Algae fibre for soil improvement (FIMO)

NORSØK REPORT | VOL. 7 | NR. 8 | 2022

[Author et al.][Company]

TITLE

Algae fibre for soil improvement (FIMO)

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DATO:	REPORT NR.	STATUS	PROJECT NR.:
18.05.2022	Vol 7/No 8 /2022	Open	NORSØK 3190

ISBN:	ISSN:	NUMBER OF PAGES:	NO. OF APPENDICES:
978-82-8202-148-7		Pages	0

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KEYWORDS:	SUBJECT:
alger, arsen, gjødsel, poteter, tang, jordhelse	Food and agriculture
arsenic, fertiliser, seaweed, potatoes, soil health	Mat og landbruk

SAMMENDRAG:

Prosjektet «Fiber fra havet gir mold i jorda» (FIMO) ble gjennomført i 2021-22 for å bidra til bedre bruk av et restprodukt fra algeindustrien i Kristiansund (Algea AS), ved å vurdere hvordan produktet egner seg til jordforbedring. Algea produserer tangmel og ekstrakt av grisetang som høstes langs kysten. Ekstraktet selges som en flytende gjødsel, og mye går til eksport. Resten etter ekstraksjon kalles algefiber, og er en finkornet, svart masse med ca. 30% tørrstoff. Algefiber inneholder mye karbon, og mineraler som kalium, svovel og magnesium, som er viktige plantenæringsstoff. Samtidig har algefiber en høy pH (ca. 9), inneholder en del tungmetaller (potensielt giftige element), og høyt innhold av natrium og kalium kan være en utfordring. Det har vært prøvd å blande algefiber med kloakkslam for kompostering, men det var krevende å få en god prosess. Derfor blir algefiber per 2022 sendt til forbrenning. Jord som brukes til dyrking av poteter bearbeides mye, og dette tærer på moldinnholdet. I Møre og Romsdal er det en betydelig dyrking av poteter i Sunndal og Rauma, hvor produsentene er tilknyttet Sunndalspotet AS. I Sunndal er det ofte sandjord med lavt moldinnhold der det dyrkes poteter. Et høyere moldinnhold i jorda ville øke vannlagringsevnen og gjøre jorda lettere å bearbeide. Kan algefiber brukes til å øke moldinnholdet i sandjorda i Sunndal? For å svare på dette overordnede spørsmålet, arbeidet vi med fem delmål i FIMO-prosjektet (1-5):
1: Beskrive og kvantifisere hvordan algefiber virker som jordforbedringsmiddel
2: Undersøke hvordan tilsetning av algefiber påvirker innholdet av mineraler (natrium-Na, kalium-K, arsen-As, kadmium-Cd) i poteter og gras
3: Undersøke om algefiber kan redusere utfordringen med svartskurv i potet
4: Foreslå en strategi for trygg bruk av algefiber ut fra innhold av mineraler (Na, K, As, Cd) i jord og algefiber
5: Formidle ny kunnskap til aktuelle brukere.

Vi brukte to feltforsøk fra tidligere prosjekt, der algefiber og andre typer marine restråstoff var tilført som gjødsel i 2019 eller 2020, og gjennomførte en rekke målinger og undersøkelser i felt i 2021. Vi registrerte avlinger av eng i forsøksfeltet som ble etablert i 2019, og vi dyrket poteter og havre i forsøket som ble etablert i 2020 og målte avlinger av disse vekstene. For en rekke viktige egenskaper i fulldyrka jord, som næringsinnhold, vannlagringevne og jordbiologi, målte vi effekten av tidligere tilsatt algefiber. Både for avlinger og jordegenskaper var sammenlikningsgrunnlaget forsøksruter som ikke ble gjødslet i 2019 (2020), eller som fikk tilført økologisk godkjent handelsgjødsel i 2019 (2020).

Tilført algefiber i 2019 og 2020 hadde god effekt på avlingsnivået i 2021, til dels betydelig bedre enn fjørfegjødsel tilført i 2019 eller 2020. I 2. års eng ble det i 2021 produsert 500 kg tørrstoff (TS) i sum for to slåtter i kontroll-leddet uten gjødsling **(K0)**. I forsøksrutene som fikk fjørfegjødsel i 2019 **(GO)** var sumavlinga, målt i 2021 på 910 kg TS, og i forsøksrutene som fikk algefiber i 2019 **(AF)** var sumavlinga hele 1,6 tonn TS per dekar. For poteter dyrka i 2021 ble avlinga i K0-leddet 2,9 tonn per dekar. Alle forsøksrutene fikk en grunngjødsling med 12 kg N per dekar tilført i tørket hønsegjødsel i 2021. I GO-leddet var avlinga 4,2 tonn, og i AF-leddet 4,7 tonn per dekar. Ett av de fire gjentakene i forsøket etablert i 2020 ble i 2021 brukt til havre, som ble høstet til grønnfôr. Her var det små forskjeller mellom avlingene i de ulike behandlingene. K0 ga 625 kg TS per dekar, mens AF ga 660 og GO ga 704 kg TS per dekar. Havren hadde en kort vekstperiode sammenliknet med potetene og enga, og det kan forklare at det ikke ble større utslag for gjødsel tilført i 2020 for denne veksten.

Selv om algefiber økte innholdet av arsen og kadmium i jorda, ble det ikke høyere innhold av disse elementene i poteter der det var tilført algefiber. I havre var innholdet av arsen noe høyere i AF-leddet (50 µg per kg TS) enn i GO og K0 (7 og 3 µg per kg TS), mens innholdet av kadmium pekte motsatt vei: 49 µg per kg TS i K0, 47 i GO, og 18 µg per kg TS i AF-leddet. Innholdet av natrium var

høyere i AF-leddet i havre. I poteter var konsentrasjonen av magnesium og kalium noe høyere i AF-leddet.

Siden tungmetaller kan anrikes i jord, er det viktig å unngå for høye tilførsler av slike element i gjødsel og jordforbedringsmidler. Forurensningsloven setter en øvre grense for innholdet av arsen (As) på 8 mg per kg tørr jord. Forskrift om gjødselmidler mv. av organisk opphav setter en øvre grense for andre tungmetaller som kopper og nikkel som er 50% av grensa i forurensningsloven. Hvis vi forutsetter et tilsvarende resonnement for arsen, vil grenseverdien for As i dyrka jord være 4 mg per kg tørr jord. Med det arseninnholdet som er i jorda på gårder som dyrker poteter i Sunndal i dag, kan det tilføres 35 tonn tørrstoff av algefiber per dekar før denne grenseverdien overstiges. Imidlertid er kadmiuminnholdet i algefiber såpass høyt at produktet kommer i klasse II etter gjødselvareforskriften. For slike materialer er det tillatt å tilføre inntil 2 tonn tørrstoff per dekar i løpet av en periode på 10 år. Med 25% tørrstoff er dette en mengde på 8 tonn. For hvert tonn med tørrstoff av algefiber (4 tonn ferskvekt) vil det tilføres rundt 92 kg med kalium. Dette er sannsynligvis mer enn ønskelig til poteter, så mengden av tilført algefiber bør nok begrenses ned mot det som er fysisk mulig å spre per dekar med en god fastgjødselspreder.

Forsøk ble gjort med tilsetning av algefiber til jord fra Sunndal med smitte av svartskurv. Mengdene som ble brukt var imidlertid så store at det dannet seg en skorpe som hemmet spiringen av poteter. En måling av jordrespirasjon i dette forsøket viste at respirasjonen økte raskt i jord tilsatt algefiber.

I jord som ble tilsatt algefiber økte pH, og det gjorde også innholdet av AL-løselig K, Mg, Ca og Na, samt innholdet av tungmetallene As og Cd. Vannlagringsevnen ble ikke påvirket av tilsetning av algefiber. Glødetapet i jorda, som er et mål for innholdet av organisk materiale, økte ikke. Innholdet av organisk materie i jorda på forsøksfeltet er imidlertid høyt; 9-12%. Vi målte også innholdet av aktivt karbon, og det var lavere i AF-leddet enn i GO-leddet. Jordrespirasjon målt i felt i 2021 var likevel høyere i AF enn i de andre leddene, men forskjellene var ikke statistisk sikre. Innholdet av spretthaler var vesentlig høyere i AF-leddet enn i øvrige behandlinger, og dette gjaldt både fargede arter som lever på overflaten, og hvite som lever litt lenger nede i jorda. Disse forskjellene var heller ikke statistisk sikre. Det ble satt ned plastpinner med materiale (fôr) som jordboende dyr kunne beite på, og mengde av fôr som forsvant over tid ble målt. Mengden som forsvant var størst i K0-leddet og AF-leddet, mens GO-leddet hadde tydelig mindre fôrforbruk. For å tolke resultater av undersøkelser av jordbiologi må vi ta hensyn til at gjødsling kan påvirke jordlivet direkte, men også indirekte gjennom virkningen som gjødsla har på planteveksten. Vi fant ingen resultater som tydet på at jordlivet tok skade av tilførsel av algefiber.

Oppsummert har FIMO-prosjektet vist at algefiber kan brukes som jordforbedringsmiddel ved dyrking av potet eller andre åkervekster. Innholdet av tungmetaller i jorda bør undersøkes hvis man skal benytte seg av jordforbedringsmidler som er i klasse I eller II. For å kunne følge med på om konsentrasjoner av tungmetaller i jorda endres over tid er det viktig å ta ut prøvene på samme måte hver gang. FIMO-prosjektet bør følges opp med et feltforsøk der tilførsel av algefiber prøves ut i praksis, og på jord med lavere moldinnhold enn vi hadde i våre forsøksfelt på Tingvoll, for å finne gode måter å spre materialet på, og undersøke hvordan plantene og jordlivet reagerer. Det trengs også videre undersøkelser av hvordan algefiberet påvirker innholdet av organisk materiale i jorda, utført i moldfattig jord. Selv om algefiber i seg selv kan være raskt nedbrytbart, vil økt plantevekst gi økt rotvekst, som kan øke mengden med organisk materiale som lagres i jorda. En positiv effekt av algefiber på flere undersøkelser av biologisk aktivitet fortjener også nærmere undersøkelser.

SUMMARY:

The project "Algae fibre for soil improvement" (FIMO) was conducted at NORSØK during 2021-22, to investigate how residual material from the production of seaweed extracts at a nearby industry, Algea AS in Kristiansund, may be applied as a soil amendment. The residue, called algae fibre, is a black paste with about 30% dry matter. The content of carbon is about 30%, and algae fibre also contains plant macronutrients such as potassium (K), magnesium (Mg) and sulphur (S). However, the material has a high pH (about 9), contains potentially toxic elements («heavy metals»), and has a high concentration of sodium (Na), which can pose a challenge for plant growth. The high content of K may also challenge a balanced uptake of minerals in crop plants. Algae fibre from Algea is currently being incinerated.

Soil applied for potato cultivation is intensively tilled, which may decrease the content of soil organic matter. In such soil, increased content of organic matter may increase the water storage capacity, reduce the mechanical resistance during soil tillage and be positive for soil living organisms. Can algae fibre be applied to increase the content of organic matter in soils which require such amendment? To investigate this overarching question, we carried out activities in five specific tasks (1-5):

1. To describe and quantify how algae fibre performs as a soil amendment.
2. To study how addition of algae fibre to soil affects the content of minerals (Na, K, As, Cd) in potatoes and grass.
3. To study if algae fibre can reduce problems caused by presence of black scurf fungi in the soil (a common disease in potato).
4. To propose a strategy for safe application of algae fibre based on the content of minerals (Na, K, As, Cd) in soil and algae fibre.
5. To communicate new knowledge to relevant end-users.

Two field experiments established in former projects were applied for the FIMO studies. Algae fibre and other marine materials were applied as fertilisers in these experiments in 2019 or 2020. During 2021, several investigations were carried out in field and laboratory. Yields were recorded in ley in the experiment established in 2019, and potatoes and oats were grown with yield recordings in the field experiment established in 2020. For several soil characteristics such as respiration, water storage capacity and biology, the effect of previous application of algae fibre **(AF)** was studied. For comparison, experimental treatments not receiving any fertiliser **(K0)**, or receiving dried poultry manure **(GO)** in 2019 **(or 2020)**, were applied.

Alga fibre applied in 2019 or 2020 had a significant positive effect on the growth of subsequent crops in 2021. The second-year grass-clover ley established in 2019 gave 5 tons of dry matter (DM) per hectare over two cuts in 2021 in the non-fertilised control, K0. Treatments fertilised by GO and AF in 2019 gave 9.1 and 16 tons of DM per hectare. Potatoes grown in 2021 gave 29 tons of tubers per hectare for K0, 42 tons for GO and 47 for AF. One of four replicate blocks in the 2020-experiment was used for the growing of oats in 2021. This crop was harvested as green fodder. Here, the yields did not vary significantly between the treatments, possibly due to a shorter growing period than for potatoes. K0 yielded 6.3 tons of DM per hectare, AF 6.6 and GO 7.0.

The application of algae fibre increased soil concentrations of arsenic (As) and cadmium (Cd) but did not increase the content of these elements in potato tubers. In oats, the As-concentration was higher in AF (50 µg per kg DM) than in GO and K0 (7 and 3 µg per kg DM), while the concentration of Cd

showed an opposite pattern with 49 µg per kg DM in K0, 47 in GO, and 18 µg per kg DM in AF. The concentration of Na was higher in oats in AF. In potatoes, the concentrations of magnesium and K were slightly higher in AF.

Potentially toxic elements (PTEs) commonly accumulate in soil, and hence, the application of such elements in fertilisers and soil amendments should be controlled and restricted. The national law on pollution states that the concentration of As in soil should not exceed 8 mg per kg dry soil. The national law on fertilisers and soil amendments of organic origin has no upper limit for As, but states that the concentrations of copper and nickel should not exceed 50% of the limits described in the law on pollution. Following the same logic for As, the concentration in dry soil should not exceed 4 mg per kg. From the current average concentration of As in soil typically applied for potato cultivation in the area studied here, 350 tons of algae fibre DM may be applied per hectare to reach this limit (if we assume that all As is accumulated in soil). However, the concentration of Cd in algae fibre categorises this material as a class II soil amendment product according to the law on fertilisers etc. Class II materials may be applied to agricultural soil with up to 20 tons of DM per hectare over a period of 10 years. With 25% DM, 20 tons of dry algae fibre corresponds to 80 tons of fresh material. One ton of algae fibre DM contains about 920 kg of K, which is much more than a potato crop requires. Hence, the amount of alga fibre needs to be adapted towards the smallest amount which may possibly be evenly spread with equipment for spreading of solid animal manure.

A trial to study the effect of algae fibre mixed with soil from Sunndal infested with black scurf on the germination of potatoes was hampered by application of too large proportions of algae fibre, which formed a crust on the soil surface that may have hampered the germination. Soil respiration measured in the soil mixtures revealed that respiration increased significantly and rapidly with application of algae fibre to the soil.

In soil amended with algae fibre, the pH increased, and we also found increased concentrations of ammonium acetate-lactate (AL) soluble K, Mg, calcium (Ca) and Na, and of As and Cd. Water storage capacity was not affected. Loss on ignition, which is a measure of soil organic material content, did not increase. However, the initial content of soil organic matter on the experimental site was high; 9-12%. The concentration of active carbon was lower in AF than in GO in 2021. The soil respiration (a proxy for microbial activity) and the numbers and groups of springtails measured in field in 2021 was higher in AF than in GO and K0 but the differences were not statistically significant. The density of springtails was considerably higher in AF, both for coloured species active on the soil surface and for white species dwelling in the topsoil, but the differences were not statistically significant. Bait lamina sticks were observed over time to record the «grazing» activity of soil fauna. Most bait was removed from the sticks in AF and K0, while the reduction of bait was significantly smaller in GO. For interpretation of soil biology studies, we must consider that fertilisers may affect the soil fauna directly, but also indirectly via the effect on plant production. We could not find any results pointing to a negative effect of algae fibre on the soil fauna.

Overall, the FIMO project has shown that algae fibre can be applied as a soil amendment for potatoes and other agricultural crops. In the soil which was applied for the FIMO field experiments, we did not find any increase in the content of soil organic matter. The content of PTEs in soil needs investigation for safe application of soil amendments in class I or II. The project should be followed up by a field experiment to test application of algae fibre in practice, on soil with less organic material than in the present study, to find practical ways of spreading the material in field and to study how the plants and some key species of soil organisms react. Further investigations are also required to reveal whether algae fibre may increase the content of organic matter in soil where the initial content is

low. Even if algae fibre as such may be rapidly decomposed in soil, increased plant growth may increase the amount of plant roots, which may increase the amount of relatively stable soil organic matter. High scores for soil biological activity in several tests indicate a positive effect that calls for further studies.

COUNTRY:	Norway
COUNTY:	Møre og Romsdal
MUNICIPALITIES:	Tingvoll, Sunndal

APPROVED	**PROJECT LEADER**
TURID STRØM	**ANNE-KRISTIN LØES**

Preface

Since 2018, NORSØK has worked with residual marine materials applied as fertilisers and soil amendments. The first project of this kind, "Residual materials from marine industries as fertilizers in organic agriculture" (RESTOR, 2017-2021) was funded by Møre og Romsdal county municipality. Soon thereafter, NORSØK became a partner in a Horizon 2020 EU project, Organic-PLUS (2018-2022), which provided an opportunity to do more thorough field experimental testing. A third project was then funded by the Regional Research Fund (RFF) Møre og Romsdal, for the studies described in the present report. This project, called "Seaweed fibre for increased soil organic matter" (FIMO, 2021-2022) was a collaboration between NORSØK and Landbruk Nordvest, the regional department of the Norwegian Agricultural Extension service (NLR). We also had two local industry partners; Algea AS in Kristiansund to provide material for testing as soil amendment, and Sunndalspotet AS with a possible interest in using material from Algea to increase soil organic matter in fields applied for potato growing.

Landbruk Nordvest was responsible for the FIMO field experiment conducted at Tingvoll farm in 2021, and for contact to potato growers in Sunndal who kindly provided chemical soil analyses. Sunndalspotet and Algea delivered materials such as seed potatoes, testing soil for black scurf, and fresh algae fibre.

