Soil health and local recirculation ensuring organic cucumber cultivation in Norway.

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ABSTRACT

New European organic regulation claims cultivation directly in soil in greenhouses. Cultivation practises in accordance with organic principles imply application of sustainable growing media and compost added for soil improvement. Local resources may be preferred. The goal of soil improvement is good soil health, including biological soil activity, nutrient availability, and physical properties. Only a few studies are done on biological soil health in greenhouses.

Biological soil activity was monitored in a greenhouse cucumber experiment on organic soil enriched with biochar and addition of local (1) compost, (2) solid digestate after biogas or (3) imported organic peat. Effects of silage mulching was tested. Biological activity was measured in soil by different indicators, and above soil, plant growth was followed.

Results indicated that the mixture with compost contained more organic matter than mixtures with solid digestate and peat. Biological activity in the compost mixture was lower and started later than in the two other mixtures and was in all mixtures more pronounced where silage mulch was added. Respiration rates and fungi content classified all three mixtures as stable growth media.

Nitrogen content and pH in all three mixtures were similar at the start of the experiment. The peat mixture needed most amendments, while phosphorous content was highest in solid digestate and lowest in peat. Plant nutrient turnover to plants was appropriate except lack of micronutrients. Yields performed well.

Preliminary conclusion is that although compost is based on microbial activity and taken for a protagonist in soil health, the results showed lower biological activity that started later than in the other mixtures. Balance between fungi and bacteria were in all three mixtures similar and equal to measurements in Norwegian, organic managed soil. Indicators were useful on farm level but could be diversified more. Local compost and digestate functioned as good as peat.

Keywords: greenhouse, new regulation, compost, solid digestate, indicators, Norwegian standard.

INTRODUCTION

New EU regulations for organic agriculture, covering Norway as associated member, claims cultivation directly in soil below greenhouses (EU, 2018). It does not restrict use of peat, but the expert group preparing the regulation recommended a proportion of 50-80 % in growing media until alternatives aligned with organic principles are found (EGTOP, 2013). The only derogation for cultivation in demarcated beds is if the plant is sold growing in a demarcated bed, which is the technical term for any pot or container with a plant in it. Growing in plastic bags filled with peat and/or compost has been a normal procedure for organic cultivation of tomato and cucumber in Northern countries. Lack of arable land specially in Norway have led to this practise; only three percent of the land area in Norway is

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cultivated land, and the best part of it is certainly not used for greenhouses (Andersen and Ladstein, 2018). Peat extraction for growing media have been common in Scandinavian countries since 1960´es. In Norway it takes place in 21 sites, concessions are currently for two more decades while Norwegian authorities aim to phase out peat extraction (Friis Pedersen and Loes, 2022). Transition to cultivation practises more in accordance with organic principles includes sustainable growing media that secures soil health.

Soil health is a broad term where at least 18 concepts and definitions are presented from 1970 until today (Seifu and Elias, 2018). Modern consensus is that "Soil health is the continued capacity of the soil to function as a vital living ecosystem that sustain plants, animals and humans" where capacity to function implies "fitness for use" and "soil quality" according to physical, chemical, and biological properties (Seifu and Elias, 2018). The European Soil Data Centre, ESDAC, suggests 21 indicators for soil health varying from observations, estimations, analysis, and modelling. One may also take into consideration whether soil and soil amendments are conducive or suppressive toward soil borne pathogens. The three most threatening pathogens to greenhouse conditions are *Pythium, Phytophtera, and Rhizoctonia* (Neher, 2021). The new Norwegian soil programme suggests estimating soil biodiversity by counting earthworms; comparing visual differences of bio pores; assessing decomposition of cotton textile; assessing bacteria, fungi, and other fauna in laboratory (Svengaard-Stokke *et al.*, 2021). Suitable indicators are still to be confirmed in a European context (EU, 2020).

Little is known related to management consequences on soil health; soil responds slowly to management. Nevertheless, the most globally used assessment of soil health, CASH, highlights that soil health is a part of, and only is meaningful in practise if it is correlated with, the goals of the grower and resources available for the enterprise (Moebius-Clune *et al.*, 2016). Comparing organic and conventional management in Norwegian raspberry cultivation outdoor have shown significant more respiration in the organic field, more microbial carbon and higher proportion of fungi (Wibe *et al.*, 2021).

