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Effect of Brown Algae (*Fucus vesiculosus* L.) on Humus and Chemical Properties of Soils of Different Type and Postgermination Growth of Cucumber Seedlings

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Abstract: The possibility of using brown algae in agriculture as an alternative source of nutrients is currentlyunder study and discussion. Our study aimed to evaluate the effect of *F. vesiculosus* on the agrochemical properties of four soil types: Retisol loamy sand soil, Retisolloam, Retisol clay, and Histosol. The *F. vesiculosus* waste was added to soil samples at a rate of 0, 0.5, 1.0, 2.0, 5.0, and 10 wt%. The brown algaewaste application significantly decreased soil acidity in the substrates of all soil types, with the larger increasesfor Retisol loamy sand and Retisol clay than for Retisol loam and Histosol. The application of *F. vesiculosus* waste products increased the C content in all soil types except Histosol. The N and P content in soil substrates were not significantly affected by algaewaste application regardless of soil type. This study showed that the effect of *F. vesiculosus* waste application varies depending on the soil type, with the strongest impact on Retisol clay and the lowest on Histosol.

Keywords: Retisolloamy sand soil; Retisol loam; Retisol clay; Histosol; soil acidity; macronutrients; brown algae; *Fucus vesiculosus* L.; cucumber

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1. Introduction

For further improvement incrop productivity, new ways of soil fertility management, especially for soils with low nutrient availability, are under study and discussion [1–4]. The soils of high latitudes are usually characterized by low natural fertility; they tend to have a thin humus layer and low content of humus and nutrients available for plants [5]. In northern regions, not only the low natural fertility of soils but also the low temperatures, inadequate soil water regime, and existence of geomagnetic, gravitational, and radiation anomalies can be recognized as stress factors limiting plant growth and yield. Agricultural production has always involved the exploitation of resources, primarily soils. In the northern regions, soil restoration is extremely slow, so agricultural production should be carried out with minimal environmental risks using new efficient methods and technologies. As one of these agricultural methods, brown algae application can be proposed.

Brown algae, which are represented by 1500 species, are the main algae of temperate and polar regions. *Fucus vesiculosus* L. is one of the brown macroalgae dominants of the rocky shores in the North Atlantic and Arctic intertidal zone. The high content of macro- and microelements, especially nitrogen (N), phosphorus (P), potassium (K), iodine, molybdenum, and boron [6], makes it possible to consider algae as promising natural fertilizers [7–11]. Chelating forms of microelements of algae species allows micronutrients to be readily available to plants. Algae fertilizer, unlike manure and compost, does not contain weed seeds and spores of fungal pathogens.

When in contact with soil water, the polysaccharides of brown algae improve the structural and mechanical properties of the surface soil layer [12]. Experimental evidence shows that algae application to soil can promote the physical and hydrophysical characteristicsof soil [7,10,13]. Saadaoui et al. [14] showed that algae application couldincrease the soil content of N, P, and K, thereby increasing soil fertility [9–11]. Algae, as biobased material, are known for their ability to increase soil microbial biomass and activity, as well as the structure of pedobiont complexes [12].

Brown algae commonly contain high concentrations ofmannitol, which is a chelating agent useful in controlling soil micronutrient availability by complexing with soil metal cations. Algae also contain salts of alginic acid, which combine with soil metal ions to form highmolecular complexes. These complexes improve soil structure and water-holding capacity and, consequently, increase root and plant growth [15–18]. Moreover, Zaborowska et al. [19] showed that algae could be useful for the remediation of soils contaminated with heavy metals.

Since the industrial processing of seaweed generates a large amount of waste, which also has nutritional value, then there is a question of their disposal, which, from our point of view, is not a rational use of nature. In this connection, in our work, we tried to consider the use of algae waste as an organic fertilizer for low-fertile soils of Karelia, their influence on the basic chemical properties of soils, and the postgermination growth of cucumber seedlings (as an assessment of bioproductivity).

Of all species of brown algae, only a small number have been studied to determine their potential applications as a soil improver [12,20,21]. The brown algae *Ascophyllum nodosum* is one of the most widely studied species, but much less information is available, however, about the impact of *F. vesiculosus* on soil fertility. Our study aimed to evaluate the effect of *F. vesiculosus* on the agrochemical properties of different soil types.