NORSØK is grateful for the financial and professional support from RFF Møre og Romsdal and the mentioned project partners.

Tingvoll 18.05.22

Anne-Kristin Løes, project leader

Frontpage photos: Top left: Two pigmented and one white springtail from an experimental field applied in the FIMO project. Photo Reidun Pommeresche, NORSØK. **Top center**: Potatoes, early cultivar "Solist", from the FIMO field experiment 15 July 2021. Photo Anne-Kristin Løes, NORSØK. **Top right:** Researcher Tatiana Rittl measuring soil respiration and collecting data on soil biology in a plot receiving algae fibre (AF) in 2019. Photo Reidun Pommeresche, NORSØK. **Bottom right:** Close-up photo of algae fibre. Photo Ishita Ahuja, NORSØK. **Bottom left:** Frode Grønmyr and Maud Grøtta from Landbruk Nordvest harvesting potatoes from FIMO field experiment. Photo Anne-Kristin Løes, NORSØK.

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1 Introduction

Since 2018, NORSØK has studied the application of marine-derived residual materials as fertilisers in pot and field experiments. We have worked with residual materials from industry partners in Møre og Romsdal, such as Algea AS in Kristiansund. The main commercial products from Algea are dried seaweed and seaweed extracts for feed and fertilisation purpose, made from bladderwrack (*Ascophyllum nodosum*) harvested along the Norwegian coast. Seaweeds are applied for use in products such as food, fertiliser, soil conditioners, bio-stimulants, animal feed, skin and hair care products, cleaners, de-greasers, and nutritional supplements (Pereira et al. 2020), and processing factories are found in several countries such as Norway, Ireland, and Canada. At Algea, the residual product of extraction, known as algae fibre with about 25% dry matter is currently disposed of by incineration of about 15 tons per week.

Algae fibre is rich in nutrients and carbon (C), which makes it interesting as a fertilizer and soil amendment. However, algae fibre contains potentially toxic elements (PTEs) such as arsenic (As) and cadmium (Cd) in concentrations that may restrict the amount of material that can be applied to agricultural soil. The extraction occurs with compounds that are not permitted for use in organic growing, such as nitric acid (HNO_3). By March 2022, three extracts (AlgeaFert Solid, AlgeaFert Solid G and AlgeaFert Solid K+) and one dry product (AlgeaFert Meal) are listed as permitted for use in certified organic growing in Norway (Debio 2022), but the residual algae fibre products are not listed as applicable in organic growing. This may be because the producer does not have an interest in such application, or because the organic regulations hamper such utilisation. Mineral nitrogen fertilisers are not permitted in organic growing, and the nitrogen in algae fibre may derive from nitric acid. The material may still be applied in conventional growing when applied according to Norwegian regulations, as further discussed in chapter 6.

NORSØK has conducted various experiments with the use of algae fibre as a fertilizer for agricultural crops such as ryegrass, oats and leek (Ahuja & Løes 2019; Ahuja et al. 2020; Løes et al. 2021). Algae fibre does not have an immediate fertilisation effect, but it has a positive effect on crops with a long period of nutrient uptake such as leek (Ahuja et al. 2020). A significant residual effect has been found in grass-clover ley, with higher yields in both 2020 and 2021 after the application of algae fibre in 2019. This confirms the results of a former Norwegian study (Riley 2002) testing a comparable material derived from FMC Biopolymer. The tested algae fibre by-product contained about 40% perlite. Perlite is volcanic rock expanded by heat to a porous mineral particle. Application of the algal fibre to soil enhanced concentrations of sodium (Na), which is not beneficial for crop growth. On the positive side, such an application increased the water holding capacity of various test soils. When perlite was mixed with soil, comprising 10% of soil volume, the amount of plant-available water increased by 1.2 vol%, whereas with 10% of soil volume being algal fibre with 40% perlite, it increased by 3.6%. The yields of potato tubers in a field experiment increased by up to 70%, with an application of 40 tons of DM per hectare, comprising 480 kg N, 24 kg P and 375 kg K per hectare. The recommended fertilisation level with mineral fertiliser was 120 kg N, 55 kg P and 187 kg K per hectare. Such fertilisation gave a potato yield of about 22 tons per hectare, which was 17% higher than the yield with 40 tons of algal fibre. Significant amounts of mineral N were present in the soil at potato harvest, and some of this N was available for a subsequent crop of ryegrass in the next growing season.

Potatoes are an important crop in some parts of Møre og Romsdal county. Potatoes are often grown in sandy soils where the content of organic matter is often initially low, and intensive soil tillage in potato growing will decrease it even more. Soil organic matter (SOM) regulates different functions in the soil, and for soils with suboptimal content of organic matter (< 5-10% SOM), increased SOM will improve soil characteristics such as aggregation, water infiltration and nutrient cycling. Of special importance for the growing of potatoes is that more SOM would increase soil water holding capacity (WHC) and hence reduce the need for irrigation. More SOM would also reduce the energy consumption required for soil tillage. Algae fibre contains organic matter (about 30% C) and significant amounts of potassium (K), which is an important mineral for potatoes. Hence, this material may be an interesting soil amendment for potato growers. Furthermore, the application of algae fibre to agricultural soil may support soil biology because soil organisms get increased access to energy and mineral nutrients. The diversity and activity of soil living organisms affect the decomposition of organic matter, nutrient mineralization, improvement of soil structure and suppression of soil-born pathogen diseases (Bonkowski et al. 2000, Six et al. 2004, Friberg et al. 2005, Pommeresche & Løes 2009, Raaijmakers et al. 2009).

Few studies have been conducted on the effect of seaweed or algae fibre application on soil microorganisms. One litterbag study was conducted in the Netherlands to study the decomposition of sea lettuce (*Ulva lactuca*) in agricultural soil (Breure, 2014). Litterbags containing 40 g of fresh and washed sea lettuce was placed in 0-20 cm soil depth over 52 days in June and July 2013. The soil was sand with 1.6 % organic matter. The decomposition was initially fast. 50 % of the original material had decomposed after 10 days and 80 % after 24 days. The study demonstrated that thin-leaved seaweed decomposed quite fast in agricultural soil.

Butt et al. (2020) tested the palatability of two coarse common macroalgae*, Laminaria digitata* (kelp, tangle or oarweed, in Norwegian "fingertare") and *Fucus serratus* (saw wrack or toothed wrack, in Norwegian "sagtang") with three species of earthworms *Aporrectodea caliginosa* (field worm), *Lumbricus rubellus* (pink worm) and *Aporrectodea longa* (long worm). These earthworm species are common in Norwegian soils, where field worm is the overall most common. Over a period of 2 months, the field worm performed well with conventional feed like horse manure and birch leaves, with 150% and 126 % body mass gain. When the worms were fed with *Laminaria,* the field worms increased their mean mass by 62 % only; and when fed by *Fucus* they lost 15 % body mass. However, worm body mass with *Fucus* feed was still above the body mass of worms only fed by soil. The two other earthworm species gained weight with both species of macroalgae, mostly by *Laminaria.* When earthworms could choose feed, they preferred horse manure and birch leaves over seaweeds, possibly due to higher N content. When field worms were offered seaweeds only, no removal of feed was recorded, whereas for long worm and pink worm, *Laminaria* was preferred over *Fucus,* and fresh material was preferred over degraded. This indicates that the soil fauna has different preferences for feed and that earthworms can digest seaweed. Macroalgae have been applied as a fertiliser in horticulture and agriculture in coastal areas for centuries, and earthworms likely contribute to their decomposition in soil.

Effects of application of algae fibre to soil have not been tested with earthworms at NORSØK, but several other characteristics relevant for decomposition of organic materials in soil were studied in the project described in the present report. **The project, called «Seaweed fibre for increased soil organic**

matter», in Norwegian «FIber fra jorda gir MOld i jorda» (FIMO) aimed to achieve a better utilisation of the residual product algae fibre nearby the production plant (Algae AS in Kristiansund), by assessing the characteristics of this material applied as a soil amendment. The FIMO project had five specific objectives:

1. To describe and quantify how algae fibre performs as a soil amendment. WP1

2. To study how addition of algae fibre to soil affects the content of minerals (Na, K, As, Cd) in potatoes and grass. WP2

3. To study if algae fibre can reduce problems caused by presence of black scurf fungi in the soil (a common disease in potato). WP3

4. To propose a strategy for safe application of algae fibre based on the content of minerals (Na, K, As, Cd) in soil and algae fibre. WP4

5. To communicate new knowledge to relevant end-users.

This report describes the output of activities conducted to fulfil the five objectives and hence is the main deliverable from the FIMO project.

2 Field experiments applied in FIMO

The starting point for the FIMO project, which was conducted over only one year (April 1, 2021-March 31, 2022) was two field experiments established in 2019 and 2020. Both experiments were located on a field called “Sagmyra” near to the center of Tingvoll farm, in Tingvoll municipality, Møre og Romsdal, Norway (62°54’N, 8°11’E), **photo 1**. Tingvoll farm belongs to the Norwegian Centre for Organic Agriculture (NORSØK), and except for experimental plots, the farm is managed as a commercial organic dairy cow farm by a tenant. The soil texture on Sagmyra is loamy sand, with a high content of organic matter, 6-11% (Løes et al 2013).

Photo 1. *Location of the FIMO field experiment with potatoes and (in the background) oats, on field “Sagmyra”, July 15, 2021. To the right, flowering white clover on the surrounding area. Photo Anne-Kristin Løes, NORSØK.*

2.1 Field experiment from 2019

A field experiment was established in 2019 **(Exp2019)** to compare the fertiliser effect of various materials applied to oats (*Avena sativa* L.). The cereal was used as a cover crop for re-establishing a perennial grass-clover ley, following to the normal crop rotation at Tingvoll farm. Fertilisers were applied on May 14, 2019 and incorporated by tractor and a horizontal rotavator on May 16. Seeds were planted on May 20 and germinated on June 3. The canopy of oats was harvested on July 31, 2019. Five treatments were compared in four replicate blocks (**figure 1**). The treatments comprised a non-fertilised **control (K0)** and four fertilised treatments where 160 kg total N per hectare was applied as

algae fibre (AF), acid-conserved fishbones (FB), a mix of these two materials (Mix; 70% of N from FB, 30% from AF), and a commercial fertiliser product made from **dried poultry manure**, in Norwegian "Grønn Øko" **(GO)**. *To achieve a better overview of the effect of algae fibre, in this report we only present results from the highlighted treatments **AF, GO** and **K0.***

Exp2020								
Mix2	Mix1	F1	K0	GO2	FB1	GO1	FB2	AF1
Mix1	F1	Mix2	FB1	GO2	FB2	GO1	AF1	K0
AF1	FB2	Mix1	FB1	GO2	F1	Mix2	K0	GO1
GO1	K0	F1	GO2	FB1	FB2	Mix1	Mix2	AF1

Other exp. Area

Exp2019				
AF	Mix	FB	GO	K0
GO	K0	AF	Mix	FB
AF	FB	K0	Mix	GO
K0	AF	FB	GO	Mix

Figure 1. *Overview of field experiments (Exp) established in 2019 and 2020 applied in the FIMO project, with treatments highlighted in grey for K0 = control, blue for AF = algae fibre and brown for GO = poultry manure (in Norwegian "Grønn Øko"). 1, 2 refers to N levels in 2020, 300 or 600 kg N per hectare. Between the two experiments, a long-term field experiment in perennial ley ("SoilEffects") is located, being larger than indicated by the figure.*

The amount of algae fibre applied in AF plots was 1.41 kg dry matter (DM) per m^2, equal to 14 tons of DM per hectare, with a DM content of 23% (**table 1**). The material has a high content of organic matter, with a loss in ignition (LOI) value of more than 50% of the dry matter (DM), and about 30% of organic C. The poultry manure applied, Grønn Øko 8-3-5, contained 8 kg total-N, 3 kg P and 5 kg K per 100 kg. The algae fibre did not increase the yield of oats in 2019 (Løes et al. 2021), but ley yields (two cuts) in 2020 were significantly increased in AF. Total yields were on average 3.8 tons of DM per hectare in K0, 5.3 in GO and 6.4 in AF.

Table 1*: Chemical characteristics of algae fibre (AF) applied in 2019 and 2020; DM= dry matter (g 100 g^{-1}), LOI = loss on ignition (% of DM), Tot-C (% of DM), g of minerals N, P, K, Mg, Ca kg^{-1} DM; mg of As, Cd kg^{-1} DM*

Material	DM	LOI	Tot-C	pH	Tot-N	P	K	Mg	Ca	As	Cd
AF 2019	23	53	32	8.7	1.3	3.6	76	12	51	27	1.1
AF 2020	26	63	31	9.0	1.8	2.3	-	-	-	28	1.0

In 2021, **Exp2019** was applied in the FIMO project for recording the yields of ley, and for studies of relevant soil characteristics.

2.2 Field experiment from 2020

In 2020, another field experiment was established **(Exp2020)** to compare the fertiliser effect of the same materials as applied in 2019, but with a different crop and with two N levels for most treatments. N1= 300 or N2 = 600 kg total N was applied per hectare, where the numbers 1 or 2 in treatment abbreviations indicate the N level. Altogether, nine treatments were compared in four replicate blocks (**figure 1**). In addition to **K0**, **GO**, **AF**, FB and Mix, we tested fresh minced fishbones (F) in 2020. *In the present report, we present results from the treatments K0, GO1 and AF 1 (see **figure 1**), and we refer to these treatments as **K0, GO** and **AF**.*

The test crop was annual ryegrass, which was cut on four dates. Fertilisers were applied by hand on May 25-26 (**photo 2**) and incorporated by a cultivator. The amount of algae fibre applied in AF plots was 2.42 kg DM per m^2, equal to 24 tons of DM per hectare in 2020. The average content of DM that year was 26%. In the 4^{th} and final cut of ryegrass, yields were somewhat higher in the AF treatment (1.8 tons of DM per hectare) than in the control K0 (1.2 tons), but significantly lower than in the positive control GO1 (2.8 tons). On former harvest dates, AF yields were below the control yields at cut 1 and 2, and equal to the control yield on cut 3. Total yields were on average 4.2 tons of DM per hectare in K0, 6.9 in GO1 and 3.9 in AF1.

In 2021, **Exp2020** was applied to grow potatoes in three replicate blocks, and oats in one block, to study residual effects on these crops of algae fibre applied in 2020, and for studies of relevant soil characteristics.

***Photo 2.** Left side: Anne de Boer (NIBIO) applying fertilisers to the Exp2020 field on May 25, 2020. Right side: Close-up photo of algae fibre (black) applied to soil along with fishbones (light yellow). Photo: Anne-Kristin Løes, NORSØK.*

2.3 Soil samples for FIMO studies and weather conditions in the growing season of 2021

On October 15 and 16, 2020, the topsoil (0-20 cm depth) was sampled from all experimental plots in Exp2019 and Exp2020. From each plot, six soil cores with a diameter of 2.0 cm were taken with equal distances between sampling cores. Soil samples were split in two aliquots where one was air-dried and sieved for chemical analysis, and the other kept frozen at -18°C until analyses of active C and lab water holding capacity were carried out in spring 2021. An overview of conducted soil tests and analyses is shown in **table 2** (chapter 3).

The weather in the growing season of 2021 is presented here because it affected the results of soil characteristics studied in field, as well as the field experiment with oats and potatoes. The weather was quite dry between June 15 and August 10 (**figure 2**). Temperatures were high in May, but the end of June was cold.

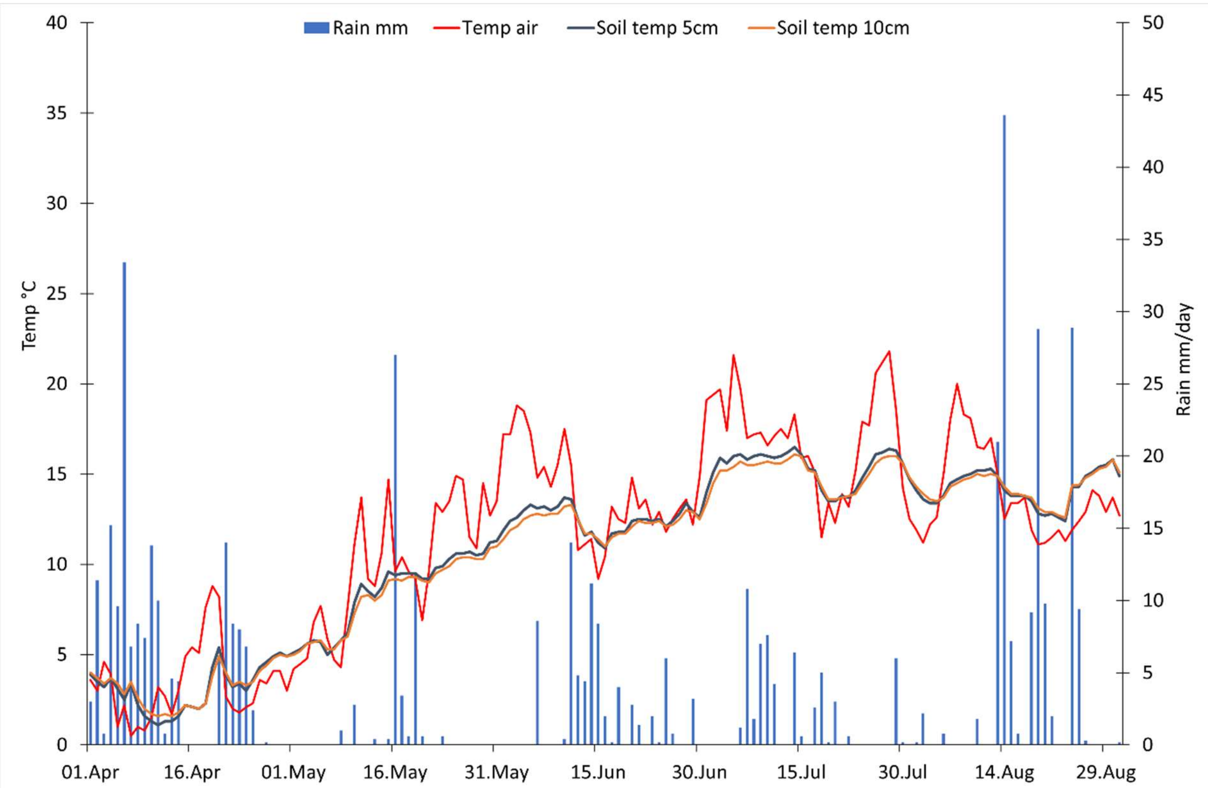

Figure 2. *Air temperature 2 m above ground level (°C), soil temperature at 5 and 10 cm soil depth (°C) and daily precipitation (mm) recorded at Tingvoll, April 1-August 31, 2021. The meteorological station at Tingvoll farm is located about 300 m SW of the experimental plots.*

3 Effects of algae fibre on soil parameters (WP1)

3.1 Methods applied to test effects of algae fibre on soil characteristics (WP1)

This section describes the methods applied to study the effect of algae fibre application on the chemical, biological and physical characteristics in Exp2019 and Exp2020. Some tests were carried out on all soil samples from October 2020, some tests were carried out in some experimental treatments only, and some tests were conducted on fresh samples or in experimental plots during the growing season of 2021 (**table 2**).

