N was extracted from 10 g (dry weight) of soil by addition of 30 cm^3 of 0.5 mol dm^{-3} K_2SO_4 and shaking for 1 h and filtering (Whatman No. 4). The concentrations of NH_4^+, NO_3^- and NO_2^- in solution were determined using a continuous-flow autoanalyser (ChemLab) and the analytical methods of Best (1976) and Brown (1973). Net N mineralization rates were calculated from the inorganic N in soils to which no glutamine had been added and potential rates of N mineralization were calculated from the differences in inorganic N contents between the glutamine-amended soils and the corresponding soils to which no glutamine had been added.

3. Results and discussion

3.1. Soil physical properties

The moisture release curves (Fig. 1) indicate that the pore volume and, therefore, total water-holding capacity of both the whole soil and the 4–7 mm aggregates were increased by addition of kelp. For the whole soil, the additional pore volume occurred in pores ranging from 75 to 150 μm in diameter, whereas for the aggregates, the additional pore volume occurred in pores less than the smallest size measured (i.e. < 60 μm diameter). For the whole soil, the differences in moisture release between the control soil and the kelp-amended soils were significant ($P < 0.05$) at all the matric potentials measured, except at -5 kPa where there was no significant difference between the control soil and the kelp-amended soils. There was no significant difference in the moisture release for the whole soil between the high and low kelp treatments at any of the matric potentials measured. For the aggregates, the differences in moisture release between the control, the high kelp and the low kelp treatments all were significant ($P < 0.05$) at all the moisture potentials measured. The effects of kelp addition on pore vol-

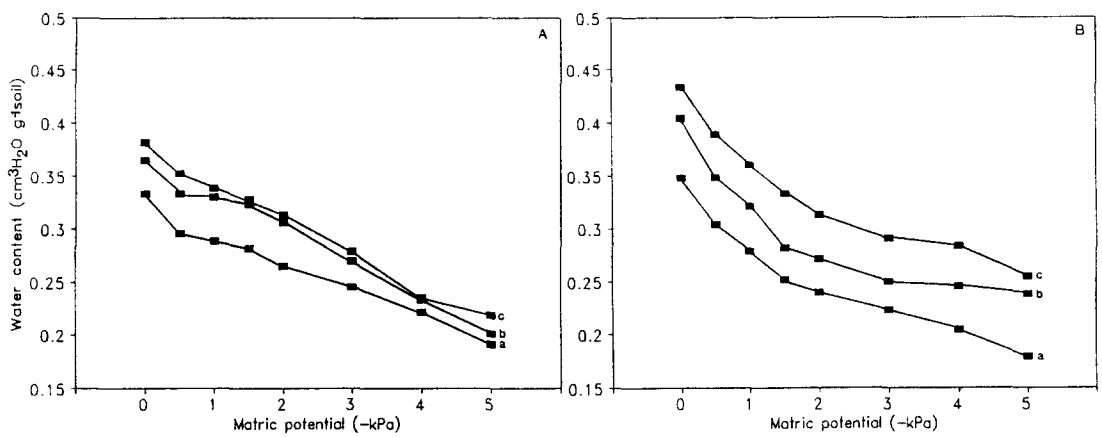

Fig. 1. Moisture release curves for the whole soil (A) and 4–7 mm aggregates (B) from (a) the control soil; (b) the soil amended with 8.2 g kelp kg^{-1} and (c) the soil amended with 16.4 g kelp kg^{-1}. Each point is the mean of duplicates.

ume in the aggregates were greater than that for the whole soils, probably because a substantial amount of non-aggregated material had been removed from the whole soil by sieving when the aggregates were separated out.

In the control soil, the volume reduction on saturation was smaller for the whole soil than for the aggregates which indicates the influence of non-aggregated particles in the control soil (Table 1). The possibility that the control soil contained particularly stable aggregates can be excluded because of the large reductions of soil volume when separated aggregates were saturated (Table 1) and also the instability of aggregates as indicated by turbidity measurements (Table 2). The stability of aggregates from the kelp-amended soil, as assessed by volume reduction on saturation, was greater than that of the aggregates from the control soil (Table 2). However, kelp-amendment apparently reduced the stability of the whole soil when assessed in the same way (Table 1). Kelp amendment led to progressively greater aggregate stability as measured turbidometrically for the whole soil (Table 2) but not when assessed by volume reduction (Table 1). The two methods of assessing aggregate stability are in broad agreement in that the turbidity measurements for the whole soil and the measurements of volume reduction on saturation for the aggregates indicate greater stability for the kelp-amended soils compared with the unamended soil. However, the fact kelp-amendment led to an apparent reduction in stability for the whole soil when assessed by volume reduction on saturation, but not when assessed turbidometrically, suggests that the two methods assessed different aspects of aggregation.