2. Materials and Methods

2.1. Study Site and Soils Description

Four types of soil of the Karelia region (northwest of Russia) (Figure 1) were used in this study: Retisol loamy sand, Retisol loam, Retisol clay, and Histosol. The soil samples of Retisol loamy sand soil were collected from a quarry, Retisol loam and Retisol clay samples were collected from the A horizon of Retisols (5–15 cm), and Histosol samples were collected from the O horizon of peat soil (10–50 cm).

Figure 1. Maps showing the location of the Karelia region.

2.2. Physicochemical Analysis of Soil

The collected air-dried soil samples were sieved with a 2 mm sieve and mixed with the waste of *F. vesiculosus* to achieve its content equal to 0, 0.5, 1.0, 2.0, 5.0, and 10 wt%. All soil substrates were incubated under 21–23 °C and 70–80% of the maximum soil water holding capacity for 60 days.

After incubation, the homogeneous soil substrates were air-dried and sieved with a 1 mm sieve. The pH_{H2O} of soil substrates was measured potentiometrically. Total soil carbon (%) was analyzed with a total organic C analyzer (TOC-L CPN, Shimadzu, Japan). Total N concentration (%) was determined by the Kjeldahl method using a Kjeltec analyzer [22]. Available P_2O_5 (mg 100 g^{-1} soil) was determined using flame photometric methods (SF 2000 OKB Spectrum, SaintPetersburg, Russia) following Kirsanov's procedure used in Russia [23]. Exchangeable Ca^{2+}, Mg^{2+}, Na^+, and K^+ (mg kg^{-1} soil) were extracted with $1MNH_4Ac$ buffered to pH 7 and then determined using spectrophotometric atomic absorption (Shimadzu AA-7000, Kyoto, Japan). Dry residue was obtained by summing the calculated method (Ca^{2+}+Mg^{2+}+Na^++K^+), and since the sum of the cations corresponds to the sum of the anions, then the sum of the cations was multiplied by 2 and converted into a percentage, following the procedure recommended by van Reeuwijk [24]. Analysis of the chemical composition of *F. vesiculosus* waste was carried out according to GOST [25] and Zhang et al. [26].

2.3. Germination of Cucumber Seeds in Various Research Media

Uniform seeds of cucumber (*Cucumis* sativus L., var. Kurag) were used for the germination and seedling growth test. The seeds were obtained from a commercial supplier and stored at 4 °C until the start of the experiment.In a viability test before germination, seeds showed 98–100% germination in distilled water. Twenty-four seed replicates were placed in 9cm Petri dishes with one disk of filter paper and 7 mL of test solution. The test solution included 0, 0.1, 0.5, 1.0, 2.5, 5.0, and 10.0 g of *F. vesiculosus* waste extract in 1 L of distilled water. All dishes were subjected to a germination chamber with conditions maintained at 26 °C in the dark with 60−70% relative air humidity. Seeds were considered germinated when the radicle emerged 2 mm from the seed. The number of germinated seeds was noted down every day after sowing. Twenty randomly chosenseedlings of each treatment were used for the measurements of growth parameters at the end of 5 days of soaking. The 5-day seedlings were separated into shoots and roots, and the root and hypocotyl lengths were measured. Then, the organs were dried at 70 °C to weight constancy and weighted. The ratio between the root and shoot dry biomass was calculated.

2.4. Statistical Analysis

For each treatment, the means were determined with at least three analytical replicates. The reliability of changes in the studied chemical properties of soils under *F. vesiculosus* waste application wasassessed by Student's test. The effect of *F. vesiculosus* waste on the postgerminative parameters of cucumber seedlings and the significant difference between the treatments were assessed by the least significant difference (LSD) of analysis of variance (ANOVA). Differences at the $p < 0.05$ level were reported as significant. All statistical tests were carried out with Statistica software (v. 8.0.550.0, StatSoft, Inc Dell., Round Rock, TX, USA).

3. Results

The content of phenolic compounds, proline, alginate (salt of alginic acid, polysaccharide), mannitol (hexahydric alcohol, low-molecular-weight carbohydrate), as well as the composition and content of sugars in fucoidan (a complex of high-molecular-weight sulfated polysaccharides, the main monosaccharide component of which is L-fucose) are presented in Tables 1 and 2.

Table 1. The content of phenolic compounds (mg gallic acid g^{-1}), proline (%), alginate (%), mannitol (μg g^{-1}),andtotal sugar concentration (mg g^{-1}) in the *F. vesiculosus* waste used in this study.