Table 2*: Overview of which tests and analyses were carried out in which experiments and treatments*

Type of test, number of samples tested (n)	Exp2019	Exp2020	Growing season 2021
Soil pH, loss on ignition + AL-extractable nutrients n= 56	All treatments (5) and replicates (4), soil sampled May 13, 2019 and Oct 16, 2020	All treatments (9) and replicates (4), soil sampled April 30, 2020 and Oct 15, 2020	
Active C in sieved soil n= 56	All treatments (5) and replicates (4), soil sampled Oct 2020	All treatments (9) and replicates (4), soil sampled Oct 2020	
Water holding capacity of sieved soil n= 56	All treatments (5) and replicates (4), soil sampled Oct 2020	All treatments (9) and replicates (4), soil sampled Oct 2020	
Field soil moisture n=12			Exp2019 Treatments AF, GO, K0 1 sample per plot
Soil respiration in field n= 36			Exp2019 Treatments AF, GO, K0 3 samples per plot
Springtails n= 12			Exp2019 Treatments AF, GO, K0 1 sample per plot
Bait lamina test n= 60			Exp2019 Treatments AF, GO, K0 5 sticks per plot

3.1.1 Chemical soil analysis

Chemical analysis of soil of samples from 2019 was carried out by Eurofins, Germany. For samples from 2020, analysis was carried out by SINTEF Norlab, Namsos, Norway.

In samples (**table 2**) of air-dried, sieved soil (< 2 mm), pH was measured after application of deionised water, with one part of soil to 2.5 parts of liquid (v : v). Loss on ignition (LOI) was measured as the percentage weight loss of oven-dry subsamples (~10 g) of sieved soil after ignition in steel crucibles at 550 °C for 4 hours in a laboratory furnace. In soils which do not contain calcium carbonate, LOI is closely related to determination of total C by dry combustion at 1050°C and measurement of emitted CO_2 (Løes et al., 2013). The topsoil at the experimental field contains little clay (7-9%; Løes et al 2013) and hence the LOI can be applied as a measure of SOM without correction for clay content.

AL-extractable nutrients were measured as described by Égner et al. (1960). Extraction by ammonium acetate lactate (AL) is the standard method in Norway to assess the plant availability of P, K, Ca, Mg and Na (Krogstad 1992). Dry soil is extracted by a mixture of 0.1 M ammonium lactate and 0.4 M acetic acid, pH 3.75, and the concentrations of nutrients in the extract are measured after filtration by Inductive Coupled Plasma mass spectroscopy (ICP-MS).

Potentially toxic elements (PTEs) were analysed by ICP-MS (Agilent ICP-MS 7900) after chemical digestion of the soil sample by a nitric acid/hydrogen peroxide solution at 120 °C for 30 min to bring ions into aquatic solution (internal method based on NS-EN ISO 17294-2: 2016).

3.1.2 Active soil C (permanganate oxidable carbon)

The amount of active carbon in soil, as measured by oxidation with permanganate, has been suggested as a potential indicator of total SOM, nutrient availability, improved soil structure and microbial activity (Bongiorno et al., 2019). The permanganate oxidable carbon was analysed (**table 2**) following the procedure of Weil, et al. (2003) modified as follows: 20 ml of 0.015 M $KMnO_4$ (= potassium permanganate) and 0.1 M $CaCl_2$ was added to the 2.5 g (± 0.3 g) of air dried and 2 mm sieved soil. The tube was shaken for 2 minutes at 200 rpm and thereafter left undisturbed on the lab bench for 10 min to continue oxidation. The $CaCl_2$ flocculated and settled the clay particles, leaving a clear solution except for the purple colour of $KMnO_4$, which varied in strength according to the amount of decomposed C (more C → less dark purple), **photo 3**. After 10 minutes, 0.5 ml of the solution was sampled and placed in a tube with 30 ml of distilled water. The absorbance of each sample at 550 nm (Abs) was determined using Genesys 50 UV-Vis Spectrophotometer.

Photo 3. *Left side: Tatiana Rittl measuring active C in soil samples for FIMO project. Right side: Extracts indicating different amounts of active C in the extracted soil. Photo Anne-Kristin Løes, NORSØK.*

3.1.3 Soil water holding capacity and field soil moisture

The maximum water holding capacity (WHC) of a soil is dependent on soil structure and the volume of soil applied for measurement, and hence the conditions for measuring this characteristic must be explained. We measured the WHC in lab (lab-WHC, **table 2**) with a small amount of sieved, air-dry soil (**photo 4**). For this, 30 g of soil was applied to a funnel plugged with cotton wool. The soil was saturated with 200 ml of deionised water and allowed to freely drain for about 4 hours until no further water drainage occurred. Samples were then dried at 105 °C for 24 h for determination of soil water content.

Photo 4. *Left side: Tatiana Rittl measuring water holding capacity (WHC) of air-dry, sieved soil for FIMO project. Right side: The amount of water retained in the wet soils determines the WHC. Photo: Anne-Kristin Løes, NORSØK.*

We also measured the field soil moisture on May 20, 2021 when soil respiration was measured in field. For this, we sampled about 500 g of soil with a spade from the top layer (0-20 cm) of the treatment plots. The soil samples were placed in sealed plastic bags, and a representative sub-sample of ca. 50 g was weighed and dried at 105°C until constant weight.

The lab-WHC and field soil moisture were calculated by the difference on the soil weight as,

((Wet soil – Dry soil)/Dry soil) × 100

3.1.4 Soil respiration rate

Soil respiration rate was measured in field (**table 2**), using the wireless Pasco CO_2 sensor, where CO_2 concentration is measured by the amount of infrared energy absorbed by CO_2 gas. The sensor has a one-point calibration in the software with a default value of 400 ppm. The wireless CO_2 sensor was operated through the mobile phone using the SPARKvue software. Soil respiration was measured in Exp2019 on May 20, 2021. For that, we placed three bottles (250 ml each) with an open bottom in plots of treatments AF, K0 and GO. The increase in CO_2 concentration inside of each bottle was recorded for three minutes and the slope of the curve was used as proxy for soil respiration rate (ppm s^{-1}).

Photo 5. *Left side: Pasco sensor inserted on the top of a bottle with no bottom. Right side: Sensor and bottle placed in sward (1-2 cm depth) on a K0-plot of the Exp2019. Photo: Reidun Pommeresche, NORSØK.*

3.1.5 Springtails

On May 20, 2021, springtails (Collembola) were collected (**table 2**), following a procedure described by Pommeresche & Løes (2014). At each sampling site the canopy was cut off by a knife, and a metal cylinder with diameter 5.8 cm and height 3.8 cm was applied to sample sward/soil volumes of 100 cm^3. The cylinders were put on soil between plants to avoid large roots in the samples. The cylinders were gently tapped with a rubber hammer into the soil, and then carefully excavated by a knife. After excavation a lid was placed on the top and bottom of each cylinder.

Photo 6. *Left side: A soil sample with soil fauna and grass tuft. Middle: the soil is put on a metal mesh in the extraction funnel. Right side: Three extraction funnels with light and heat on the top, and a small bottle underneath to collect springtails and other soil fauna forced out of the soil. Photo: Reidun Pommeresche, NORSØK.*

Within one hour, the samples were placed without lids and top down on a metal mesh closing in a slightly modified Tullgren funnel system, to extract the soil fauna from the soil/sward sample. The funnels were 25 cm in diameter on top and 2.6 cm at the bottom and were placed in a wooden frame (**photo 6**). The cylinder samples were placed on a nylon mesh (0.8 mm x 0.8 mm) which covered a metal mesh in the funnel, to ensure air contact to dry the sample and to avoid soil to fall into the sampling bottles underneath the funnels. The samples were slowly dried by means of a light bulb (40 Watt) placed above and close to the funnel, forcing the fauna to move downwards where they were trapped and preserved in a glass with 70 % ethanol (**photo 6**). The extraction period lasted for 7 days with continuous light.

Photo 7. *Left side: metal cylinder with sample to extract soil fauna. Middle: the complete soil fauna extracted from one (rich) sample. Springtails float on the surface, one earthworm is pressed towards the bottle wall. Right side: close-up of one pigmented springtail (Isotoma* sp.) *and one white springtail (Protaphorura* sp.). *Photo: Reidun Pommeresche, NORSØK.*

After the extraction period, all springtails were carefully picked out of the sampling bottles, counted, and sorted into white and pigmented individuals. The total number of springtail species in a field experiment located close to the Exp2019 site was 39 in 2012 (Pommeresche et al., 2017). With such large diversity, a sorting to ecological groups may be useful. A sorting between white and pigmented individuals, which belong to two different ecological groups, gives an estimate of the proportions of endogeic and epigeic species, as discussed in Pommeresche et al. (2014). Pigmented springtails dwell on the soil surface (epigeic). They have colored bodies and well-developed eye organs. White springtails are soil-dwelling (endogeic). They are white with poorly developed eye organs, and generally with shorter extremities (antenna, legs, and (spring)tails) than the epigeic group. To calculate the density of springtails per m^2 (0-3.8 cm depth), the number of individuals per cylinder (volume 100 cm^3) were multiplied by 380.

3.1.6 Bait lamina test

The bait lamina test was developed by Kratz (1998) to study consumption of a controlled substrate (bait) in soil over time (**photo 8**). The lamina sticks applied here had 16 holes filled with substrate. The rate of consumption was recorded over time (**photo 9**) to follow the changes in various soil depths. Five bait lamina sticks were placed in the topsoil of all replicate plots of treatments AF, K0 and GO on May 12, 2021. Consumption was recorded on May 20, May 27 and June 3 = day 8, 15 and 22. The bait sticks were inserted vertically into the soil with the topmost hole 1 cm below the ground surface. To avoid damaging the strips, a steel nail file was used to prepare the ground prior to insertion (**photo 8**).

The bait lamina sticks are made by rigid PVC and measure 1 mm × 6 mm × 160 mm. Each stick contains 16 holes of 1.5 mm diameter in 5 mm distance filled with a bait substrate consisting of 70% cellulose powder, 27% wheat bran, and 3% activated carbon, prepared by Terra Protecta, Germany. Studies diverge on which type of soil fauna that consumes the standard bait, but larger animals like earthworms, springtails and enchytraeids will remove more bait material from the holes than microorganisms (Gestel et. al. 2003).

For each hole and measuring date, bait consumption was recorded as empty hole = consumed (1); partly empty hole = partly consumed (0.5); or filled hole = not consumed (0). From these values, we computed the average bait consumption per plot in %, where 16 empty holes would be 100 % consumption. To study of the bait consumption variation with soil depth, the holes were attained increasing numbers (1-16) with increasing soil depth. Hence, we could calculate average consumption in each depth and compare between treatments. On each observation date, the sticks were carefully lifted from the soil, cleaned between two fingers and soil particles removed by blowing along the stick. Uneaten bait material was not affected by blowing. After recording the consumption values, the sticks were placed in the same soil slice.

Photo 8. *Left side: A grey bait lamina stick with all holes filled with organic matter, and a steel nail file with a wooden handle to prepare a slit in the soil to insert the stick easier. Right side: A bait lamina stick in the soil. Photo: Reidun Pommeresche, NORSØK.*

Photo 9. *A bait lamina stick affected by consumption of soil-dwelling organisms. Empty holes are recorded on sheet of paper with a value of 1, filled holes with a value of 0, and half-eaten holes with a value of 0.5. Photo: Reidun Pommeresche*, NORSØK.

3.2 Data analysis

Variance analysis by a general linear model was used to check if the treatments significantly affected the recorded soil characteristics, with treatment (AF, K0, GO) as fixed factor and plot number as a covariant. Statistically significant treatment effects were detected using Tukey t-test, with level of significance at $P < 0.05$. When data were not normal distributed (springtails), log transformed data was used for the statistical analyses.

We performed two different analyses to interpret the effect of treatments on the soil characteristics: response ratio of the treatment, and cluster analysis. For the response ratio, we quantified the effects of treatments on soil characteristics by calculating the response ratio (RR) of the treatment plots with the mean value of the control: $RR = \ln(X_{treat}/X_{meanK0})$, where X_{treat} represents the characteristic's value in the treatment (AF, GO) and X_{meanK0} represents the characteristic's mean value (n=4) in the control (K0).

RR values were scaled after analysis to percent change, to facilitate the interpretation, using the equation: % change = (eRR -1) × 100

Cluster analysis was applied to identify clusters of plots with similar topsoil characteristics and compare this classification with treatments. Our objective with this approach was to see if the amendments applied in 2019 left a fingerprint in the soil characteristics which could still be identified. We ran several analyses with different sets of the soil characteristics. In the present report, we show the results of the set of soil characteristics that distinguished best between treatments. This set comprised soil respiration, bait lamina, field soil moisture and active C.

All statistical analyses were performed with Minitab software.

3.3 Effects of algae fibre on soil characteristics (WP1)

3.3.1 Soil chemical characteristics

In **Exp2019**, before application of fertilisers, no statistically valid differences were found between the mean values of soil characteristics in experimental plots assigned to the various treatments (**table 3**), except for Zn which was slightly higher in the AF treatment compared to K0. The average value of soil pH was 5.7, and loss on ignition (LOI) 11%. Mean values of AL-extractable nutrients were medium to low for P (< 3 mg 100 g^{-1} air-dry soil), medium for K (7-15 mg 100 g^{-1} air-dry soil), medium for Mg (3-5 mg 100 g^{-1} air-dry soil) and medium for Ca (51-100 100 g^{-1} air-dry soil; all classifications referring to Krogstad 1992).

Table 3. Mean values of soil characteristics pH, AL-extractable nutrients (mg kg^{-1} air-dry soil), loss on ignition (LOI, % of DM) and concentrations of potentially toxic elements (mg kg^{-1} soil DM), and p-values for differences between treatments, in treatments in the field experiment established in 2019 (**Exp2019**), sampled before fertilisation in May 2019, and in October 2020. Treatments assigned by different letters (a, b) are statistically significantly different (p<0.05)

Soil	2019				2020			
charact.	AF	GO	K0	p-value	AF	GO	K0	p-value
pH	5.78 a	5.73 a	5.73 a	0.823	**5.98 a**	**5.55 b**	**5.55 b**	**0.006**
P-AL	23.67 a	23.75 a	23.00 a	0.870	36.50 a	47.75 a	38.50 a	0.112
Mg-AL	50.00 a	37.00 a	45.00 a	0.872	**80.25 a**	**48.00 b**	**42.25 b**	**0.000**
K-AL	112.25 a	45.00 a	39.50 a	0.083	**135.00 a**	**37.50 b**	**31.50 b**	**0.000**
Ca-AL	795.00 a	785.00 a	855.00 a	0.604	480.00 a	427.50 a	415.00 a	0.052
Na-Al	52.50 a	37.00 a	40.00 a	0.148	109.50 a	106.50 a	96.25 a	0.219
LOI	8.63 a	10.80 a	11.08 a	0.655	10.38 a	11.15 a	10.80 a	0.946
Pb	4.75 a	4.50 a	4.25 a	0.840	4.90 a	5.13 a	5.08 a	0.916
Cd	0.18 a	0.18 a	0.20 a	0.444	0.07 a	0.05 a	0.06 a	0.252
Cu	3.75 a	5.00 a	3.75 a	0.432	5.85 a	4.80 a	3.88 a	0.414
Cr	12.50 a	9.50 a	12.25 a	0.622	8.18 a	8.88 a	8.30 a	0.737
Hg	0.04 a	0.04 a	0.04 a	0.898	0.70 a	0.70 a	0.70 a	
Ni	5.00 a	4.25 a	4.75 a	0.723	4.70 a	5.05 a	4.55 a	0.713
Zn	**34.50 a**	**31.25 ab**	**28.25 b**	**0.037**	31.50 a	33.50 a	27.50 a	0.428
As	< 2.00	< 2.00	< 2.00		**0.81 a**	**0.60 b**	**0.65 b**	**0.004**
As-AL*	-	-	-		0.09 a	0.08 a	0.07 a	0.825

* In 2019 the detection limit of As was 2 mg air-dry soil kg^{-1}

After fertilisation in 2019 and the harvest of crop yields in 2019 (green fodder oats) and 2020 (1st year grass-clover ley), some characteristics were affected by the fertilisation. Soil pH was significantly higher after application of AF, which may be explained by the alkaline pH, close to 9.0 (**table 1**). The concentrations of AL-extractable Mg and K, and of arsenic (As), were also increased by algae fibre. The content of soil organic matter, measured by loss on ignition (LOI) did not increase.

In **Exp2020**, before application of fertilisers, no statistically valid differences were found between mean values of soil characteristics in experimental plots assigned to the various treatments **(table 4**). The average value of soil pH was 5.45, and LOI 12%. Mean values of AL-extractable nutrients were medium for P, K, Mg and Ca. Again, fertilisation affected several soil characteristics, but not the LOI-values. Soil pH was significantly increased after application of AF. AL-extractable P was lower in AF than GO, reflecting the low content of P in AF. AL-extractable K, Mg, Ca and Na were significantly higher than in GO and K0. Application of AF also increased concentrations of cadmium (Cd) and As. A higher concentration of As in the Exp2020 than the Exp2019 soil may reflect a higher application if AF in 2020, and/or that in the Exp2019 soil, one more year had passed between application of AF and soil testing. Since As has some similarities with P, we also analysed the concentration of As in the AL-extract, and this characteristics was also increased by application of algae fibre. Soil concentrations of Cd should not exceed 1.5 mg kg^{-1} soil, and concentrations of As should not exceed 8 mg (KMD 2022). PTEs are further discussed in Chapter 6.