In greenhouse soil, biological properties are essential because the area is isolated from the outside climate and fauna. Organic matter added and incorporated into the soil will then provide better soil life. Norwegian Food Safety Authority emphasizes this as a keystone (M. Stubberud, pers. comm.). Organic amendments are also in accordance with agroecological design and approach (Dussi and Simon, 2022).

Amendments like compost is a result of an aerobic process. It is taken for a protagonist in soil health because it promotes chemical and biological activity and assists sound physical structure, water retention and promotes humus (Van der Wulf *et al.,* 2016). Compost used as soil improvement has in most cases suppressive effect on soil borne disease (Doyle, 2017). In some cases, the raw material is decisive; bark from *Pices* suppress *Pythium* and cow manure suppress *Fusarium* in context with cucumber production (Raviv, 2016). Anyhow process management of the compost is concluded as most important for potential disease suppression, before raw material and maturity (Van der Wulf *et al.*, 2016).

Solid digestate, synonym to bio-rest, synonym to solid residue after anaerobic biogas process, contributes positively as fertilizer more than it affects soil quality (Van der Wulf *et al.,* 2016).

In both cases raw material for either composting or bio-gassing process can be selected from a broad spectre of materials. It is important to avoid residues from medicine, heavy metals and/or toxic elements because contentious inputs like these would harm soil health. Both compost and solid digestate contribute to circulation of resources and interaction between producers at a local level.

Peat is usual in professional greenhouse horticulture but, it is a controversial ingredient. Sustainability is jeopardized by harvesting an extremely slow renewable raw material from mires, which are important carbon sinks counteracting climate crisis (Friis Pedersen and Loes, 2022). The Norwegian market finds it hard to replace peat; substitutes do not fulfil demands for peat-free growing media (Brodd and Haraldsen, 2017). Complete replacement of peat demands more testing in different plant cultures and more research on mixing rates of materials. Mixing rates may solve challenges of too high pH-level, too high cation exchange capacity and challenges linked to structural homogeneity (Brod and Haraldsen, 2017).

Supporting a Norwegian transition for existing and future growers to the new organic regulation, a project consortium between NIBIO, NORSØK, NLR (Norwegian Agricultural Extension Service) and reference group from business stakeholders was set up. The project "Organic greenhouse cultivation in soil for Norwegian conditions" concerns the most common productions, which are cucumber and tomato. It is presumed that transition is welcomed even better if material and methods are in reach for growers – adaptable, appliable, low tech and inexpensive. Furthermore, utility might be met in both small scale and upscaled gardener enterprises. Measurements of soil biome may illustrate abundance, diversity, food web structure and community stability. Criteria for indicators might then 1) be sensitive to management changes over time 2) have good correlation with beneficial soil functions, 3) be useful as illustration of ecosystem processes, 4) be comprehensive and useful to grower and 5) be easily appliable and inexpensive (Doran and Zeiss, 2000). Using locally found resources may as well reduce transport cost and gain confidence. This is the background for choice of materials and methods.

MATERIALS AND METHODS

The compost in this experiment derived from green waste from public green areas, from agricultural animal production, and from maritime surplus. Compost process performed in windrows on concrete flour and under roof, consequently, it was considered as a cold composting process. The solid digestate in this experiment derived from pig slurry from conventional pig production. The peat in this experiment was imported from Sweden (Hasselfors Reko-jord).

The experimental lay-out for the three growing media were 63% soil, 10 % biochar and 27 % either compost, solid digestate or peat, measured by volume. The mixtures were placed in 0,8 x 0,8 x 8 m open box constructions with planted culture on the top, with a density of 2,43 cucumber plants per square meter. Two varieties were compared. Plant growth, nutrient status, and fluctuation as well as yield were measured during the period. Concerning nutrients, soil samples were taken at start, in the middle and at the end of the culture and analysed using Spurway analysis, which is new to Norwegian horticulture. In addition to solid fertilisation added before the start of the culture, liquid fertilisation by drip watering was applied. pH was respectivlely 6,9 in the compost, 6,6 in the biorest and 6,4 in peat mixtures. During the first experiment the mean temperature was 22,3 °C, the relative humidity 63,6 % and mean CO_2 level was approx. 775 ppm.