F. vesiculosus Material	Phenolic Compounds	Proline	Alginate	Mannitol	Total Sugar Content
			n = 5		
Waste	2.10 ± 0.03	0.048 ± 0.004	7.4 ± 0.03	1.1 ± 0.1	104.1 ± 5.2

Table 2. The composition and content of sugars in the fucoidan of *F. vesiculosus*.

F. vesiculosus Material	Type of Sugar	Sugar Content, %
	n = 5	
Waste	Ribose	4.0 ± 0.4
	Xylose	12.9 ± 1.6
	Hexose	10.6 ± 0.8
	Pentose	26.4 ± 2.7
	Glucose	5.1 ± 0.5
	Galactose	23.4 ± 2.1

As shown in Table 3, the *F. vesiculosus* waste application significantly affected soil acidity. In accordance with the increase in algae content, pH values increased in the substrates of all soil types used in this study, with alarger increase for Retisol loamy sand and Retisol clay than for Retisol loam and Histosol. A statistically significant relation was determined between the algae content and pH values of soil substrates.

Table 3. The pH values and C, N, P_2O_5, Ca, Mg, Na, K, and dry residue content in soils of different types under *F. vesiculosus* waste application with arate of 0, 0.5, 1.0, 2.0, 5.0, and 10 wt%.

Treatments	pH_{H2O}	C Total	N Total	P_2O_5	Ca^{2+}	Mg^{2+}	Na^+	K^+	Dry Residue
		%		mg 100g^{-1} soil		mg kg^{-1} soil			%
				n = 5					
Retisol loamy sand									
0	5.41	1.28	0.12	10.2	394.0	18.7	40.6	34.4	0.10
0.5	5.38	1.62 *	0.13	9.7	371.4	22.8	65.1 *	46.1 *	0.10
2.0	6.38 *	1.71 *	0.12	14.3	566.4	51.6 *	139.5 *	65.3 *	0.16
5.0	7.33 *	2.24 *	0.14	13.6	574.1	58.2 *	223.0 *	93.2 *	0.19
10	8.01 *	3.12 *	0.19	13.8	899.8 *	112.3 *	437.4 *	213.3 *	0.33*
Retisol loam									
0	5.77	3.96	0.22	162.0	2856	164.1	67.2	379.7	0.69
0.5	5.56	4.71 *	0.23	172.0	3090	253.6 *	104.9 *	270.5	0.74
2.0	5.80	4.94 *	0.21	172.5	2956	284.6 *	177.3 *	357.7	0.76
5.0	5.94 *	5.44 *	0.21	174.7	2975	290.3 *	186.3 *	462.6 *	0.78
10	7.40 *	5.50 *	0.20	165.5	2511	316.2 *	371.6 *	472.4 *	0.73
Retisol clay									
0	6.30	0.48	0.18	105.0	630	194.9	99.1	84.2	0.20
0.5	6.89 *	0.66	0.23	111.5	671	191.8	96.7	78.4	0.21
2.0	7.47 *	1.48 *	0.21	107.5	742 *	177.0	155.2 *	79.7	0.23
5.0	8.11 *	1.76 *	0.21	128.3	1073 *	271.3 *	229.2 *	47.9	0.32
10	8.62 *	2.78 *	0.28	122.6	1260 *	249.5 *	379.5 *	92.7 *	0.40*
Histosol									
	5.49	35.93	1.80	42.3	8914	635.8	81.2	53.2	1.94
0.5	5.34	36.51	1.68	45.5	8849	626.1	82.7	48.4	1.92
2.0	5.39	35.78	1.73	47.3	9357	682.5	232.3 *	67.8	2.07
5.0	5.54	36.31	1.65	65.3 *	8404	682.3	283.2 *	108.9 *	1.90
10	5.71 *	36.93	1.80	60.1 *	9316	832.8 *	633.7 *	180.3 *	2.19

* Significant changes in chemical properties were observed ($t_{emp} > t_{tbl}$ at $p \leq 0.05$); in other cases, the changes were not significant ($t_{emp} \leq t_{tbl}$ at $p \leq 0.05$).

It is well known that organic matter mineralization causes an increase in the content of soil organic carbon [22,23]. The application of *F. vesiculosus* waste products also increased the C content in all soil types under the study, except Histosol. The largest increase inC content was found for Retisol clay, with anincrease of 1.4, 3.1, 3.7, and 5.8 times when 0.5, 2.0, 5.0, and 10% algae were added into the soil, accordingly. For Retisol loamy sand and Retisol loam soils, the total carbon content increased by 2.4 and 1.4 times, accordingly, in the treatments with 10% *F. vesiculosus* waste.