The soil at the experimental site was not very suitable for studies of changes in soil organic material over time, since the initial content of organic matter in the topsoil was very high (9-12%). Hence, no significant changes found for LOI from application of algae fibre in the two experiments needs to be followed up by studies in soil with much lower contents of organic matter.

Table 4. Mean values of soil characteristics pH, AL-extractable nutrients (mg kg^{-1} air-dry soil), loss on ignition (LOI, % of DM) and concentrations of potentially toxic elements (mg kg^{-1} soil DM), and p-values between treatments, in treatments in the field experiment established in 2020 (**Exp2020)**, sampled before fertilisation in May 2020, and in October 2020. Treatments assigned by different letters (a, b) are statistically significantly different (p<0.05). When no statistically valid differences were found (May 2020), no letter was assigned.

Soil charact.	AF	GO	K0	p-value	AF		GO		K0		p-value
pH	5.47	5.45	5.45	0.789	**7.18**	**a**	**5.45**	**b**	**5.50**	**b**	**0.000**
P-AL	39.75	38.5	37.5	0.893	**22.50**	**b**	**32.50**	**a**	**26.25**	**ab**	**0.025**
Mg-AL	58.5	58	55.25	0.874	**175.00**	**a**	**28.25**	**b**	**37.75**	**b**	**0.000**
K-AL	130	146.8	145	0.753	**260.00**	**a**	**76.80**	**b**	**80.25**	**b**	**0.000**
Ca-AL	447.5	425	400	0.178	**537.50**	**a**	**230**	**b**	**265.00**	**b**	**0.000**
Na-Al	375	370	357.5	0.685	**735.00**	**a**	**283**	**b**	**330.00**	**b**	**0.000**
LOI	11.78	12	11.85	0.960	11.80	a	11.70	a	11.85	a	0.979
Pb	6.65	8.18	7.85	0.821	6.00	a	6.55	a	6.83	a	0.933
Cd	0.06	0.06	0.062	0.903	**0.07**	**a**	**0.04**	**b**	**0.05**	**b**	**0.003**
Cu	7.77	8.07	8.2	0.987	7.38	a	22.30	a	7.25	a	0.475
Cr	18.25	16.75	16.75	0.681	14.75	a	12.50	a	13.75	a	0.682
Hg	<0.7	<0.7	<0.7	-	<0.7		<0.7		<0.7		-
Ni	10.68	9.88	9.93	0.837	9.4	a	8.8	a	8.2	a	0.875
Zn	43.25	44.75	42	0.964	33.8	a	28.3	a	44.0	a	0.494
As-AL	0.09	0.09	0.082	0.327	**0.12**	**a**	**0.06**	**b**	**0.06**	**b**	**0.000**
As	0.847	0.87	0.85	0.477	**1.28**	**a**	**0.69**	**b**	**0.67**	**b**	**0.000**

3.3.2 Active soil C (permanganate oxidable carbon)

Active C refers to the labile fractions of soil C and serves as an indicator of changes in management-induced soil quality. The labile fractions of soil C fuel the soil food web and therefore greatly influence nutrient cycles and many soil characteristics affected by soil biology. Thus, this C fraction is dynamic oscillating over time and quickly responds to management types. In soil sampled in October 2020, after amendment of fertilisers in May 2019, AF showed the lowest value (568 mg C oxidable kg^{-1} air-dry soil, **figure 3**) and GO the highest (653 mg oxidable C kg^{-1} air-dry soil). This was somewhat surprising, since AF contains a high proportion of organic C which could possibly increase the active C in soil, but the soil fauna is dependent not only on C, but also on nutrients for their activity.

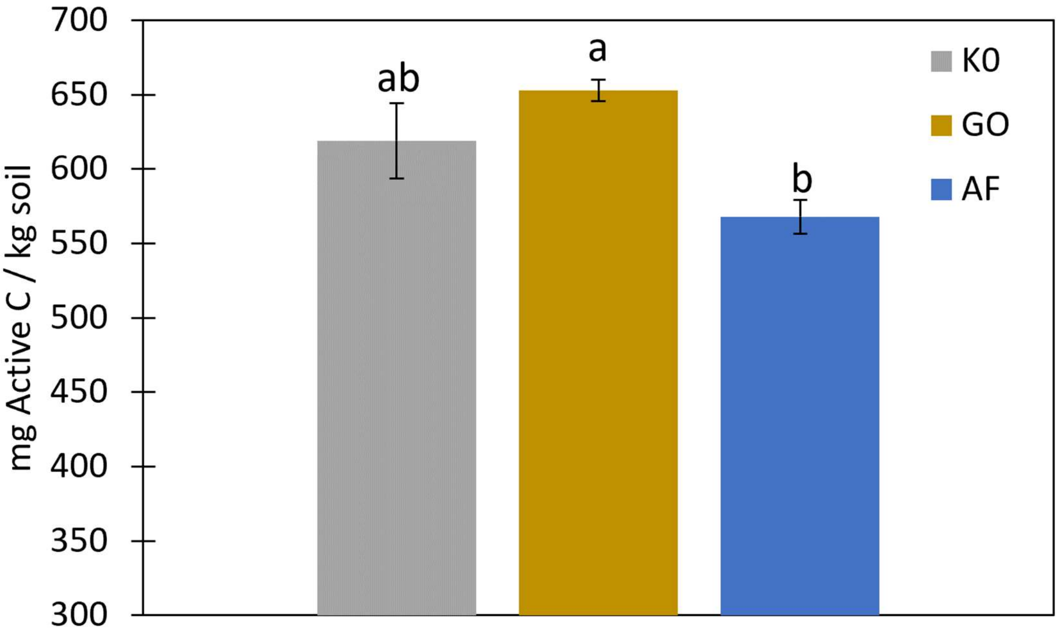

Figure 3. *Effect on the quantity of soil active C (mg active C kg^{-1} air-dry soil) by application of algae fibre (AF) or poultry manure (GO) in May 2019, measured in soil sampled in October 2020. K0= control with no amendment. Different letters indicate statistically difference between the values within the treatments (P < 0.05). Error bars n=4.*

The relationship between active C and LOI in soil was rather weak, but statistically significant (r^2=0.23; **figure 4**). A higher increase in LOI in the AF than in the GO treatment from 2019 to 2020 was not in line with the results of active C, but the LOI increases were not statistically significant (assessed by paired t-test).

Brown algae material is mainly composed of soluble fractions, possibly around 78% as calculated from values presented by Mišurcová et al. (2010) and hence we could expect a rapid decomposition of AF in soil. However, as presented in Chapter 4, application of AF in spring 2019 did not affect positively on yields in 2019, which may indicate that for the extracted algae fibre, decomposition may take longer than for fresh materials, since we assume that decomposition will release mineral nutrients for plant growth. In 2020, AF applied in 2019 had a positive effect on ley yield, and the concentration of Mg-AL and K-AL were higher in AF than GO and K0. This may indicate that decomposition and release of nutrients occurred in that season.

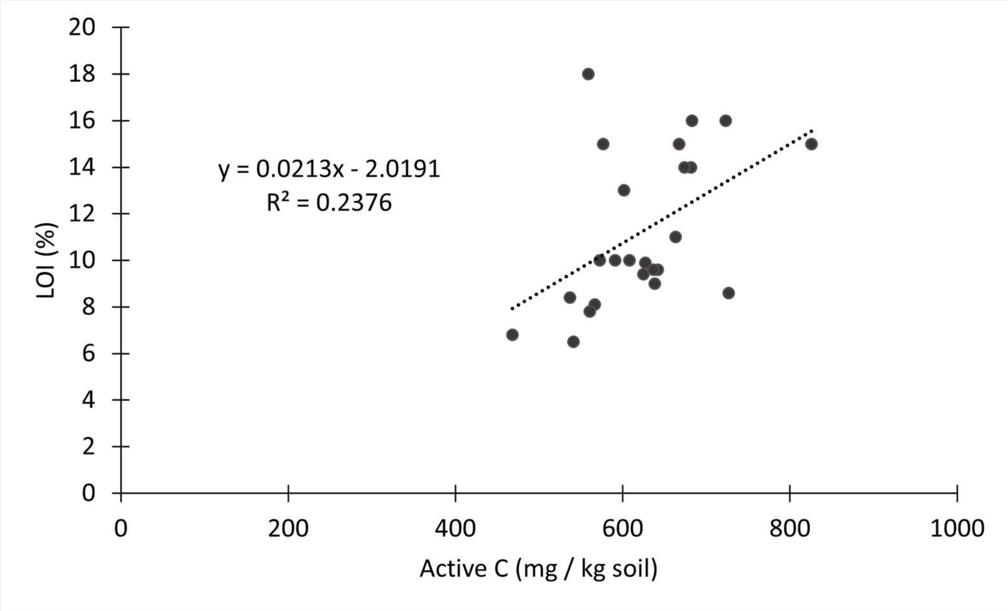

Figure 4. Relationship between active C (mg kg^{-1} air-dry soil) and soil loss on ignition (LOI, % soil dry matter, y-axis) in soil from treatments amended with algae fibre, poultry manure or unamended (control) in May 2019 or 2020, sampled in October 2020.

3.3.3 Soil moisture

Two methods were used to determine the soil moisture: maximum lab-WHC of soil collected in October 2020, and field soil moisture in spring 2021. The lab-WHC was measured with sieved and dried soil, while the field moisture was measured on fresh soil sampled on May 20, 2021. There was no relationship between these characteristics, and we did not find any significant differences between treatments for the lab-WHC or the field moisture (**figure 5**). All treatments showed a maximum lab-WHC of about 80%, while the field soil moisture of the topsoil (0-20 cm) was about 45% in all treatments.

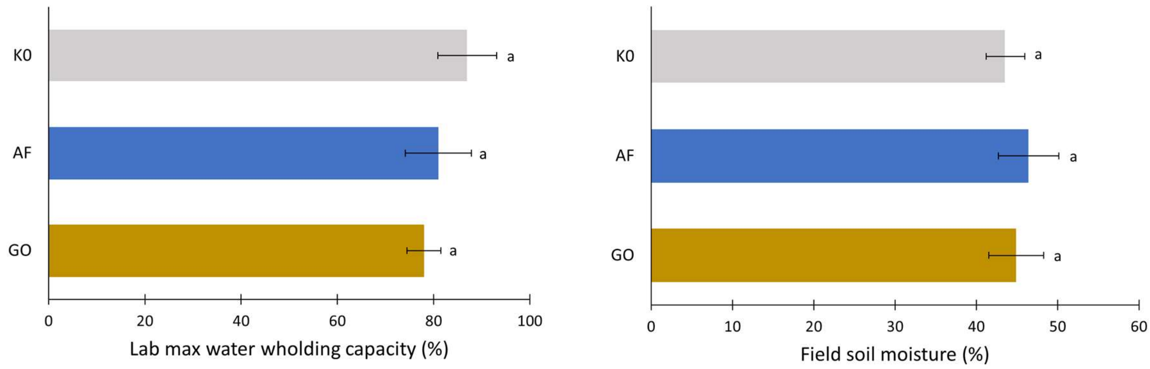

Figure 5. *Left side: Mean values of maximum water holding capacity measured in laboratory (lab-WHC), right side: field soil moisture, both measured in soil amended with algae fibre (AF) or poultry manure (GO) in May 2019. K0= control with no amendment. Treatments assigned by equal letter (a) were not significantly different ($p > 0.05$). Error bars n=4.*

3.3.4 Soil respiration rate

Even if both AF and GO treatments (from **Exp2019**) had higher mean values for soil respiration than the control (**figure 6**), the differences were not statistically significant. Soil respiration varied from 0.85 CO_2 ppm s^{-1} for the K0 to 1 CO_2 ppm s^{-1} in the AF treatment.

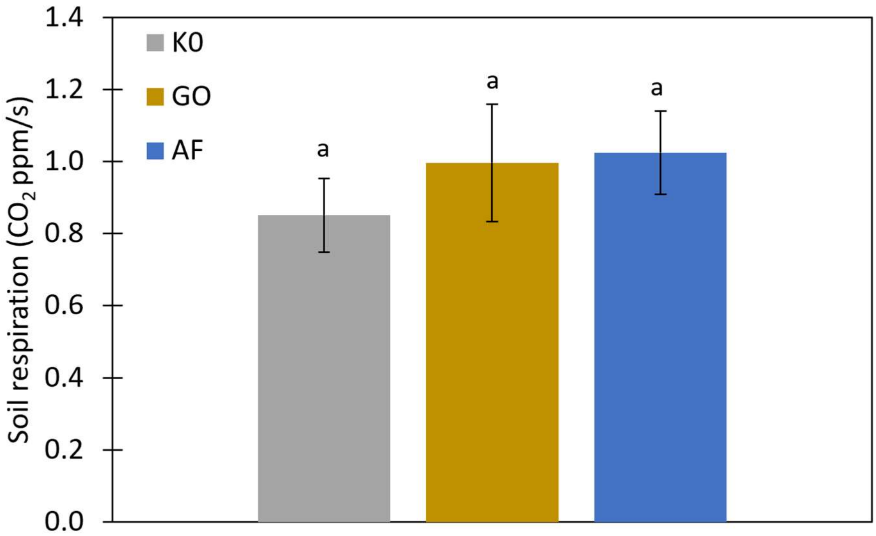

Figure 6*. Mean value of soil respiration in field on May 20, 2021 in treatments amended with algae fibre (AF) or poultry manure (GO) in May 2019. K0= control with no amendment. Treatments assigned by equal letter (a) were not significantly different (p > 0.05). Error bars n=4.*

3.3.5 Springtails

In **Exp2019**, the total average number of springtails in May 2021 was 43 130 in the AF treatment, 28 785 in GO and 19 000 in K0 (**figure 7**). In all treatments, there was a much higher number of pigmented than white springtails. The ratio white: pigmented was 34% in AF, 31% in GO and 23% in K0 plots. On average, AF plots had higher total number of springtails, more pigmented and more white springtails, followed by GO, and with lowest values for K0, but the differences were not statistically significant (p=0.330). One replicate plot of AF had extremely high values (90 060 individuals m^{-2}).

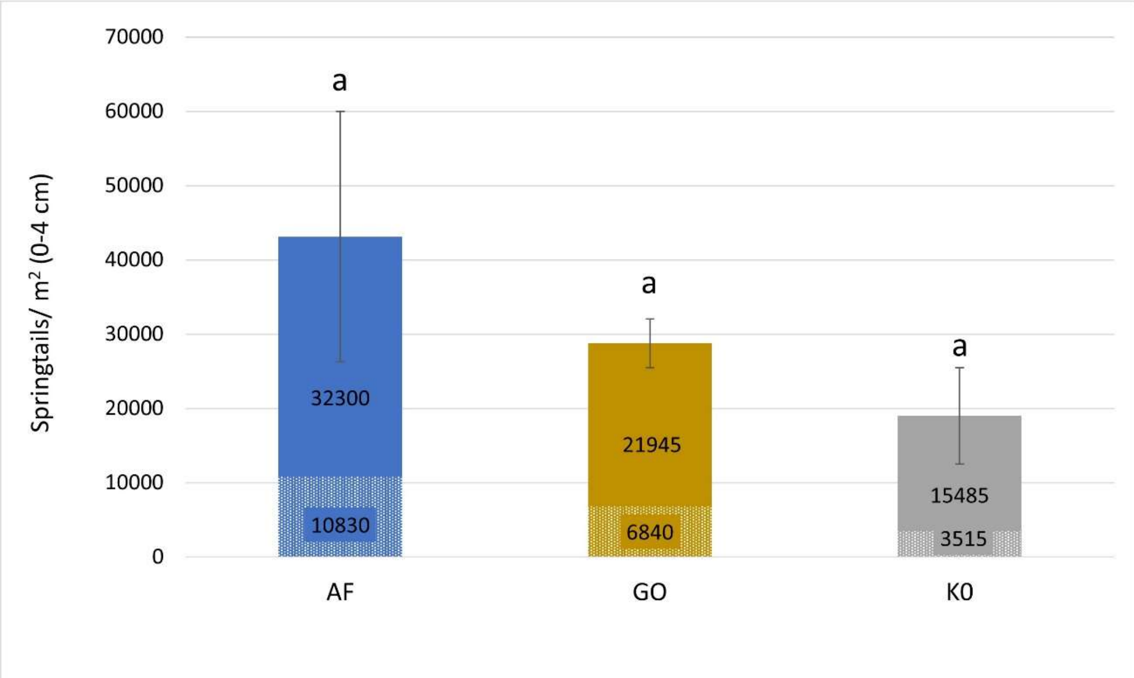

***Figure 7**. Numbers of pigmented (full colours) and white (shaded colours) springtails from treatments receiving algae fibre (AF) or poultry manure (GO) in May 2019, assessed on May 20, 2021 with soil depth 0-4 cm. K0 = control with no amendment. Standard errors of the total number of individuals are shown as bars. Treatments assigned by equal letter (a) were not significantly different (p > 0.05).*

The density of springtails (individuals per m^2) was comparable with a former study on the same field, conducted in 2012 to study effects of manure application. On average, 16 000 individuals m^{-2} were found in unmanured plots, and 42 000- 55 200 in plots receiving manure (Pommeresche et al. 2017). A positive effect on springtail density from application of organic materials (manure and crop residues) was also found by Kautz et al. (2006). Whereas the effect of AF and GO was not statistically significant here, the application of organic materials seems to have had a positive effect on the springtail density, but it is not clear if this effect is directly from the application of AF or GO, or indirectly because both materials increased the plant growth on the experimental plots.