Methods for description of soil life started out assessing content of organic matter. Ingredients as compost, solid digestate, peat and biochar added organic matter to the growing media. For each mixture, content of organic matter was estimated by loss of ignition (LOI). This a widely used method but does not have a universal standard protocol (Hoogsteen *et al.,* 2015). Following procedure was used: From each mixture, two kilograms soil were sampled in the upper layer from 10-12 plots. Out of this portion 3 x 200 gram soil were dried at 60 °C in 48 hours and dry matter measured. From each of the three repetitions 3 x approximately 17 – 22 gram of the particles smaller than 2 mm in diameter were taken out. The samples were then dried at 550 °C in three hours. Then they were weighted and average loss of weight from starting weight of original sample were calculated in percentage. For Norwegian conditions, adjustment depending on clay content is recommended (Pommerresche *et al.*, 2019). In this context the samples were not adjusted for content of clay, because it was soil of anthropogenic mixture. In Scandinavian soil it is assumed that mould is approximately 50 % of organic matter (Petersen, 1994; Pommeresche and Rittl, 2022).

All organic matter is not available or exposed for microbiome in the soil. The microbiometer method measures microbial carbon available for microbiome and shows whether the microorganisms are either fungi or bacteria, based on a standardized colour scale. The level of microbial carbon µg/g soil is low when it is 200 and excellent if 800µg C/g soil according to the test provider. Solvita® CO_2 test indicates respiration of soil biome, which is compared to a standardized scale of colour.

Feeding habit was measured by bait lamina sticks. Bait lamina sticks are PVC sticks with 16 holes (1.5mm diameter and 5 mm distance) filled with 70 % cellulose powder, 27 % wheat bran and 3 % activated carbon for microorganisms' consumption. The method is developed in Germany in the 1990-ies and is among other purposes applicated in agroecosystems to describe soil improvement (Kratz, 1998). Counting amount eaten over time (1, 2, 3 weeks) indicates activity among microorganisms in upper soil layer. Ten sticks for each mixture were evenly placed. Half of them in soil with silage mulching and half of them in soil without covering mulch.

RESULTS AND DISCUSSION

The compost mixture contained more organic matter (15,32%) than the bio-rest (13,90 %) and peat mixture (13,46 %). The content of organic matter (13-15 %) is high compared to cultivated soil in Norway, which for 27% of the area is 6 % (Lågbu *et al.,* 2018). The Norwegian average is as well high compared to agricultural land situated more south in Europe and to the critical level for plant cultivation at at least 3-4 % organic matter (Lal *et al.*, 2015). Danish empiric study suggests 7-8 % mould is good for greenhouse growing media (J. Søllingvrå Jensen, pers. comm.). When the content of organic matter is 13-15 % it is considered equal to 7 % mould according to Scandinavian assumptions. Dutch data states that above 8 % mould in greenhouse production one may face nutrient loss, too high EC, wood louses and millipedes (Van der Wulf *et al,* 2016).

Solvita respiration test showed more biological activity in the mixture with compost than in the other two mixtures and a colour scale closer to the highest value. Results are shown in table 1, deviations were from 42,6 CO_2 ppm s^{-1} to 71,9 CO_2 ppm s^{-1} It might be due to maturing process which implies microbial activity. The activity declined the following year unless in the mixture with biorest, table 1.

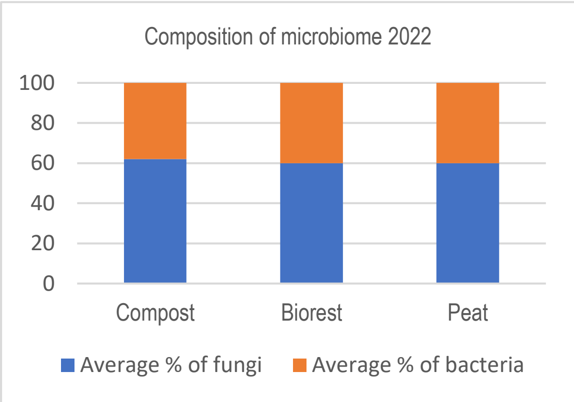
Table 1 Respiration from microbiome (ppm CO_2- S^{-1}) in 2022 and 2023. Compost showed most biological activity but declined the following year. Data average of 3 measurements in each patch.