For Retisol loam and Histosol, no significant differences in the total N content were observed among all algae treatments, but for Retisol loamy sand soil and Retisol clay, the N content tended to be higher in soil substrates with 5.0 or 10% than with 0% algae. The significant effect of *F. vesiculosus* waste application on the content of available P was found only for Histosol. For this type of soil, the substrates with 5.0 or 10% algae had about a 50% higher P_2O_5 content than the substrate without algae. The *F. vesiculosus* application caused a significant increase in the content of Ca, Mg, Na, and K ions in substrates regardless of soil type.

In general, the application of algae residues resulted in an increase in the content of water-soluble salts in almost all variants of the experiment, with the exception of variants with Histosol (doses of 0.5 and 5%), but a significant increase was noted only in variants with 10% addition to Retisol loamy sand and Retisol clay, which may be due to, initially, the uneven salt content in algae waste and in the soil itself.

Seed germination was not affected by *F. vesiculosus* waste application and was close to 100% among all treatments (data not shown). Hypocotyl length increased according to the increase in *F. vesiculosus* waste extract content (Figure 2a). Among all treatments, the highest and lowest hypocotyl length was found in 10.0 and 0 g L^{-1} treatments, respectively.In contrast to the hypocotyl length, *F. vesiculosus* reduced root length (Figure 2b). The root length of seedling germinated in 5.0 and 10.0 g L^{-1} solution was significantly lower than in other treatments. Regardless of *F. vesiculosus* waste extract content, no significant differences in shoot dry mass of cucumber seedlings were found (Figure 2c); however, the root dry mass of seedlings of 10.0 g L^{-1} treatment was the highest among all treatments (Figure 2d). The increased root mass caused an increase in the root/shoot ratio (Figure 2e).