Some springtail species are selective, feeding on either organic material, fungi or other microarthropods, while many species are omnivorous, feeding a wide spectrum of food items in their close vicinity (Ponge 2000; Jørgensen et al. 2003). Springtails also have differences in preference range and plasticity in their diet strategies (Krab et al. 2013; Ponge 2000; Jørgensen et al. 2003). When organic material applied to a soil is suitable, the springtail population will increase, which was seen here both for AF and GO. However, directly after the application of organic material, a negative effect may be found, as shown for digested and non-digested cow slurry by Pommeresche et al. (2017). It would be interesting to study short-term effects on springtails of application of AF in field, since the material has a high pH (**table 1**) and possibly also other characteristics which affects negatively on soil fauna in a short-term perspective, such as a high content of easily soluble cations and anions.

3.3.6 Bait consumption / decomposition test

In all treatments, the amount of bait in the lamina sticks decreased over time, indicating consumption (**figure 8**). The consumption was higher in AF and K0 than in GO on all dates of recording, and the differences between treatments became more evident with time. The p-values were p= 0.258 on Day 8, p= 0.085 on day 15, and p=0.021 on day 22. In AF and K0, about 30% of bait was consumed after 8 days, and about 50% after 22 days. In GO, 13% was consumed on day 8 and 31% on day 22. The pattern of difference between treatments was the same on each day of observation, which indicates that observations made between 1 and 3 weeks after placing the sticks in field will give the same relative difference between treatments.

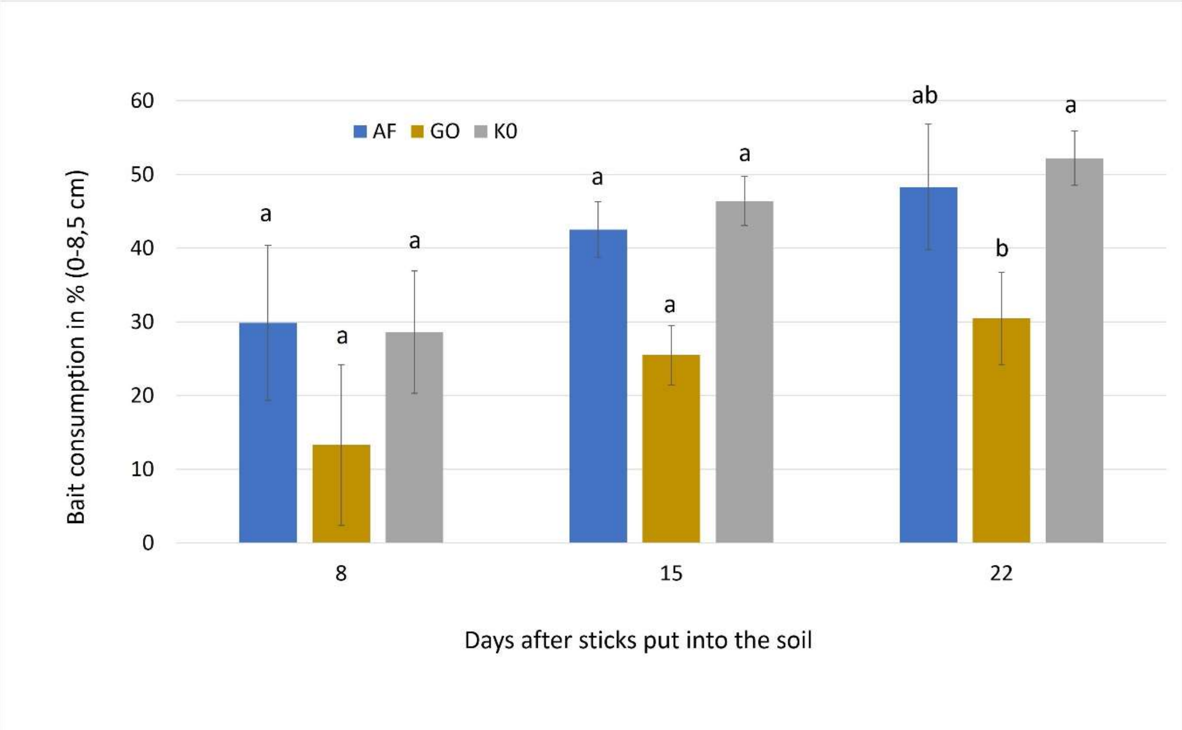

Figure 8. *Consumed amount of standardised organic material (bait) from bait lamina sticks recorded 8, 15 and 22 days after placement in soil on (grass-clover ley, Exp2019) on May 12, 2021. Treatments were compared which were amended with algae fibre (AF) or poultry manure (GO) in May 2019, with K0 as an unamended control. Treatments assigned by different letters (a, b) were significantly different on the respective date (p > 0.05). Standard errors are shown as bars. n = 20.*

The accumulated consumption per stick on day 22 was 65 % -85 % in the upper hole (1) about 1 cm below the soil surface. As shown in figure 9, the accumulated consumption, distributed along a soil depth of 8.5 cm, decreased with increasing soil depth in all treatments. At 8.5 cm depth, only 15-35% of the bait was consumed. The consumption was lower in GO in all soil depths except at 4.5 cm.

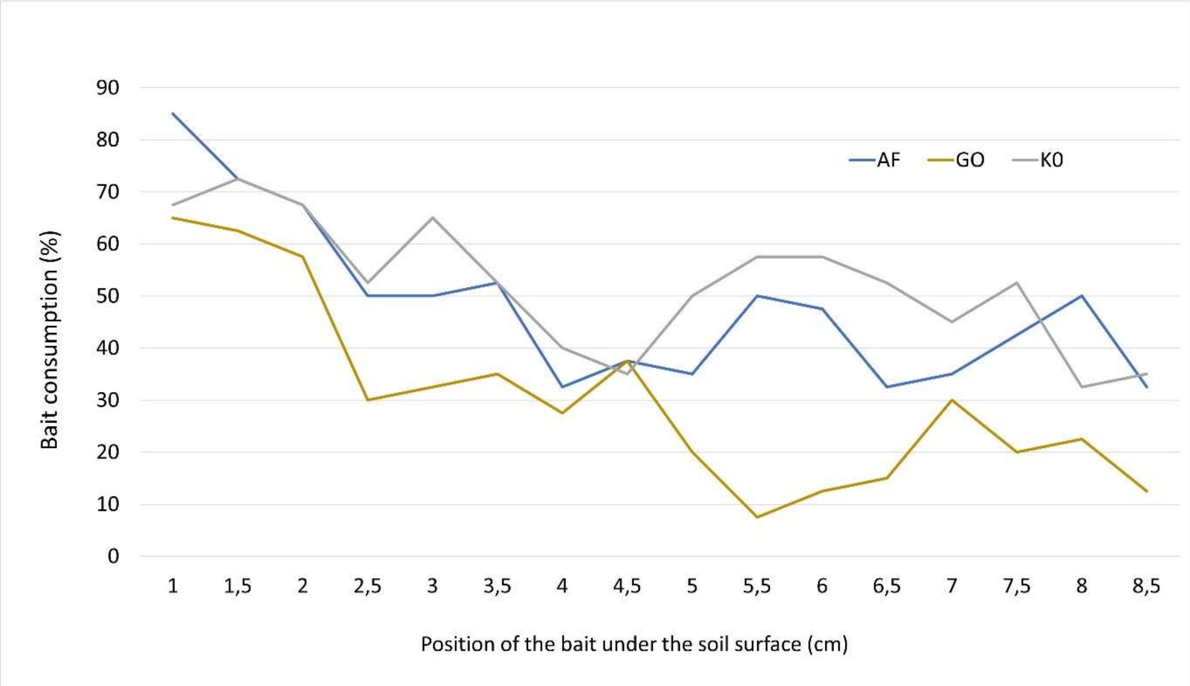

Figure 9. *Accumulated consumption of bait with increasing soil depth (1-8.5 cm) after 22 days in the soil (May 21-June 3, 2021), in treatments amended with algae fibre (AF) or poultry manure (GO) in May 2019. K0= unamended control.*

The consumption of bait at day 22 decreased linearly in all three treatments in the upper 4 cm of the soil, R^2= 0.7-0.9 (figure 10). Below this depth, the soil depth did not show any clear effect on the bait consumption, $R^2 < 0.1$.

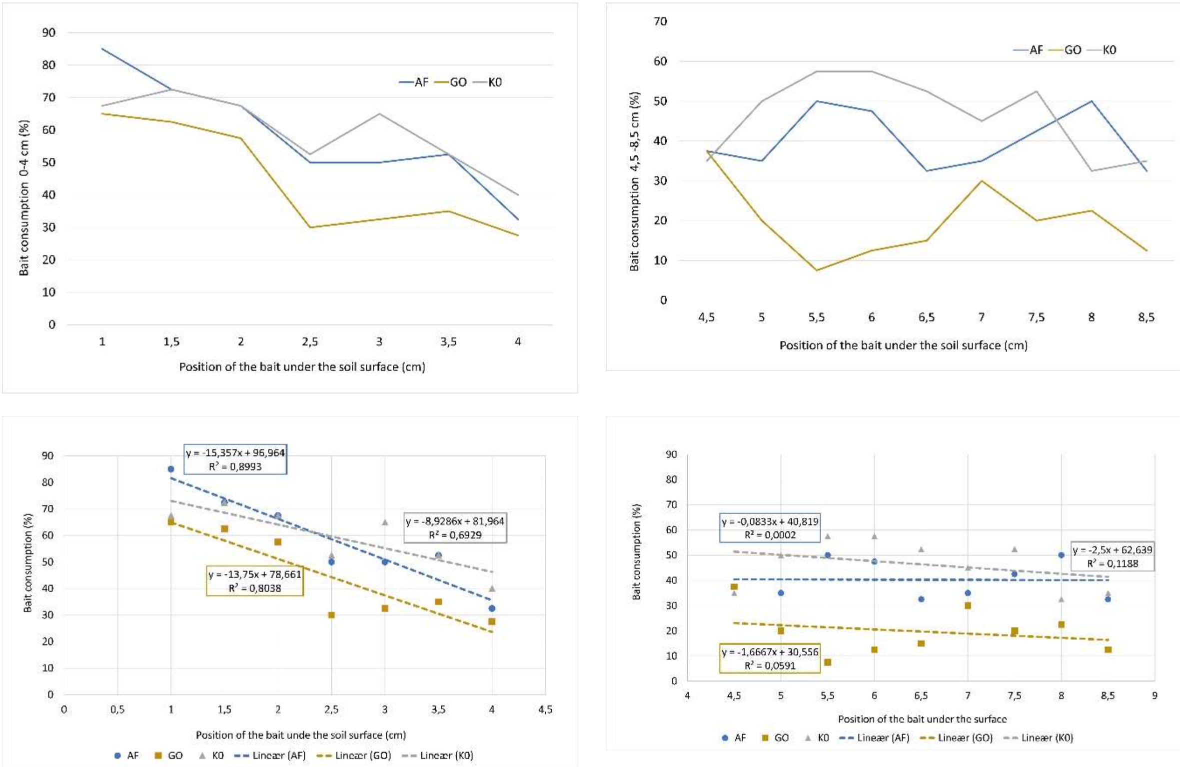

Figure 10. *Left side: Accumulated consumption of bait with increasing soil depth (1-4 cm). Right side: Accumulated consumption of bait with increasing soil depth (4.5-8.5 cm). Bottom line: regression lines for each figure. Treatments amended with algae fibre (AF) or poultry manure (GO) in May 2019. K0= unamended control.*

It was surprising that the accumulated removal of bait in K0 plots was higher than for AF and GO. One possible explanation may be that the soil fauna in K0 plots had less access to feeding materials and were very "hungry". The lower density of springtails in K0 also indicates less available feed for the soil fauna in this treatment. Alternatively, the soil fauna in AF and GO plots may have preferred to consume residues of organic materials applied in 2019 and the resulting increased amount of crop residues, rather than the bait.

3.4 Overall effects

All residual effects on soil characteristics of applying AF and GO to soil in 2019 are compiled and compared with the control treatment (K0) in **figure 11**. Differences between treatments (AF, GO and K0) were mostly not statistically significant, but addition of GO and AF increased the density of springtails and the soil respiration whereas active C in soil was reduced with AF. Addition of AF and GO increased the concentrations of some AL-extractable nutrients in the soil, and especially for K-AL, the increase was large in AF. AF also increased soil pH. The organic matter (LOI) was not significantly affected by the application of organic materials. Soil water content in field, and water holding capacity measured in lab were not affected by the treatments. Overall, AF increased the measured characteristics more than GO.

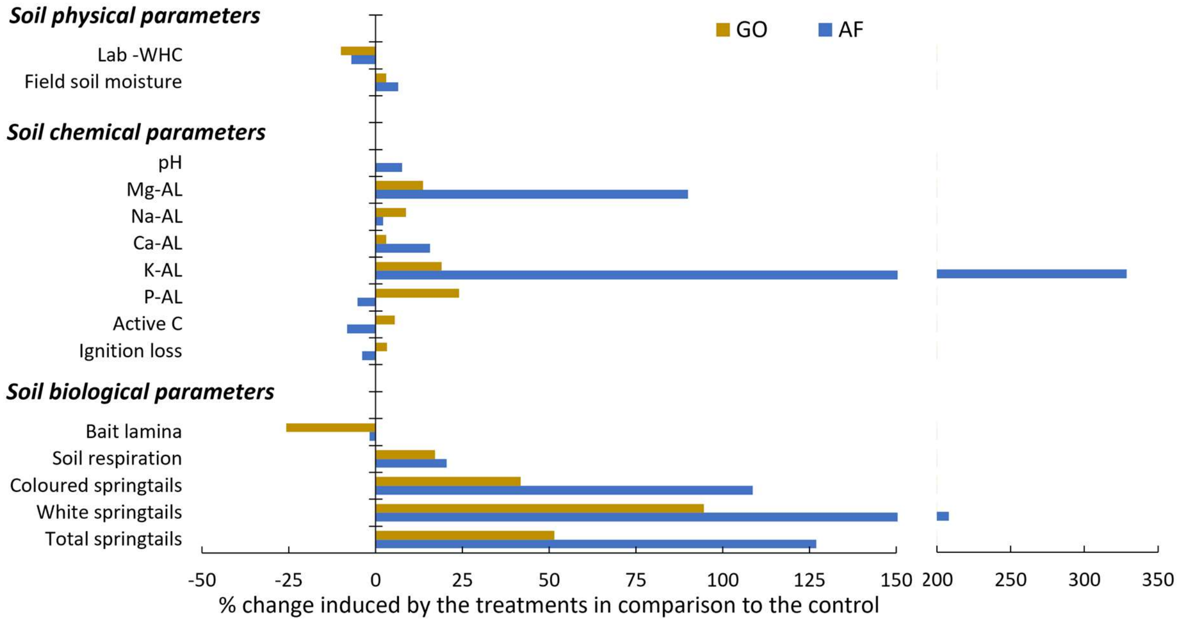

Figure 11. *Effects on all measured soil characteristics of application of algae fibre (AF) and poultry manure (GO) in May 2019, compared with the control treatment (K0), for samples taken in October 2020 (soil chemistry, lab-WHC) and in spring 2021 (field soil moisture, soil biology,).*

A cluster dendogram (figure 12) was applied to organise each individual plot, here numbered 1-12, according to their similarity. The cluster dendrogram nested the plots by degree of similarity, using the results of the characteristics which gave the best discrimination between treatments: soil respiration, bait lamina, field soil moisture, and active C. The diagram shows that, for example plots 1, 11, 4, 9 and 5 share more similarities among them (62-94%) than with the plots 2, 10, 6 , 7 and 12, and with the plots 3 and 8. It is interesting to see that the nested plots clustered into three main groups, which correspond to the treatments AF (2, 6, 7, 12), GO (1, 4, 9, 11) and K0 (plots 3, 8, 5, 10). Note that the plot numbers 1-12 in the cluster analysis differs from the plot numbers in the field. Thus, except for the plot 5, which as clustered as GO but actually was K0, and plot 10, which actually was K0 but was clustered as AF, the cluster analysis nested the plots in correspondence to the treatments. This shows that the treatments left an individual “ finger-print” in the soil. It is worth to mention that, although the plot 5 was not nested as K0, it had about 45% similarity with K0.

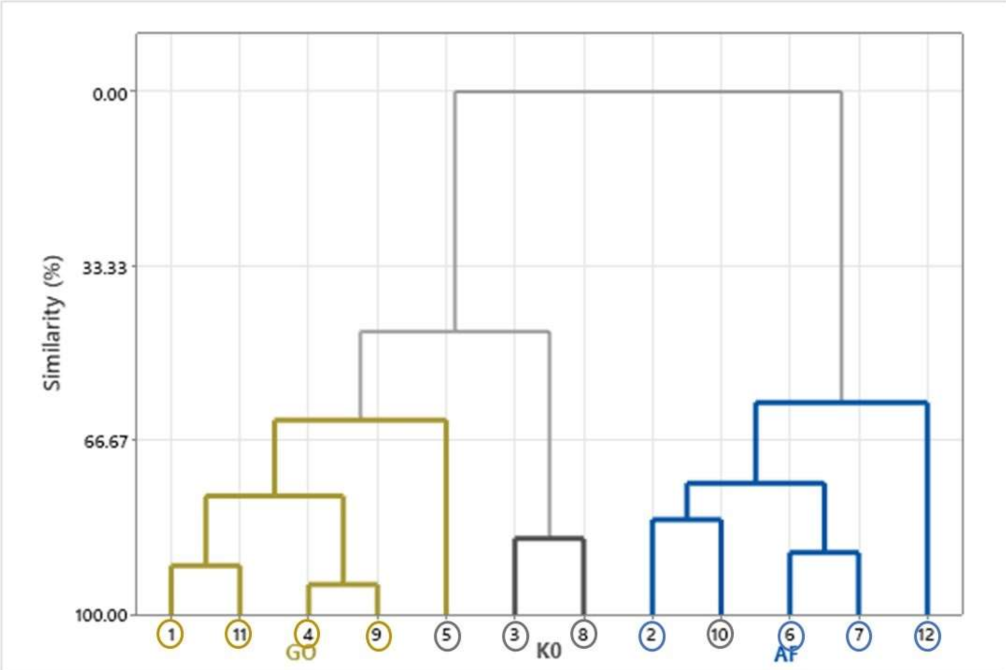

Figure 12. *Cluster diagram of individual plots (4 replicates plots per treatment) into three groups, corresponding to treatments receiving algae fibre (AF), poultry manure (GO) or no organic material (control, K0) in May 2019, based on results of soil respiration, bait lamina, field soil moisture and active C. The presented dendrogram shows a partition of 3 clusters with a similarity level of approximately 40%. Circles around the numbers indicate to which treatment the plots belong in the experiment.*

4 Minerals in potatoes and oats 2021 (WP2)

To study how addition of algae fibre to soil affected the content of minerals (Mg, Na, K) and potentially toxic elements (As, Cd) in potatoes and grass, a field experiment was conducted in 2021 on the **Exp2020** plots which had been used for ryegrass and amended with different organic materials in 2020, as described in Chapter 2. The residual yield effects of AF applied in former years was observed in 2021, also in the Exp2019 plots, which had a 2nd year grass-clover ley in 2021. In 2021, the yields in Exp2019 were generally higher, and the AF treatment had a much higher residual effect than GO. On average, 5 tons of DM per hectare was produced in K0, 9.1 in GO and 16.3 in AF, as a sum of two cuts.