Mixtures	Respiration (ppm CO_2 s^{-1}) 2022	Respiration (ppm $CO_2 s^{-1}$) 2023
Compost	62,9	49,6
Biorest	57,3	58,2
Peat	51,3	41,5

Microbiometer tests showed similar content of fungi and bacteria in the three mixtures, with more fungi than bacteria (62; 60; 60% fungi). The following year this was even more pronounced overweight of fungi (74; 74; 68%) as shown in figure 1 and 2. Solid fertilizer may provide proportional more fungi than bacteria but, both solid and liquid fertilizer were added.

Incorporation of organic matter like biochar, biorest or farmyard manure in Norwegian potato cultivation did not show any significant difference between these treatments either (R. Pommeresche and T. Rittl, pers. comm.).

Distribution 50:50 among fungi and bacteria in organic greenhouse management is possible by adding/preferring solid fertilisers, shows Danish empiric research. Feeding fungi with lignin will promote certain nutrient release supporting fruit development instead of vegetative growth (J. Søllingvrå Jensen, pers. comm.).



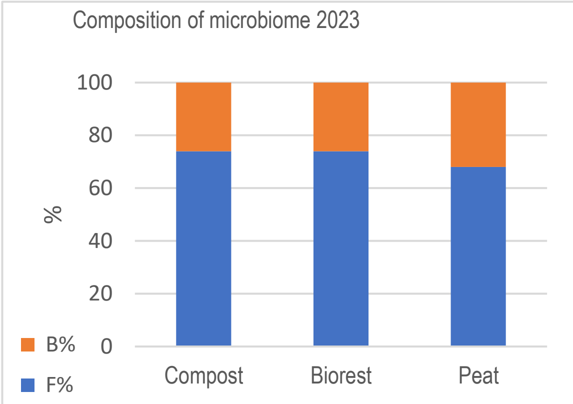


Figure 1 and 2 Composition of microbiome with distribution of fungi and bacteria in the mixtures 2022 and 2023.

A limitation of this sort of measurement of fungi is that it does not indicate the species or group of fungi like pathogens, decomposers or mycorrhizas. To do DNA/RNA analysis is expensive and rare. In Norway one can refer to an experiment at NIBIO Apelsvoll, but no difference between fungi diversity, nor amount, could be correlated to crop rotation nor organic versus conventional management over a long-term period (Pommeresche and Rittl, 2022). Swedish greenhouse experiments could not either correlate diversity in microbial species to management strategies with more or less crop rotation and co-cultivation, but having cruciferous species augmented diversity e.g. mycorrhizal fungi (A.K. Rosberg, pers. comm.) Trials with increased number of cultures in greenhouse did not augment diversity of fungi cultures (Rosberg and Alsanius, 2022) even though a shorter crop rotation than five years indicates that in a meta-analysis (Venter *et al.* , 21016 in Rosberg and Alsanius, 2022).

The levels of microbial carbon available for microbiome were close to excellent in the three mixtures. Data from a Norwegian potato experiment adding similar organic amendments did not reach same level, maybe due to different temperature regime. The results are shown in table 2.

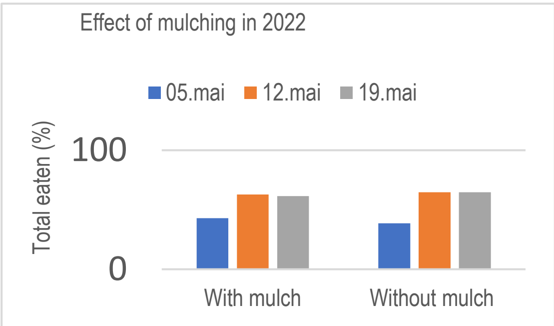
Table 2 Microbial carbon available for microbiome in present experiment in cucumber and potato cultivation.

Results	**MBC-C (µg C/g dw)**
Organic amendment in present experiment[a]	
Mixture with compost	776
Mixture with biorest	752
Mixture with peat	764
Organic amendment compared residual effect in potato cultivation[b]	
Biochar + liquid digestate	392
Biorest	434
Farmyard manure	399
Control	425

[a] Results from present experiment [b] Results from Pommeresche and Rittl (2023).

Comparing to an outdoor, Norwegian experiment, a similar pattern could be seen. In potato cultivation there were no significant differences between treatments with added solid digestate, fluid digestate and biochar, horse manure with bedding or no organic matter added (Hansen *et al.* 2021).