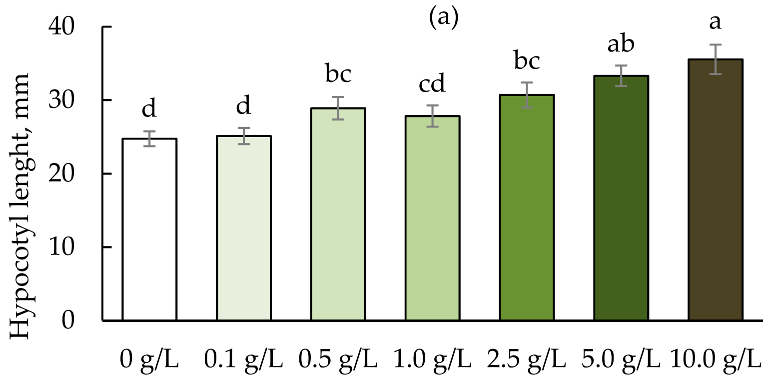

Figure 2. *Cont.*

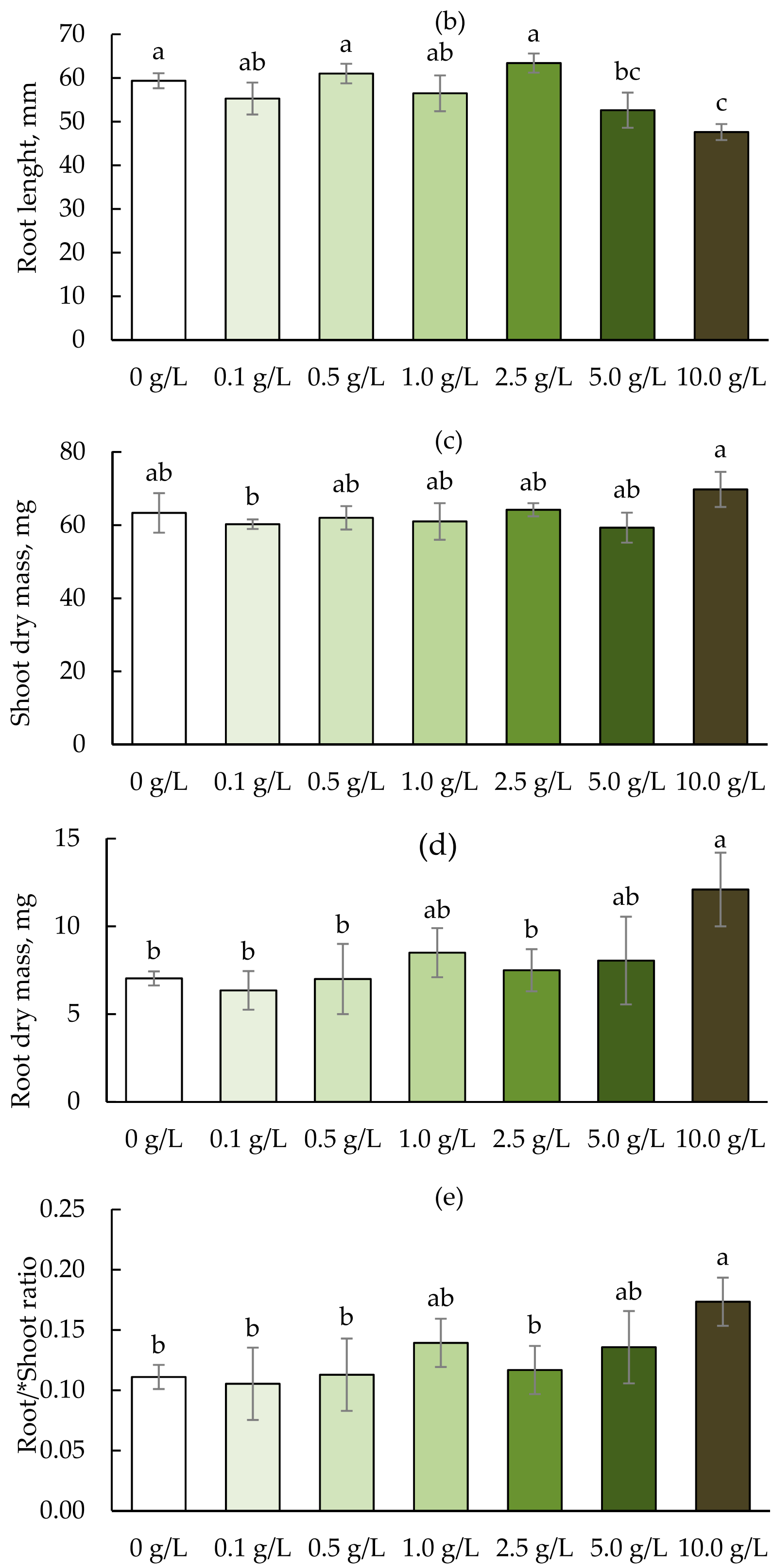

Figure 2. The effect of *F. vesiculosus* waste extract of 0, 0.1, 0.5, 1.0, 2.5, 5.0, and 10 g L^{-1} content on postgerminative parameters of cucumber seedlings. Different letters indicate significant differences in the means at $p < 0.05$., (**a**)—hypocotyl length, mm; (**b**)–root length, mm; (**c**)—shoot dry mass, mg; (**d**)—root dry mass, mg; (**e**)—root/shoot ratio.

4. Discussion

Karelia is located within the Baltic crystalline shield with bedrocks, mainly granites, gneisses, crystalline schists, quartzitesandstones, and gabbro–diabases. The bedrocks are covered with loose glacial, fluvioglacial, and lacustrine–glacial Quaternary sediments, which are represented by sands, sandy loams, loams, and clays mixed with gravel, pebbles, and boulders in places. These deposits, as well as the topography, climate, and vegetation, have a great influence on the formation of soil cover. The climate of the study area is cool and humid; the average annual temperature varies from north to south from +0.1 °C to +3 °C, and the average annual precipitation is 400–650 mm [27]. The vegetation is represented by the northern and middle subzones of the southern taiga with such main forest-forming species as pine, spruce, birch, and alder. Meadows are mostly secondary and arose on the site of former forests and along river floodplains. In areas of dissected relief, peat bog complexes were formed.