4.1 Field experiment with potatoes and oats in 2021

Soil tillage was conducted twice to reduce weeds, especially annual meadow gras (*Poa annua* L.), on May 5 and 11 by a manual rotavator along the plots, to avoid transfer of soils from one plot to another. Care had to be taken since plots were only 1.5 m wide. The area between each block, being 2 m wide, was left without tillage (**photo 10**). Rows for potatoes were established with a small tractor on May 14, 2021. With a row distance of 75 cm and a plot size of 1.5 m x 8 m, each potato plot contained one central row and two rows which were shared with the neighbour plot (**photo 10**). The medium 6 m of each central row was used for recording canopy colour, yields, germination and mineral composition. The distance between each seed potato was 40 cm, and potatoes (cv. Solist) were planted by hand on May 14, 2021. The potatoes were quite large, which explains a large planting distance.

Photo 10. *Left side: Rows of potatoes ready for planting on May 14, 2021, in experimental plots where algae fibre and other fertilisers were applied in 2020. Right side: Potato rows on May 28, after flattening the row tops. In the background: germination in the plots with oats, where seeds were planted on May 14, 2021. Photo: Maud Grøtta, Landbruk Nordvest*.

A basic fertilisation of each experimental plot was carried out by application of dry poultry manure "Grønn Øko" 8-3-5 corresponding to 120 kg N ha^{-1}. The fertiliser was distributed by spreading an equal amount of fertiliser to each experimental plot by hand. It was incorporated by the making of potato rows or by the planting of oats seeds. Seeds of oats were planted by an Øyjord plot seeder, walking type.

The top of the rows were flattened by a rake held upside down on May 28, 2021 (**photo 10).** The number of plants per harvest plot was recorded on the harvesting date of potatoes on August 30, 2021. In all harvest plots, all potatoes had germinated (n= 15 per harvest plot).

The vigour of the potato canopy was recorded by visual assessment by Frode Grønmyr on August 12, 2021. Each harvest plot was assigned a value between 0 and 100% in 10% intervals, where the number indicated how much of the canopy was green. At this date, late blight had started to infest the field (**photo 11**), and low values were related to attack of this fungal disease.

Potato yields were measured on August 30, 2021 by lifting each plant in the harvest plot by hand after manual loosening of the soil, picking the potatoes and weighing them and computing the yield per m^2. For one block where the growth was generally satisfactory, the size distribution was recorded. Dry matter contents were determined in one sample per treatment only.

In the plots of oats, the middle 1.2 m x about 7 m (length recorded) was harvested by a mower (same equipment as used for harvesting experimental plots of ryegrass and ley) when the canopy had reached the maximum dry matter yield, on August 4, 2021. The fresh and dry weight of the canopy on each plot was recorded, and the mineral composition of the canopy.

Chemical analysis of oat canopy and potato tubers was carried out by SINTEF Norlab, Namsos, Norway. Before chemical analysis the potato tubers were thoroughly cleaned by hand washing and cut to pieces, without removing the potato peel, before drying. Oat canopy was dried and cut to small pieces. In the laboratory, the plant material was homogenised before chemical digestion by a nitric acid/hydrogen peroxide solution at 120 °C for 30 min to bring ions into aquatic solution, followed by a quantitative assessment of concentrations of a range of elements by inductive coupled plasmatic mass spectroscopy (ICP-MS; Agilent ICP-MS 7900).

For assessing is differences between treatments were statistically significant, variance analysis with a general linear model was applied, with treatment as the fixed factor, using Minitab software.

4.2 Results

Despite a quite dry summer in 2021 and a significant occurrence of weeds especially annual meadow grass and coach grass (*Elytria repens* L.), the potatoes grew generally well. The canopy was affected by late blight at harvest (**photo 11**), but potatoes were not affected and could be utilised for food throughout the winter. The canopy seemed to be more heavily infected with late blight where high loads of fishbones had been applied in 2020 (**photo 11**).

Photo 11. *Potato canopy on August 9, 2021 in a plot where algae fibre (AF) or fishbones (FB) were applied in 2020, seemingly affecting the incidence of late blight, causing more wilting of the canopy after fishbones (brown colour). Photo: Anne-Kristin Løes, NORSØK.*

Plots where AF was applied in 2020 performed quite well and yielded on average better than plots amended with poultry manure in 2020 (**table 5**), even if the difference between GO and AF treatments was not statistically significant (**table 5**). A positive effect of algae fibre on potatoes was also observed by Riley (2000), along with a significant residual effect in ryegrass the subsequent year. From observations in the field (**photo 11**), we expected that the application of AF decreased the incidence of late blight disease, since the average amount of fresh canopy was highest in this treatment (**table 5**). The differences were nearly statistically significant (p=0.065). The assessment was carried out somewhat late, and it is well possible that a recording some days earlier had given a more certain result.

The proportion of potatoes of appropriate size for sale (40-60 mm diameter) was lower for AF than for GO (**table 5**). Further, the proportion of high-quality potatoes (with no disease or other quality issues) was lower in AF and K0 than in GO, and the dry matter content (DM%) was highest in GO. The major reasons for potatoes being sorted out for quality issues were scurf and green colour.

Table 5. Yields, quality characteristics and concentrations of minerals (g kg^{-1} DM for K, Mg) and PTEs (µg kg^{-1} DM for As, Cd) in potatoes produced in 2021, in plots receiving dried poultry manure (GO), algae fibre (AF) or no organic amendment (control, K0) in 2020. For each characteristic where all experimental blocks were assessed, treatments assigned by different letters (a, b) are significantly different ($p < 0.05$)

Treat-ment	Fresh canopy, %	Tuber FW, tons ha^{-1}	40-60 mm, %	Saleable quality, %	DM, %	K	Mg	As	Cd
K0	70 a	29.5 a	67	74	21.1	15 b	0.8 b	16 a	44 a
GO	57 a	41.6 b	74	81	24.4	14 b	0.8 b	15 a	42 a
AF	77 a	46.6 b	64	74	20.0	22 a	1.2 a	15 a	37 a

For most elements, there was no statistically valid differences between the treatments for concentrations in potato tubers. The mineral composition differed significantly between treatments only for potassium (K) and magnesium (Mg; **table 5**). Application of AF clearly increased the concentration of K and Mg in the potatoes, but not the concentration of sodium (Na), which was 0.9 g kg^{-1} DM in K0 and 1.3 g in GO and AF. For potentially toxic elements (PTEs), the average concentration of arsenic (As) did not differ between treatments, when 10 samples (out of 27) which had a concentration lower than the detection limit of 10 µg As kg^{-1} DM were set equal to the detection limit. In other treatments (not referred here), the concentrations of As varied between 14 and 23 µg kg^{-1} DM, and there was no relationship between application of algae fibre to the soil in 2020 and concentrations of As in potatoes in 2021 (**figure 13**; r^2= 0.017). In China, the maximum accepted value of As in fresh vegetables is 0.5 mg kg^{-1} (fresh weight) (USDA 2018). The values obtained in the current study are well below this threshold. Also for cadmium, no statistically significant differences were found between the treatments. Hence, even if AF increased the concentrations of As and Cd in the soil in Exp2020 (**table 4; table 6**), this did not cause increased concentration of these elements in the potato tubers.

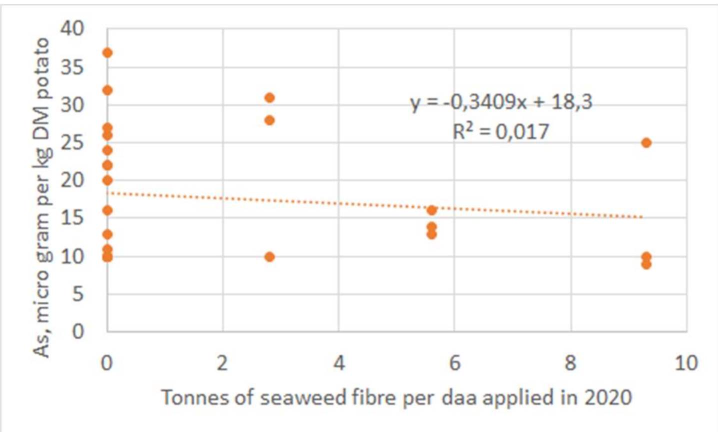

Figure 13. Relationship between concentration of arsenic (As) in potato tubers grown in 2021, and amount of algae fibre (AF) applied to experimental soil in 2020.

Table 6. Mean values of soil pH, AL-extractable nutrients (mg kg^{-1} air-dry soil), loss on ignition (LOI, % of DM) and concentrations of potentially toxic elements (mg kg^{-1} soil DM) in the treatments in field experiment established in 2020 (**Exp2020**) before planting oats and potatoes, sampled in October 2020. Treatments assigned by different letters (a, b) are statistically significantly different (p<0.05)

Soil	Oats (n=1)			Potato (n=3)						
parameters	K0	GO	AF	K0		GO		AF		p-value
pH	5.4	5.4	7.0	**5.5**	**b**	**5.5**	**b**	**7.2**	**a**	**0.000**
P-AL	36.0	40.0	28.0	23.0	a	30.0	a	20.7	a	0.147
Mg-AL	**40.0**	**33.0**	**170.0**	**37.0**	**b**	**26.7**	**b**	**176.7**	**a**	**0.000**
K-AL	130.0	110.0	300.0	**63.7**	**b**	**65.7**	**b**	**246.7**	**a**	**0.004**
Ca-AL	260.0	240.0	510.0	**266.7**	**b**	**226.7**	**b**	**546.7**	**a**	**0.000**
Na-AL	300.0	340.0	910.0	**340.0**	**b**	**263.3**	**b**	**676.7**	**a**	**0.000**
LOI	18.0	16.0	15.0	9.8	a	10.3	a	10.7	a	0.392
Pb	4.0	4.2	4.4	7.8	a	7.3	a	6.5	a	0.904
Cd	0.06	0.06	0.07	**0.04**	**b**	**0.03**	**b**	**0.07**	a	**0.005**
Cu	7.3	8.0	6.9	7.2	a	27.1	a	7.5	a	0.492
Cr	11.0	13.0	13.0	14.7	a	12.3	a	15.3	a	0.343
Hg	0.7	0.7	0.7	0.7	-	0.7	-	0.7	-	-
Ni	6.9	8.1	8.1	8.6	a	9.0	a	9.8	a	0.871
Zn	76.0	31.0	29.0	33.3	a	29.7	a	35.3	a	0.580
As	0.65	0.72	1.3	**0.7**	**B**	**0.7**	**b**	**1.3**	**a**	**0.002**
As-AL	0.07	0.07	0.14	**0.06**	**B**	**0.06**	**b**	**0.12**	**a**	**0.009**

The yields of oats were only measured in one replicate plot per treatment. The content of DM was somewhat higher in GO and AF than in K0; 27 vs. 25%. DM yield was lowest in K0 with 6.25 tons ha^{-1} followed by 6.60 in AF and 7.04 in GO (**table 7**). Hence, the large and positive residual effect of AF and GO applied in 2020 which we found in potato tubers, was not found when oats were grown. Since this is a result with no replicate observations it must be assessed with care. However, the result fits well to the observation made in the 2019-season of the Exp2019, when the test crop was oats which was also harvested while green. The oats could well demonstrate the effect of easily available nutrients in that season, producing 3.8 tons of DM ha^{-1} with 160 kg N ha^{-1} applied in GO (and 4.8 tons with the same amount of N applied as fishbones), compared with 2.5 tons where AF was applied as fertiliser, and 2.7 tons in the unfertilised K0 treatment. The poultry manure applied in 2021 to ensure satisfactory growth in all experimental plots, with an amount of 120 kg N ha^{-1}, may have levelled out the possible residual effect of fertilisers applied in 2020 for oats which has a much shorter period of nutrient uptake than the potatoes, which were harvested 26 days later.

The mineral composition of oats could not be analysed statistically since only one sample per treatment was analysed, but values per treatment for K, Mg, Na, As and Cd are referred in **table 7**. The concentration of sodium and arsenic seemed to be higher in AF, whereas the concentration of cadmium was lower.

Table 7. Yields and concentrations of minerals (g kg^{-1} DM for K, Mg, Na) and PTEs (µg kg^{-1} DM for As, Cd) in greenfodder of oats produced in 2021, in plots receiving dried poultry manure (GO), algae fibre (AF) or no organic amendment (control, K0) in 2020.

Treatment	Yield, ton DM ha^{-1}	K	Mg	Na	As	Cd
K0	6.25	21	1.4	0.6	3	49
GO	7.04	18	1.1	0.6	7	47
AF	6.60	19	1.3	2.6	50	18

5 Effects on black scurf? (WP3)

We performed a germination test to study the effect of algae fibre (AF) in the reduction of the severity of potato disease caused by black scurf fungi in the soil. To do so, we collected soil from an arable field in Sunndal with a historical problem of infestation of black scurf (*Rhizoctonia solani)*. The soil was dried in room temperature, sieved (2 mm) and mixed with two quantities of crushed, dried and sieved AF: 5 or 20% by volume of the soil-AF mixture was AF. A control without any addition of AF was also included. The study was conducted in triplicate, comprising 9 pots with one seed potato per pot. The replicates of each treatment were put together in a plastic tray as one experimental unit. After mixing the soil with AF, soils were kept at room temperature with 60% water content for one week, to allow the soil microfauna to adapt to the addition of organic material. After this period, soil with and without AF was put in 1.5 l flowerpots, and one seed potato cultivar Folva was placed in each pot on June 29, 2021. The potato pots were kept outside under a roof to provide natural light conditions, and water was regularly applied. After 56 days, the trial was terminated, and the development of the seed potatoes assessed.

Black scurf may hamper the germination of seed potatoes, and in the control treatment, only one seed potato germinated successfully, whereas one had started to germinate, and one was rotten (figure 14). This confirms the results from a former NORSØK-study, where soil from the same sampling site in Sunndal showed a strong ability to hamper the germination of potatoes (Rittl et al. 2021). Whereas all planted potatoes germinated in a test soil where no black scurf was expected to be found, only 5 out of 24 potatoes germinated in the Sunndal site test soil in that study.

We did not observe any improved germination with addition of AF. In the treatment with 5% and 20% AF, none of the seed potatoes germinated. Some, but not all potatoes decayed in these treatments (**figure 14**). In both treatments, a crust had formed on the soil surface. Even if this crust was easily breakable, it may have hampered the germination e.g., by reducing the gas exchange.

We also incubated small amounts of soil with the same volumes of AF as in the germination study, to study how freshly applied algae fibre affected the soil respiration. For that, about 75 g of sieved soil or soil amended 5 and 20% of AF were added in a 250 ml bottle. The moisture of treatments was adjusted to 60% field capacity and maintained at that level throughout the experiment by weighing the bottles and adding water if necessary. Bottles were incubated at room temperature about 20°C. All treatments were replicated three times (n=3). CO_2 measurements were performing using Pasco sensor (see chapter 2). Measuring dates were June 8, June 14 and August 18, 2021. Analysis of variance was applied to check if the treatments significantly affected the CO_2 respiration on each date of measurement. Statistically significant treatment effects were detected using Tukey t-test, with level of significance at $P < 0.05$.

Figure 14. *Seed potatoes photographed 56 days after being placed in soil infected with black scurf, with or without alga fibre (AF) mixed into the soil.*

With AF, soil respiration increased compared with the control, suggesting a significant increase in soil microbial activity (**figure 15**). In the second measurement, soil respiration of the treatment with 20% AF was more than 3 times higher than AF 5% and 48 times higher than the control (soil only). The respiration dropped significantly until the third measurement, when the soil respiration was below 1 CO_2 ppm s^{-1} for all treatments, but still significantly higher with the highest application of AF.