Readings of lamina bait sticks showed that feeding habits in the mixture with compost started later than in the other two mixtures. Activity increased from first to second week in all mixtures. Comparing between soil with and without silage mulch appeared difficult to interpretate. Without mulch resulted as good as with mulch in mixture with biorest and peat, but even better without in compost. A similar experiment with silage mulch in outdoor cultivation of onion and leek concluded that feeding of microorganisms were stimulated by the added organic mulch (Rittl *et al,* 2023). In the similar outdoor trial, it was as well found challenging comparing the feeding activity showed in the sticks. The outdoor results may have been influenced by different humidity and temperature. Results from one of the five locations turned out equal to present trial where microbial activity was higher without mulch. The authors of the outdoor trial suggest that when the soil content is over a certain level of organic matter, then the microbiome is indifferent to the sticks. While the effect of mulching did not come clear at once, they tested a nearby place for residual effect after mulching. Then it came clear that mulching does have a positive effect on microbial activity (Rittl *et al,* 2023). In the cucumber greenhouse trial, the positive influence did not appear in the measurements from May in any of the three mixtures. Without regards to mixture the effect of mulching appeared as shown in figure 3. Third week reading failed, eating amount must be progressive. A repetition of measurements later in the next trial gave a clearer picture of positive influence of mulching, figure 4. It may be interpretated as a residual effect like the results in the trial with leek and onion.



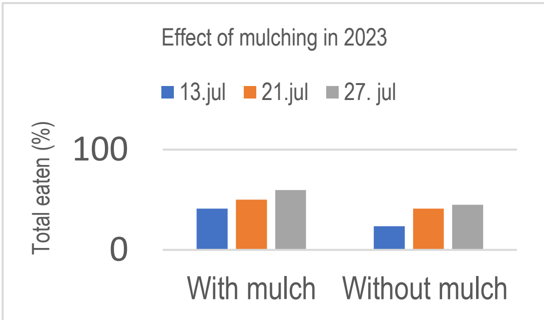


Figure 3 and 4 Comparing effect of mulching on microbiomes feeding habit did not come clear in May 2022, but repetition in 2023 gave a clearer picture of positive effect of mulching.

Phosphorous (P) content was highest in solid digestated bio-rest and lowest in peat. Using fresh animal manure could provide much P (J. Søllingvrå Jensen, pers. comm.) and the bio-rest contain pig manure, while compost and peat does not contain animal manure. High levels of P in soil may affect mycorrhiza fungi negatively (A.K. Rosberg, pers. comm.).

Another indicator for biological activity in soil could have been decomposition of tea bags. The method is cheap and easy to apply and could be compared to other data (Tresch and Fliessbach, 2017), even though data from greenhouse production is difficult to find. For an enterprise plan toward better soil health, it is essential to consider both strategy and indicator. Common for all production are four strategies: 1) conservation of soil and organic matter, 2) minimizing erosion, 3) balancing production and environment and 4) optimize use of renewable resources. Following indicators might measure 1) organic matter and change over time, 2) surface property and covering degree, 3) plant cultures character and nitrogen status and fluctuation and 4) Plant culture character and economy (Doran and Zeiss, 2000). Economy is not in the scope here but will be highlighted in another outcome of the project.

CONCLUSION

Data from soil life – specially in greenhouses – are difficult to find. Data found by chosen indicators for soil life are useful to a certain point. As mentioned, beyond statement on fungi, it could have been useful to categorize fungi to decomposer, pathogen or mycorrhizae. For a sound organic production, presence of both fungi and bacteria are essential. High proportion of fungi provides a stable growing media, which were the case in all three mixtures.

The chosen methods were found reliable, doable, and economic reasonable. They showed that content of organic matter was appropriate in all three mixtures. This promoted good conditions for soil life. Respiration of microbiome were close to excellent in all three mixtures. The effect of silage mulch was difficult to interpretate but, in 2023 a positive effect came clearer. It seems like microbiome does not feed on bait lamina sticks if the growing media supplies them sufficiently.

Mixtures chosen did ensure healthy soil, and local recirculation. For long-term ensuring of healthy soil, longer time experiments are needed. To describe the soil pathogen suppression, other than these methods are needed. The methods chosen are suitable for farm level where management aims towards more sustainability. Mentioned tea bag index for biological activity could be implied as well.

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