The peculiarities of the natural and climatic conditions of Karelia contributed to the formation of a wide variety of soils, among which primitive underdeveloped, podzolic, soddy, marsh, and alluvial soils predominate. Podzolic soils are the most common; they develop under coniferous and coniferousbroad-leaved forests under conditions of a leaching water regime and the influx of plant residues depleted in ash and nitrogen. All podzolic soils, depending on their mechanical composition, are divided into two groups—those formed on sands and sandy loams and on loams and clays. Podzolic sandy and sandy loamy soils have a clear differentiation of the profile into horizons: forest litter A0, podzolic A2, illuvial B, and soil-forming rock C. The thickness of the forest litter ranges from 2–2.5 cm to 7–9 cm. The podzolic horizon is represented by a whitened thin layer 1–2 cm with inclusions of fragments of coarse organic matter, passing into the illuvial horizon of ocher color.The podzols are formed on fluvioglacial and lacustrine sands and sandy and sandy loamy moraines. Soil-forming rocks are characterized by a low content of dust and dust particles, which leads to a low rate of organic matter accumulation.The content of organic matter in the podzol profile is low. Organic matter accumulates on the soil surface as litter, and its content decreases from 0.9–1.6% in the podzolic horizon to less than 0.1% in the parent rock. The content and distribution of nitrogen correlates with the content of organic matter and varies from 0.15% in the podzolic horizon to 0.018% in the parent rock. Sandy and sandy loamy podzols are characterized by an acid reaction. The absorption capacity in mineral horizons is low at −2–3 cmol (+) kg^{-1}; among the absorbed cations, the content of calcium is −0.9–1.1, magnesium −0.4–0.6, sodium 0.1–0.2, and potassium 0.07–0.2 cmol (+) kg^{-1}. Podzolic loamy and clayey soils are formed on boulderless loams and are characterized by a high content of silty and fine silt particles, which contributes to the accumulation of organic matter and mobile elements of nitrogen, phosphorus, and potassium. Under the forest floor with a thickness of 3–6 cm, the formation of a dark gray humus-accumulativeeluvial horizon A1A2 with a thickness of 2–15 cm is noted, which gradually turns into a podzolic horizon A2 (15–30 cm thick) with a brownish tint, under which there is an illuvial horizon B, smoothly transitioning into the parent rock. The content of organic matter in the A1A2 accumulative horizon is 1.5–3.8% and gradually decreases down the profile to 0.15–0.2%; the content of total nitrogen ranges from 0.4 to 0.1%, respectively. Loamy and clayey podzols are characterized by an acid reaction of the medium in the upper part of the profile and close to neutral in the lower part. The absorption capacity in the accumulative horizon is 6–8 cmol (+) kg^{-1}; among the absorbed cations, the content of calcium (3.4–3.8 cmol (+) kg^{-1}) and magnesium (2.0–2.2 cmol (+) kg^{-1}).prevails [28].

The development of podzolic soils for arable land leads to a change in the structure of the profile. The upper horizons, including the A2 podzolic horizon, are completely plowed up, and the upper part of the B illuvial horizon is plowed up, resulting in the formation of an arable humus-accumulative plow horizon. Plowing and cultivation of podzolic soils lead to a change in the reserves of organic matter. As a result of plowing, the conditions for the decomposition of organic matter are improved (improvement inair and water regimes, a decrease in acidity, an increase in microbiological activity), which leads to a sharp decrease in its content. In this regard, there is a need for the constant application of organic fertilizers. There is also a removal with the harvest and washing out into the underlying horizons of elements of the mineral nutrition of plants (nitrogen and mobile forms of phosphorus and potassium), which also leads to the need for their regular application to the soil in the form of fertilizers. As an alternative source of organic and mineral fertilizers in the Republic of Karelia, a small amount of cattle manure is used; the absence of large livestock farms makes it difficult to introduce the required amount of organic matter. Peat soils are formed under conditions of excessive moisture in deep relief depressions, in hollows between moraine hills, and among outwash plains. The soil profile is poorly differentiated into genetic horizons—A0–T1–T2, and the thickness of peat horizons varies from 0.5 to 8 m. These soils are characterized by low ash content (1.5–4%), acid reaction of the medium (pH_{KCl} 3–3.5), organic carbon content 30–40%, and total nitrogen content 1.0–2.5%. Peat soils are infertile and poor in microorganisms, and the processes of the mineralization of organic matter proceed very slowly. During the period of development and cultivation, they need liming and mineral fertilizers [29].

The composition of algae often depends on the time of collection and the method of processing. In our studies, the average proline content was noted in algae processing waste (Table 1). The free amino acid proline is one of the most common low-molecular-weight organic osmolytes in higher plants. Proline performs osmoregulatory and cryoprotective functions and participates in the synthesis of protein molecules. It is also an efficient energy substrate, a source of carbon, and a reserve for nitrogen.