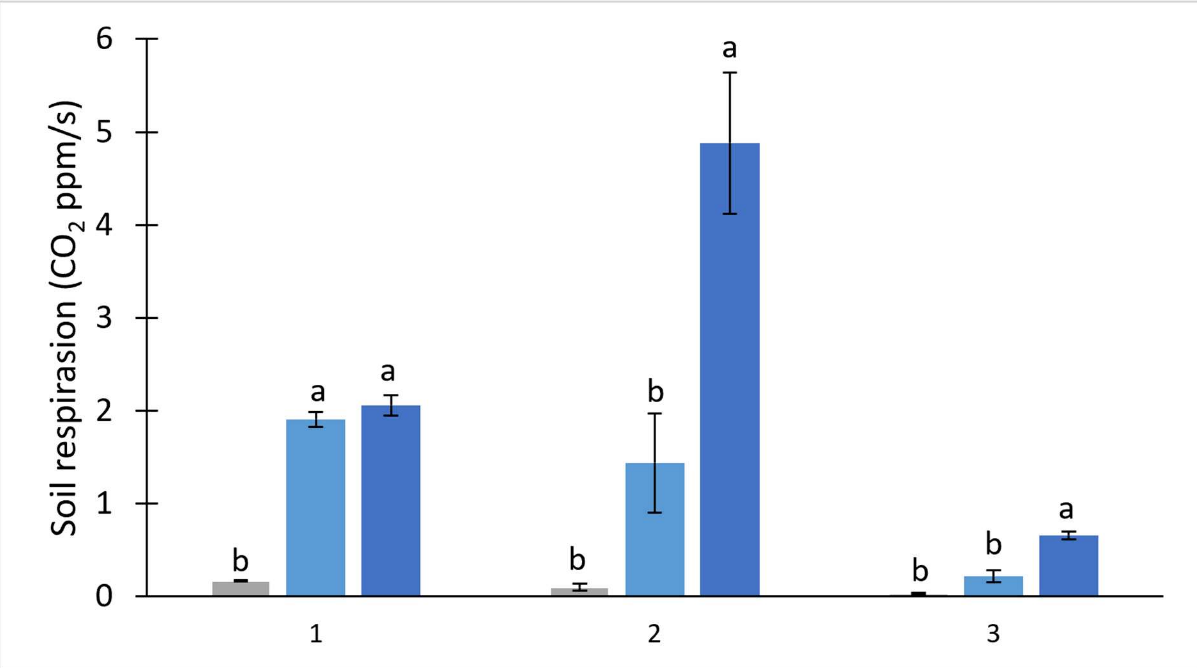

Figure 15. *Soil respiration measured three times during two months for soil mixed with 0, 5 or 20% (by volume) of algae fibre, AF. For each date, treatments assigned with different letters (a, b) are statistically significantly different (P < 0.05). Standard errors are shown as bars. n=4.*

The test soil was collected in an area with high incidence of black scurf, which is a significant challenge in potato production in the region of Sunndal. By adding organic material to the soil, we expected to support the soil microflora/fauna, and possibly suppress, through processes such as competitive exclusion and/or predation, the fungus causing black scurf. Although, we observed a significant increase in soil microbial activity (soil respiration), we did not observe any effect on potato germination. Conditions were poor for germination in these treatments, because of the crust which was formed in both treatments with AF. With a field bulk density of soil being 1.3 kg/litre, and of dry, sieved AF being 0.68 kg/litre (analysed by Eurofins), addition of 5% of AF by volume to the topsoil (0-20 cm) would imply an addition of 68 tons of DM of AF per hectare, which is an extremely high amount of application, which would never occur in practice.

6 Safe application of algae fibre for soil amendment (WP 4)

The final specific objective of the FIMO-project was to propose a strategy for safe application of algae fibre based on the content of minerals, especially sodium (Na), potassium (K), arsenic (As) and cadmium (Cd) in soil and algae fibre. In work package 4, this objective has been reached by mapping the concentrations of potentially toxic elements (PTEs) such as As and Cd, and the content of organic material, Na and K in soil from 10 potato growers in Sunndal. Based on the mineral content in the soil, in the algae fibre and national threshold values for various PTEs, we have assessed which amounts of algae fibre may be relevant to apply to soil used for potato cultivation in Sunndal, and with what frequency.

6.1 Soil samples and analysis

In Sunndal municipality, along the highway RV 70 between Sunndalsøra and Gjøra, soil samples were taken by Landbruk Nordvest on October 28, 2020, from representative fields of 10 farms where potatoes are regularly grown (**figure 16**). The locations were, Furu, Furu Øyan, Hol, Einhaugen, Nerskeiet, Leangen, Løykja, Grøa, Torske and Fahle. One composite soil sample with 20 subsamples were taken from each field, along a diagonal across the field with a sampling depth of 20 cm. Subsamples for each field were thoroughly mixed in a bucket, and sward lumps, plant residues and rocks were removed before the soil was filled into sampling boxes of 0.5 litre. The samples were sent in parallel to Eurofins, Germany and to SINTEF Norlab, Namsos, Norway for analyses of loss on ignition (LOI) (bot labs), pH (both labs), AL-extractable nutrients (Eurofins) and concentrations of elements comprising plant nutrients, plant structural elements and PTEs (SINTEF Norlab).

Soil loss on ignition is a measure of the soil's content of organic matter and is measured as the weight loss of air-dry soil in % after ignition at 550 °C for four hours. Soil pH was measured after application of deionised water (v : v 1 : 2.5). Al-extractable nutrients are extracted by ammonium lactate-acetate (AL) solution. The AL-method (Egner et al. 1960) is the standard method in Norway to assess the plant availability of P, K, Ca, Mg and Na (Krogstad 1992). Air-dry, sieved soil (2 mm) is extracted by a mixture of 0.1 M ammonium lactate and 0.4 M acetic acid (pH 3.75), and the concentrations of ions in the extract are measured after filtration by Inductive Coupled Plasma Mass Spectroscopy (ICP-MS).

Total concentrations of elements were measured by ICP-MS after chemical digestion of the soil samples by a nitric acid/hydrogen peroxide solution at 120 °C for 30 minutes to bring ions into aquatic solution, followed by a quantitative assessment of concentrations of elements by Agilent ICP-MS 7900.

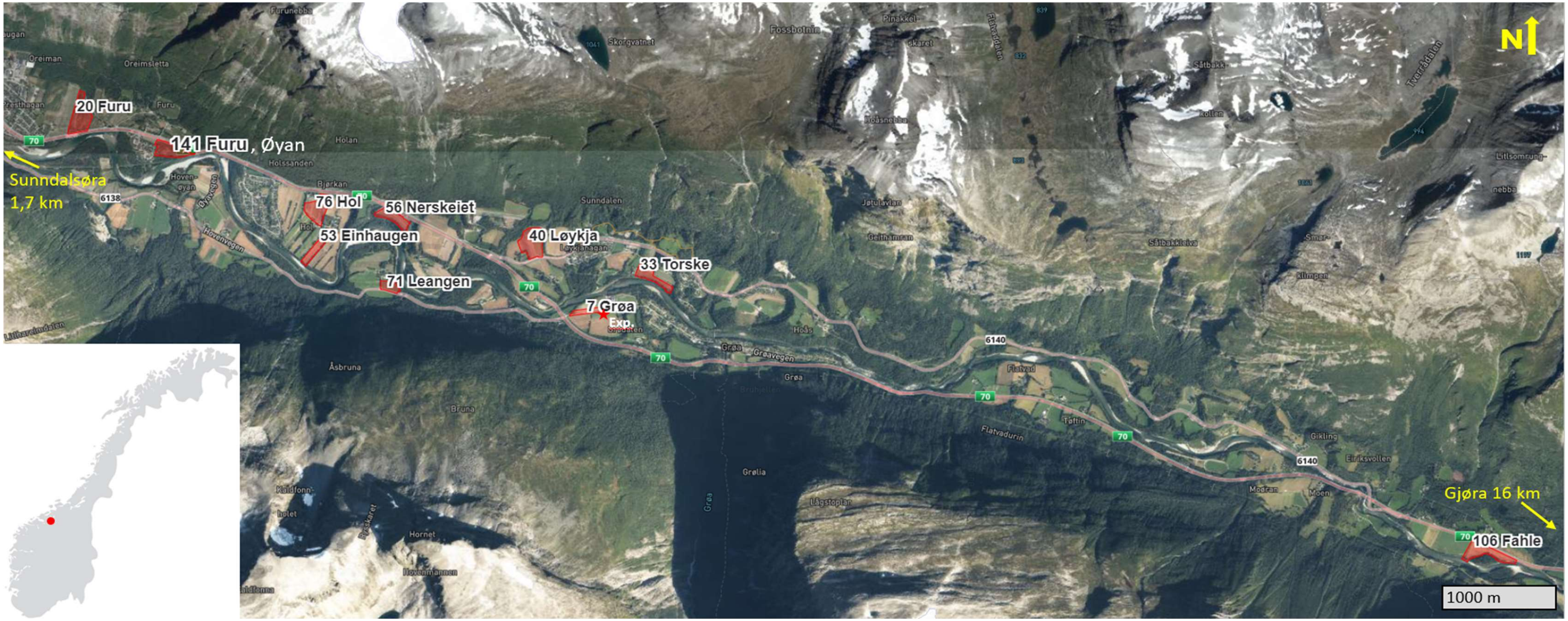

Figure 16. *Satellite image of Sunndal municipality between Sunndalsøra (left) and Gjøra (right), with sampled potato fields marked in red.*

6.2 Regulations and threshold levels for soil and soil amendments

Organic waste such as algae fibre must meet some quality requirements defined in Norwegian regulations, to be applied as fertilisers. Organic waste must be safe to use both in terms of the environment and health. The use of organic waste as fertilisers or soil amendments in Norway is therefore regulated in the national regulation on fertilisers etc. of organic origin (LMD et al. 2021). According to this regulation, the content of heavy metals (PTEs) must be limited in materials applied for soil amendment, and materials are classified in quality classes 0-III based on the concentration of PTEs (**table 8**). In 2018, a quite strict limit for arsenic (As) was proposed to be included in the national regulation for fertilisers etc. of organic origin, and we have referred this proposal in **table 8**.
A basic request for any application of materials from class I or II to soil, is that concentrations of PTEs must be below threshold levels defined in the national regulation on fertilisers etc. og organic origin, referred in **table 8**. These threshold levels are well below threshold levels set for soil in the national regulation for pollution (KMD 2022; **table 9**).

Table 8. *Limits of concentrations of potentially toxic elements (heavy metals, mg kg^{-1} DM) currently allowed in soil conditioners and organic fertilisers in Norway (LMD et al. 2021), and limits for arsenic (As) proposed by Norwegian Agriculture Agency 2018.*

Quality classes:	***0***	***I***	***II***	***III***
Cadmium (Cd)	0.4	0.8	2	5
Lead (Pb)	40	60	80	200
Mercury (Hg)	0.2	0.6	3	5
Nickel (Ni)	20	30	50	80
Zinc (Zn)	150	400	800	1500
Copper (Cu)	50	150	650	1000
Chromium (Cr)	50	60	100	150
Arsenic (As)	*5*	*8*	*16*	*32*

Organic waste in quality class 0 may be applied according to crop demand on all types of land. Organic waste in class I and II may be used in amounts up to respectively 40 and 20 tons of DW per hectare of agricultural land over a period of 10 years. Alternatively, such materials may be applied to land not used for growing food or feed crops in a layer of up to 5 cm thickness, and then incorporated in the soil. Organic waste in class III cannot be used as a soil amendment or fertiliser on agricultural land but may be applied to land not used for growing of food or feed crops in a layer of maximum 5 cm thickness, and incorporated in the soil, once per 10 years. Class III materials may also be applied as a top layer up to 15 cm to cover waste deposits.

6.3 Categorising algae fibre as soil amendment

Concentrations of nutrients and PTEs, and some other characteristics of algae fibre are referred in **table 8**, with analytical values provided by former projects at NORSØK (RESTOR and Organic-PLUS). Analyses were carried out by Eurofins, Germany or SINTEF Norlab. Concentrations of total N were determined as Kjeldahl-N, and total C by combustion. Assessed by the values in **table 8**, algae fibre is categorised as a class 0 material for all PTEs except cadmium (Cd, **table 8**), for which it comes in class II, with an average value of 1 mg Cd kg^{-1} DM and a range of variation from 0.9 to 1.1. If the proposed Norwegian threshold levels for As had been accepted, algae fibre would have been categorised as a class III material, and with a risk of being sometimes above the limit since the range over 5 analyses was 27-33 (**table 9**). The proposal, if accepted, would significantly hamper the application of seaweed materials on agricultural soil. Recent information from the Norwegian Food Safety Authority (NFSA) indicates that the limits of As in organic materials to be applied as soil conditioners and organic fertilisers in Norway will follow the EU regulations on fertilisers (EC 2019) from July 2022 (Compaore, pers. communication). Marketing of products may also follow EU regulations instead of Norwegian regulations, if wanted by the producer/distributor. In the EU-regulation (2019), the maximum value of inorganic As in fertilisers, organic fertilisers, inorganic soil improvers and growing medium is 40 mg kg^{-1} DM. This threshold needs to be observed by producers of seaweed products for soil amendment, since brown algae may have concentrations well above this value. Up to 107 mg total As kg^{-1} DM was found in a sample of oarweed (*Laminaria digitata*; Taylor & Jackson 2016).

Table 9 also includes norm values for soil in Norway defined by the two national regulations, one being on *fertilisers* etc. of organic origin (LMD et al. 2021), and the other on *pollution* (KMD 2022). The pollution regulation implies that above these limits, soil will be considered as polluted, and hence should not be exceeded. Below the limits, the risk for affecting negatively on (human) health or environment is considered as acceptably low (Norwegian Environment Agency 2017). The values defined in the regulation on fertilisers etc. are norm values for soil quality. Especially for Cd, the difference between the two regulations is significant.

Table 9. *Nutrient concentrations and other characteristics of algae fibre produced by extraction of bladderwrack (Ascophyllum nodosum) at Algea AS, Kristiansund, Norway. For sodium (Na), only ammonium acetate-lactate soluble concentrations were available. For analytical values of Ni, Pb and Hg, values which were below limit of detection (1 for Ni, 4 for Pb, 1 for Hg) were set equal to the level of detection to compute an average value. FM= fresh material, DM = dry matter.*

Charact.	Units	Mean value	Range	n	Class	Limits set in Norwegian regulations on pollution, mg/kg soil DM	Limits set in Norwegian regulations on fertilisers etc. of organic origin, mg/kg soil DM
pH		9.1	-	-	-	-	-
DM	(%)	25.5	(22.6-29.4)	4	-	-	-
N_{total}	(g kg^{-1} FM)	3.6	(2.9-4.8)	4	-	-	-
NH_4^+-N	(g kg^{-1} FM)	0.0098	(0.001-0.005)	3	-	-	-
C	(% DM)	31.7	(31.0-32.3)	6	-	-	-
N	(% DM)	1.41	(1.21-1.80)	6	-	-	-
C:N		23	(17-26)	6	-	-	-
P	(g kg^{-1} DM)	2.78	(2.3-3.6)	6	-	-	-
K	(g kg^{-1} DM)	91.8	(74-130)	4	-	-	-
S	(g kg^{-1} DM)	11.5	(8.7-15)	5	-	-	-
Ca	(g kg^{-1} DM)	54.3	(48-68)	4	-	-	-
Mg	(g kg^{-1} DM)	14.8	(11-25)	4	-	-	-
Na-AL	(g kg^{-1} DM)	23	(13-52)	4	-	-	-
Cl	(mg kg^{-1} DM)	13	(10-16)	4	-	-	-
Zn	(mg kg^{-1} DM)	95	(82-110)	5	0	200	150
As	(mg kg^{-1} DM)	28	(27-33)	5	-	8	-
Cd	(mg kg^{-1} DM)	1	(0.9-1.1)	5	II	1.5	1
Cr	(mg kg^{-1} DM)	6	(3.8-9.2)	5	0	50 (total Cr III) 2 (Cr IV)	100
Cu	(mg kg^{-1} DM)	11	(4-34)	5	0	100	50
Ni	(mg kg^{-1} DM)	4.4	(1.5-10)	5	0	60	30
Pb	(mg kg^{-1} DM)	1.4	(0.3-4)	5	0	60 (inorganic)	50
Hg	(mg kg^{-1} DM)	0.044	(0.02-0.8)	5	0	1	1

6.4 Soil bulk density to compute effects of application of algae fibre in field

To calculate the amount of algae fibre which may be applied per hectare, and how such application may affect on soil concentrations of PTEs, we need a reliable value of the field bulk density of soil. Then, we can compute the weight of soil per hectare to a certain level of depth, and assess how a certain amount of application in tons per hectare will affect on soil concentrations of PTEs and minerals.

Riley (1996) calculated the dry field bulk density for typical soil types in South-East Norway, and we have referred them in **table 10**. From this table, we applied a value of 1.36 kg litre^{-1} representing silty sand with 2.5 % organic matter, which is typical for potato fields in Sunndal (table 9). This is somewhat above the values measured in the laboratory (**table 11**), where sieved, air-dry soil was applied to measure the density (volume weight).

Table 10. *Calculated values of dry bulk density for typical soil types of SE Norway, from the relationship with soil organic matter (SOM), depth, gravel content and textural composition, and corresponding data for the relative degree of compactness (in brackets). From Riley, 1996.*

Soil type	Texture			Depth	15 cm	15 cm	45 cm	75 cm
	Sand	Silt	Clay	SOM%	5.5%	2.5%	1.1%	0.8%
Sand	92	5	3		1.20 (81)	1.40 (86)	1.56 (93)	1.66 (98)
Gravelly sand	92	5	3		1.36 (82)	1.56 (87)	1.73 (94)	1.82 (98)
Silty sand	67	30	3		1.17 (83)	1.36 (89)	1.53 (96)	1.63 (101)
Sandy silt	30	65	5		1.12 (86)	1.31 (92)	1.48 (100)	1.58 (105)
Silt	5	90	5		1.08 (89)	1.27 (95)	1.44 (103)	1.54 (108)
Loam	45	37	18		1.18 (84)	1.38 (90)	1.55 (97)	1.65 (102)
Gravelly loam	45	37	18		1.35 (86)	1.54 (91)	1.71 (97)	1.81 (102)
Silty loam	15	67	18		1.14 (87)	1.34 (93)	1.51 (100)	1.60 (106)
Clay loam	30	37	33		1.22 (85)	1.41 (91)	1.58 (98)	1.68 (103)
Silty clay loam	10	57	33		1.19 (87)	1.38 (93)	1.55 (100)	1.65 (105)
Heavy clay	5	45	50		1.24 (87)	1.44 (92)	1.61 (99)	1.71 (104)

With a bulk density of 1.36 kg litre^{-1}, the dry weight of the topsoil (0-20 cm) on one hectare of land will be 1.36 kg x 10 000 m2 x 0.2 m x 1000 = 2720 tons.

6.5 Soil characteristics of Sunndal potato farms

Table 11 shows the general characteristics of soil regularly applied for potato production in Sunndal. The soil type is sand or silty sand, commonly with low content of organic matter.