Table 2
Effect of kelp addition on the turbidity measurements at 540 nm of whole soil suspensions. Each value is the mean five replicates and the standard errors are shown in brackets

Kelp amendment ($g\ kg^{-1}$)	Turbidity at 540 nm	Turbidity ratio [a]
0	0.495 (0.0219)	0.72
8.2	0.316 (0.040)	0.46
16.4	0.278 (0.012)	0.40

[a] Turbidity ratio is the derived by dividing the turbidity of the suspensions from the treated and control soils by that of suspensions of totally dispersed soil.

3.2. Soil biological properties

Addition of kelp led to increased soil biological activity as measured by CO_2 evolution, by a factor of between 4.8 and 5.3 (Table 3). This increase in microbial activity reflects a combination of increased amount of substrate for microbial decomposition and possibly improved physico-chemical conditions, such as aeration, in the soil as an indirect effect of kelp addition. The fact that the rate CO_2 evolution was slightly less for the soil amended with the greater compared with the smaller amount of kelp indicates that microbial activity was not restricted by availability of organic substrate above 8.2 g kelp kg^{-1} soil, and that at the higher addition rate the kelp may have had inhibitory effect on microbial activity. The soil microbial biomass was greater in the kelp-amended soil than in the control soils, and, like CO_2 evolution, the increase in the amount of microbial biomass was not proportional to kelp addition (Table 3). This indicates that factors other than addition of substrate determined the amount of biomass. The net rate of N

Table 1
Effect of water saturation on the volume occupied by 20.0 g (dry weight) of whole soil and soil aggregates (4–7 mm) amended with 8.2 and 16.4 g kelp kg^{-1} soil. Each value is the mean of five replicates and the standard errors are shown in brackets

Kelp amendment ($g\ kg^{-1}$ soil)	Whole soil			Soil aggregates		
	Soil volume (cm^3)		Percent reduction	Soil volume (cm^3)		Percent reduction
	Before saturation	After saturation		Before saturation	After saturation	
0	16.0 (0.33)	15.9 (0.37)	0.6	20.4 (0.16)	18.1 (0.58)	11.3
8.2	16.2 (0.44)	15.5 (0.27)	4.3	20.6 (0.31)	20.1 (0.27)	2.4
16.4	18.0 (0.75)	17.3 (0.31)	3.9	21.7 (0.20)	20.7 (0.23)	4.6

Table 3
Effects of kelp addition on the biological properties of the whole soils. Each value is the mean of three replicates for respiration rate and biomass C and of two replicates for the net and potential N mineralization rates. The standard errors are shown in brackets

Kelp amendment ($g\ kg^{-1}$)	Respiration rate ($nmol\ CO_2\ g^{-1}\ soil\ h^{-1}$)	Biomass C ($\mu g\ C\ g^{-1}$ soil)	Net N mineralization rate ($nmol\ N\ g^{-1}\ soil\ h^{-1}$)	Potential N mineralization rate ($nmol\ N\ g^{-1}\ soil\ h^{-1}$)
0	1.42 (0.445)	157 (49.3)	1.43 (0.053)	58 (10.1)
8.2	7.53 (0.282)	272 (10.2)	1.06 (0.054)	82 (10.4)
16.4	6.84 (0.176)	335 (3.72)	ND	ND

ND, no determination.

mineralization was lower in the soil amended with 8.2 g kelp kg^{-1} than in the control which indicated either greater N immobilization or less N mineralization in the kelp-amended soil compared with the control soil (Table 3). The potential rate of N mineralization was, however, significantly increased by kelp-amendment and this increase was consistent with the greater biomass C.

3.3. Concluding remarks

Addition of kelp increased the total pore volume and the aggregate stability of the soil. This may be associated with the increases in the microbial biomass and biological activity in the soil. However, it is not possible to separate the direct effects of kelp addition on soil physical properties and the indirect effects of kelp on soil microorganisms. The effects of kelp could be the result of interaction of soil particles with algal polysaccharide exuded from the kelp. The fact that the aggregation effects were detected in aggregates smaller than the pieces of kelp originally added indicates that the increased microbial biomass and activity were probably due to the input of decomposable substrate, and that microbially produced adhesives and the binding effects of fungi could have contributed to soil aggregation and aggregate stability.

In coastal regions, many of which have sandy-textured soils with low organic matter and weak structure, seaweed residues deposited naturally on the beaches provide a potentially useful soil amendment. The work presented here has indicated the large increase in soil pore volume and aggregate stability that follow kelp addition. Clearly, other work is needed to establish the longer term effects of seaweed addition to soil, the suitability of both other seaweed species and other soil types, and whether the effects observed in the laboratory are reproduced reliably under field conditions. This work has, however, given a quantitative indication of the specific effect of seaweed on soil properties.

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