Alginates form the main structural polysaccharide of many marine brown algae (40% dry weight). The alginate fraction in algae processing waste is quite high. In the presence of charges, polysaccharides can behave like polyelectrolytes, which have a special ability to ionize in aqueous media. Ionization promotes the dissolution of polyelectrolytes and determines their unique properties. The dissolution of polyelectrolyte is accompanied by the formation of polyion and counterions. Polyions are mobile and hold many charges in close proximity so that individual charges are firmly connected to the macromolecular backbone [30].

The six-hydric alcohol mannitol, isolated from brown algae, is a valuable material. Mannitol is a low-molecular-weight carbohydrate from brown algae. In the tissues of algae, it is formed because of the peculiarities of the processes of biosynthesis and assimilation. Mannitol is one of the first and main products of photosynthesis, acting as a reserve substance, which is used in the synthesis of structural elements of macrophyte cell walls and, at the same time, performs an important osmoregulatory function for brown algae [31]. The concentration of mannitol in natural algae is hundreds of times higher than in deep processing waste.

Fucoidans are complex high-molecular sulfated polysaccharides of brown algae, the main monosaccharide component of which is L-fucose. In addition to fucose, fucoidans can also contain other monosaccharides: xylose, mannose, glucose, and galactose. Seasonal fluctuations in the content of fucoidans in brown algae of the White and Barents Seas are significant and vary within 5–17% depending on the order, genus, and species of algae. The structure and properties of fucoidans also differ between brown algae species [32]. Analysis of the main polysaccharide of *F. vesiculosus*, fucoidan, also showed the presence of significant differences in the concentration of sugars (Table 2).

The rate of soil organic matter mineralization is affected by many factors, including soil texture, granulometric composition, and clay content in the soil [33]. Among all studied soil types with different granulometric compositions, Retisol clay demonstrated the largest extent of organic carbon accumulation when brown algae waste was added into the soil. Clay minerals play an important role in stabilizing soil organic matter [34] and its accumulation in the soil [35]. Vidal et al. [36] showed that the addition of clay minerals to organic composts not only contributed to the accumulation of organic carbon in the soil but also increased the productivity and yield of agricultural plants.

Peat soils are among the largest carbon stores in the terrestrial biosphere [37] due to the low rate of organic matter decomposition [38]. Waste addition did not affect the carbon content of Histosol, possibly due to the insufficient incubation time for the microbial community to adapt to the new, less acidic soil conditions. Moreover, the soil microbial activity could be limited by toxic macronutrients included in the composition of the waste and the lack of macronutrients, primarily nitrogen, due to a change in the C:N ratio.

Soil microbial community activity regulates the rate of organic matter decomposition [39]. The process of mineralization of organic matter is accompanied by the production of greenhouse gases, including CO_2 [40,41]. Organic matter mineralization and CO_2 production can also occur in saline soils [42]. As a result of the dissolution of a part of CO_2 in soil water in the presence of various salts, carbonates and bicarbonates are formed, which lead to a change in the acid–base properties of soils toward alkalization [43]. Carbonate formation can also be the result of microbial processes. Thus, the waste application could initiate the production of salt carbonates due to the reaction of soil CO_2 and salt cations supplied with algae or released during the decomposition of algae waste [44]. The algae application caused an increase in pH in Retisol clay, Retisolloam, and Retisol sandy loams, but not in Histosols due to their greater degree of mineralization.

5. Conclusions

This study showed that the effect of *F. vesiculosus* waste application can vary depending on the soil type. The highest rate of mineralization was found for the Retisol clay, apparently due to the high content of clay minerals, which play an important role in the stabilization of organic matter, and due to the low initial level of soil organic matter. Increased mineralization led to an increase in the content of organic matter in the soil, with the largest increase observed in treatments with the highest application rate of algae (10%). The lowest mineralization rate was found for Histosol, which may be due to insufficient time for acclimation of the microbial community to changed conditions, as well as the toxicity of sea salts introduced with algae and the change in soil C:N ratio.

The appearance of soil CO_2 and sea salts (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} cations) on algae leaves or the release of cations due to the mineralization of algae waste can lead to the formation of soil carbonates and bicarbonates, which can reduce the acidity of Retisol clay, Retisol loam, and Retisol loamy sand. The algae application did not affect the acidity of Histosol, apparently due to the low degree of soil mineralization.

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