Table 11. *Soil characteristics of topsoil (0-20 cm) of 10 fields in Sunndal, Norway which are regularly applied for potato growing. VW = volum weight of sieved, dry soil; CC= clay class; SOM = soil organic matter, LOI = loss on ignition.*

Location	VW kg/l	Soil type	CC	SOM % DM	LOI % DM	pH	P-AL mg/kg	Ca-AL mg/kg	Na-AL mg/kg	Mg-AL mg/kg
Furu, Øyan	1.3	Silty fine sand	2	0.6	1.6	5.6	110	250	290	39
Furu	1.1	Silty fine sand	2	1	2	6.2	200	790	400	100
Hol	1.2	Silty fine sand	2	1.6	2.6	5.8	100	290	420	60
Einhaug en	1.2	Fine sand	1	3	3	6.4	130	360	320	66
Ner-skeiet	1.1	Sandy silt	2	3.9	4.9	5.9	87	320	360	48
Leangen	1.2	Silty medium sand	2	2	3	5.7	110	280	340	45
Løykja	1.2	Silty medium sand	2	3.7	4.7	5.7	220	330	470	71
Grøa	1.3	Medium sand	1	1.8	1.8	5.5	100	240	270	42
Torske	1.2	Silty fine sand	2	2.7	3.7	6.1	260	390	300	83
Fahle	1.3	Sandy silt	2	1.7	3.7	5.8	120	410	410	82
Average	1.2	Silty medium sand	1.8	2.2	3.1	5.8 7	144	366	358	63.6

Table 12 shows the concentrations of PTEs in soil on typical potato fields in Sunndal, and the threshold levels from the two national regulations, on fertilizers from organic origin (LMD et al. 2021) and on pollution (KMD 2022). The regulation on fertilisers etc. of organic origin does not define any threshold for arsenic, and hence we applied the level from the regulation on pollution for As.

Table 12. *Concentrations of potentially toxic elements (PTEs) in the topsoil (0-20 cm) on 10 fields in Sunndal regularly applied for potato growing. Threshold values from national regulations are shown in red colour. The different colours show how close the results are to the threshold values, from green (far below) to orange (close).*

Nr.	**Locations**	**As**	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**	**Hg**
					mg / kg DM				
20	Furu, Øyan	0.91	0.06	29	26	19	4	43	0.7
141	Furu	1.30	0.13	27	34	19	12	100	0.7
76	Hol	0.55	0.04	30	18	18	4	37	0.7
53	Einhaugen	0.52	0.04	19	14	11	3	26	0.7
56	Nerskeiet	0.58	0.05	20	35	16	4	61	0.7
71	Leangen	0.49	0.04	27	15	16	4	32	0.7
40	Løykja	0.8	0.05	39	24	20	6	74	0.7
7	Grøa	0.86	0.07	32	24	20	5	55	0.7
33	Torske	0.6	0.06	24	20	15	6	54	0.7
106	Fahle	0.78	0.05	43	21	24	5	75	0.7
	AVERAGE	0.74	0.06	29	23.1	17.8	5.3	55.7	0.7
Treshold soil quality			**1**	**100**	**50**	**30**	**50**	**150**	**1**
Treshold pollution		**8**	**1,5**	**50**	**100**	**60**	**60**	**200**	**1**

For the two elements in algae fibre which may cause concern, As and Cd, the concentrations in the soil are generally quite low and well below the threshold limits posed by the regulations.

With the weight of topsoil per hectare being 2720 tons (see 6.4), the average content of As and Cd per hectare in potato soil in Sunndal will be:

0.74 mg kg^{-1} x 2720 x 1000 kg = 2013 g of As

0.06 mg kg^{-1} x 2720 x 1000 kg = 163.2 g of Cd

6.6 Calculations

The application of one ton of DM of alga fibre per hectare, corresponding to 3.9 tons of fresh material with a DM% of 25.5 (**table 9**) would increase the average concentrations of As and Cd in the soil by:

28 mg As kg^{-1} x 1000/2720 000 kg = 0.01029 mg kg^{-1} soil

1 mg Cd kg^{-1} x 1000/2720 000 kg = 0.00037 mg Cd kg^{-1} soil

If we increase the amount to 10 tons of DM per hectare, corresponding to 1 kg DM per m^2 or 1 ton of DM per daa (Norwegian measure of field size), the concentrations will increase by 0.1029 mg kg^{-1} soil for As and 0.0037 mg kg^{-1} soil for Cd.

Hence, if we assume that all PTEs applied to the soil will be stored there, it will take 8/0.01029 = 777 tons of DM of algae fibre to increase the concentration of arsenic in the topsoil from zero to 8 mg kg^{-1} of dry soil. Since the average concentration in soil was 0.74 mg As kg^{-1}, we subtract 0.74/0.01029 = 72 tons and derive to 705 tons of DM. 8 mg kg^{-1} is the limit in the national regulation on pollution, and if we assume that the threshold level will be reduced by 50% in the regulation on fertilisers (as for copper, Cu and nickel, Ni), we may apply 350 tons of algae fibre DM per hectare.

To derive to the limit concentration of cadmium in soil in the national regulation of fertilisers etc. of organic origin (1 mg/kg dry soil), it would take 1/0.00037 = 2703 tons of algae fibre if we started by a concentration of zero in the soil. Since the average concentration was 0.06 mg Cd kg^{-1}, we subtract 0.06/0.00037 = 162 tons and derive to 2541 tons of DM.

Hence, it is the content of arsenic rather than the content of cadmium which restricts the application of algae fibre to agricultural soil, if the only thing we consider is the threshold limits of PTEs in soil. However, since algae fibre is categorised as a class 2 material due to the content of Cd (table 8), the maximum amount which will be permitted is 20 tons of DM per hectare over a period of 10 years. This corresponds to an application of 20/0.25 = 80 tons of fresh material (with a dry matter content of 25%).

An application of 80 tons of algae fibre would imply a high application of potassium, and a high liming effect. It will be more reasonable to split the application in two and apply 40 tons each 5^{th} year, with a careful monitoring of how that would affect soil pH and K-Mg-Ca-Na-AL. 92 g kg^{-1} of potassium corresponds to 92 kg of potassium per ton of DM, which implies that 10 tons of alga fibre DM per hectare will contain 920 kg of K. This may be too high for potatoes, and it may be better to reduce the volume even more. However, for even application in field, the amount of material per m^2 cannot be too low.

As shown in **table 11**, the concentrations of PTEs in soil vary between the sampled fields, and we may observe a gradient when we compare the values in **table 11** with the satellite photo of the fields in **figure 16**. Close to the main road, higher levels of Pb, Cd, Cu and Zn in the soil may occur because of traffic pollution. The field 141 Furu has the longest surface area adjacent to the main road and contains the highest amounts of the mentioned PTEs in the soil compared to the other fields. Two of four fields located with a certain distance from the main road, 53 Einhaugen and 71 Leangen, contained relatively small amounts of Pb, Cd, Cu and Zn compared to the other fields. Closeness to the municipal centre Sunndalsøra and Hydro aluminium factory may also contribute to explain the higher levels of heavy metals on the fields Furu Øyan and Furu.

7 Conclusions

The FIMO-project investigated whether algae fibre may be applied as a soil amendment to increase the content of organic matter in soil, in a safe manner. Studies were conducted to describe and quantify how algae fibre performs as a soil amendment, measuring soil nutrient concentrations, potentially toxic element (PTE) concentrations, carbon content and several characteristics of soil biology. Further, we studied if such amendment affects the content of certain minerals (Na, K, As, Cd) in crop plants, and proposed a strategy for safe application of algae fibre based on the content of these minerals in soil and algae fibre. Field experiments where algae fibre had been applied in previous years (2019 or 2020) were utilised. Previous application of algae fibre had a significant positive effect on the growth of grass-clover ley and potatoes cultivated in 2021, but not for oats. This may be explained by a with a short period of growth and nutrient uptake in oats.

Addition of AF and GO increased the density of springtails and the soil respiration, whereas active C in soil was reduced with AF. Addition of AF and GO increased the concentrations of some AL-extractable nutrients in the soil, and especially for K-AL, the increase was large in AF. AF also increased soil pH. The organic matter content as recorded by loss on ignition was not significantly affected by the application of algae fibre, and the water holding capacity measured in lab was also not affected. The applied amounts of algae fibre did not show any negative effects on the soil biology recorded two years after application. Application of algae fibre increased soil concentrations of arsenic (As) and cadmium (Cd) but did not increase the content of these elements in potato tubers. The concentrations of Mg and K were only slightly higher in potato tubers in AF than in GO and K0.

From the limits stated in national regulations, and current average concentration of As in soil typically applied for potato cultivation in Sunndal, 350 tons of algae fibre DM may be applied per hectare to reach a limit of 4 mg As per kg of dry soil. However, the concentration of Cd in algae fibre categorises this material as a class II soil amendment product, which may be applied to agricultural soil with up to 20 tons of DM per hectare over a period of 10 years. With 25% DM, 20 tons of dry algae fibre corresponds to 80 tons of fresh material. One ton of algae fibre DM contains about 920 kg of potassium, which is much more than a potato crop requires. Hence, the amount of alga fibre needs to be adapted towards the smallest amount which may possibly be evenly spread with equipment for spreading of solid animal manure. A low, and regular application of algae fibre to agricultural soil which demands a supply of organic matter, and potassium and other minerals, can be recommended, but further studies are needed to reveal to which crops and at which time of the year the material should best be applied. The content of PTEs in soil needs investigation for application of soil amendments in class I or II.

Amendment with algae fibre will increase soil pH and concentrations of AL- soluble minerals (K, Mg, Ca, Na) and of As and Cd. In the experimental soil applied here, the loss on ignition (reflecting the soil content of organic matter) did not increase. However, the initial content of soil organic matter on the experimental site was high; 9-12%, and results might have been different in a soil with less organic matter. The effect of soil biology and soil biological activity seemed to be positive, in spite of the high pH and content of soluble elements.

The project should be followed up by a field experiment to test application of algae fibre in practice, on soil with less organic material than in the present study, to find practical ways of spreading the material in field and to study how the plants react. Further investigations are also required to reveal whether algae fibre may increase the content of organic matter in soil where the initial content is low. Even if algae fibre as such may be rapidly decomposed in soil, increased plant growth may increase the amount of plant roots, which may increase the amount of relatively stable soil organic matter.

References

- Ahuja, I., de Boer, A. & Løes, A.-K. 2020. Forsøk med gjødsel fra havet (Experiments with fertilisers from the sea; in Norwegian). Agropub. https://www.agropub.no/fagartikler/forsok-med-gjodsel-fra-havet. Last updated May 4, 2021.

- Ahuja, I. & Løes, A.-K. 2019. Effects of fish bones and algae fibre as fertilisers for ryegrass. NORSØK Report 4 (7). Norwegian Centre for Organic Agriculture (NORSØK), Tingvoll, Norway.

- Bongiorno, G., Bünemann, E. K., Oguejiofor, C. U., Meier, J., Gort, G., Comans, R., ... & de Goede, R. 2019. Sensitivity of labile carbon fractions to tillage and organic matter management and their potential as comprehensive soil quality indicators across pedoclimatic conditions in Europe. Ecological Indicators 99: 38-50.

- Bonkowski, M. 2000. Food preferences of earthworms for soil fungi. Pedobiologia 44(6): 666-676.

- Breure, M. S. 2014. Exploring the potential for using seaweed (*Ulva lactuca*) as organic fertiliser. MSc Thesis Plant Production Systems. PPS-80436, Wageningen University. Netherlands.

- Butt, K.R., Meline, C. & Peres, G. 2020. Marine macroalgae as food for earthworms: growth and selection experiments across ecotypes. Environment. Science & Pollution Research 27: 33493-33499.

- Compaore, T.T. 2021. Norwegian Food Safety Authority. Personal communication, January 29, 2021.

- Debio 2022. Driftsmiddelregisteret. Gjødsel- og jordforbedringsmidler. https://debio.no/driftsmiddelregisteret/, accessed April 6, 2022.

- EC (European Commission). 2019. Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products and amending Regulations (EC) No 1069/2009 and (EC) No 1107/2009 and repealing Regulation (EC) No 2003/2003.

- Égner, H., Riehm, H. & Domingo, W.R. 1960. Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährtofzustandes der Boden. II. Chemische Extraktionsmetoden zur Phosphor-und Kaliumbestimmung. (Studies of chemical soil analysis to assess the nutrient content of soil. II Chemical extraction methods for measurement of phosphorus and potassium). Kungliga Lantbrukshögskolans Annaler 26: 199-215.

- Friberg, H., Lagerlöf, J. & Rämert, B. 2005. Influence of soil fauna on fungal plant pathogens in agricultural and horticultural systems. Biocontrol Science and Technology 15(7): 641-658.

- Gestel, C.A.M, Kruidenier, M. & Berg, M.P. 2003. Suitability of wheat straw decomposition, cotton strip degradation and bait-lamina feeding tests to determine soil invertebrate activity. Biology and Fertility of Soils 37: 115-123.

- Jørgensen, H.B., Elmholt, S. & Petersen, H. 2003. Colembola dietary specialisation on soil grown fungi. Biology and Fertility of Soils 39: 9-15.

- Kautz, T., Lopez-Fando, C. & Ellmer, F. 2006. Abundance and biodiversity of soil microarthropods as influenced by different types of organic manure in long-term field experiment in Central Spain. Applied Soil Ecology 33: 278-285.

- KMD (Ministry of Climate and Environment). 2022. Forskrift om begrensning av forurensning (forurensningsforskriften) (Regulation on pollution; *in Norwegian)*. Regulation June 24, 2004. https://lovdata.no/dokument/SF/forskrift/2004-06-01-931/KAPITTEL_1-2-1#KAPITTEL_1-2-1, accessed March 15, 2022.

- Krab, E.J., Berg M.P., Aerts, R., van Logtestijn, R.S.P. & Cornelissen, J.H.C. 2013. Vascular plant litter input in subarctic peat bogs changes Collembola diets and decomposition patterns. Soil Biology & Biochemistry 63: 106-115.

- Kratz, W. 1998. The Bait-Lamina Test. ESPR- Environ. Sci. & Pollut. Res. 5(2): 94-96.

- Krogstad, T. 1992. Metoder for jordanalyser (Methods for soil analyses; *in Norwegian*). NHL Institutt for jordfag Report 6 (92). Norwegian University of Life Sciences, Ås, Norway.

- LMD, KMD & HOD (Ministry of Agriculture and Food, Ministry of Climate and Environment & Ministry of Health and Care Services). 2021. Forskrift om gjødselvarer mv. av organisk opphav (Regulation on fertilizers etc. of organic origin; *in Norwegian*). Regulation July 7, 2003. https://lovdata.no/dokument/SF/forskrift/2003-07-04-951, accessed March 15, 2022.

- Løes, A.-K., Johansen, A., Pommeresche, R. & Riley, H. 2013. SoilEffects - start characterization of the experimental soil. Bioforsk Report 8(96). Bioforsk Organic Food and Farming, Tingvoll, Norway.

- Løes, A.-K., Ahuja, I. & De Boer, A. 2021. Harvesting Our Fertilisers From The Sea - An Approach To Close The Nutrient Gaps In Organic Farming. Paper at: Organic World Congress 2021, Science Forum: 6th ISOFAR Conference co-organised with INRA, FiBL, Agroecology Europe, TP Organics and ITAB, Rennes, France, 8 - 10 September, 2021. https://orgprints.org/id/eprint/42198/1/OWC2020-SCI-463.pdf

- MišurCoVá, L., KráčMar, S., KLeJduS, B., & VaCeK, J. 2010. Nitrogen content, dietary fiber, and digestibility in algal food products. Czech Journal of Food Sciences. 28(1): 27–35.

- Norwegian Environment Agency (Miljødirektoratet). 2017. Veileder til forurensningsforskriften kapittel 2 (guidelines for the national regulation on pollution; *in Norwegian*). M-820.

- Pereira, L., Morrison, L, Shukla, P. & Critchley, A. 2020. A concise review of the brown macroalga *Ascophyllum nodosum* (Linnaeus) Le Jolis. Journal of Applied Phycology 32: 3561–3584.

- Pommeresche, R. & Løes A.-K. 2009. Relations between agronomic practice and earthworms in Norwegian arable soils. Dynamic Soil, Dynamic Plants 3(2): 129-142.

- Pommeresche, R. & Løes A.-K. 2014. Diversity and density of springtails (Collembola) in a grass-clover ley in North-west Norway. Norwegian Journal of Entomology 61: 165-179.

- Pommeresche, R., Løes A.-K. & Torp, T. 2017. Effects of animal manure application on springtails (Collembola) in perennial ley. Applied Soil Ecology 110: 137-145.

- Ponge, J.-F. 2000. Vertical distribution of Collembola (Hexapoda) and their food resources in organic horizons of beech forests. Biology and Fertility of Soils 32: 508-522.

- Raaijmakers, J.M., Paulitz, T.C., Steinberg, C., Alabouvette, C. & Moënne-Loccoz, Y. 2009. The rhizosphere: a playground and a battlefield for soilborne pathogens and beneficial microorganisms. Plant and Soil 321: 341-361.

- Riley, H. 1996. Estimation of physical properties of cultivated soils in southeast Norway from readily available soil information. Norwegian Journal of Agricultural Science. No. 25 (suppl.).

- Riley, H. 2002. 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. Acta Agriculturae Scandinavica, Section B — Soil & Plant Science 52: 86-95.

- Rittl, T., Bakken, I., Grønmyr, F., Heltolf, P., Stewart, L., Husby, A., Fløystad, K. & Løes, A. K. 2021. Biochar coating potential to suppress storage diseases in carrots and potatoes (CHARCOAT). NORSØK Report 6 (12). Norwegian Center for Organic Agriculture (NORSØK), Tingvoll, Norway.

- Six, J., Bossuyt, H., Degryze, S. & Denef, K. 2004. A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. Soil & Tillage Research 79: 7-31.

- Taylor, V.F. & Jackson, B.P. 2016. Concentrations and speciation of arsenic in New England seaweed species harvested for food and agriculture. Chemosphere 163: 6–13.

- USDA Foreign Agricultural Service. 2018. China Releases the Standard for Maximum Levels of Contaminants in Foods. https://www.fsis.usda.gov/sites/default/files/media_file/2021-02/GB-2762-2017.pdf, accessed March 29, 2022.

- Weil, R. R., Islam, K. R., Stine, M. A., Gruver, J. B., & Samson-Liebig, S. E. 2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. American Journal of Alternative Agriculture, 18(1): 3-17.

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