Soil health with local recirculation and local amendments ensuring organic cucumber cultivation in Norway

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Abstract

The new European organic regulation claims that cultivation must occur directly in soil in greenhouses. Cultivation practices in accordance with organic principles require the use of sustainable growing media and the addition of compost for soil improvement, preferably local resources. Soil improvement aims to achieve good soil health, including biological soil activity, nutrient availability, and favourable physical properties. However, only a few studies have been conducted on biological soil health in greenhouses. Biological soil activity was monitored in a greenhouse cucumber experiment on organic soil enriched with biochar and supplemented with local 1) compost, 2) solid digestate from biogas production, or 3) imported peat. The effects of silage mulching were also tested. Biological activity was measured in the soil using different indicators, while plant growth was monitored above soil. Results indicated that the mixture with compost contained more organic matter than other mixtures. Biological activity in the compost mixture was lower and started later than in the other mixtures. Silage mulch increased biological activity in all mixtures. Respiration rates and fungi content classified all three mixtures as stable growing media. At the start of the experiment, nitrogen content and pH levels in all three mixtures were similar. The peat mixture required the most mineral amendments, phosphorous content was highest in solid digestate and lowest in peat. Plant nutrient turnover to the plants was appropriate, although a lack of micronutrients was observed. Yields performed well. Our results show that biological activity in compost starts later in compost compared to the other mixtures. Anyhow compost is considered a key component of soil health. Fungi:bacteria balance was similar and comparable to measurements in Norwegian organically managed soil. Indicators were useful at farm level; they could be diversified further. Local compost and digestate performed as good as peat.

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

INTRODUCTION

New EU regulations for organic agriculture, which also apply to Norway as associated member, claims that cultivation must occur directly in soil beneath greenhouses (EU, 2018). It does not restrict the 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 while growing in a demarcated bed, which is the technical term for any pot or container containing 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, especially in Norway, has led to this practice; only 3% of the land area in Norway is cultivated land, and the best part of it is certainly not used for greenhouses (Andersen and Ladstein, 2018). Peat extraction for growing media has been common in Scandinavian countries since the 1960s. In Norway it takes place in 21 sites, concessions are currently for two or more decades, while Norwegian authorities aim to phase

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out peat extraction (Friis Pedersen and Loes, 2022). Transition to cultivation practices 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 the 1970s 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 sustains 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*, *Phytophtora*, and *Rhizoctonia* (Neher, 2021). The new Norwegian soil program 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 (European Commission, 2020).

Little is known about the management consequences on soil health, as soil responds slowly to management practices. Nevertheless, the most widely used assessment of soil health, CASH, highlights that soil health is meaningful only when it is correlated with the goals of the grower and the resources available for the enterprise (Moebius-Clune et al., 2016). For example, comparing organic and conventional management in Norwegian raspberry cultivation outdoor have shown significant more respiration in the organic field, along with higher microbial carbon and a greater 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. commun.). 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 Wurff et al., 2016). Compost used as soil improvement often has a suppressive effect on soil borne diseases (Doyle, 2017). In some cases, the raw material is decisive; for example, bark from *Picea* suppresses *Pythium,* and cow manure suppresses *Fusarium* in context of cucumber production (Raviv, 2016). However, the management of the composting process is concluded to be the most important factor for potential disease suppression, surpassing the significance of raw material and maturity (Van der Wurff et al., 2016). Solid digestate, the solid residue from the anaerobic biogas process, contributes positively as fertilizer and has impact on soil quality (Van der Wurff et al., 2016).

In both cases, the raw material for either the composting or biogas process can be selected from a broad spectrum of materials. It is important to avoid residues from medicines, heavy metals and/or toxic elements, as these contentious inputs could harm soil health. Both compost and solid digestate contribute to the circulation of resources and facilitate interactions between producers at a local level.

Peat is commonly used in professional greenhouse horticulture, but it is a controversial ingredient. Sustainability is jeopardized by the harvesting of this extremely slowly renewable raw material from mires, which are important carbon sinks that help counteract climate crisis (Friis Pedersen and Loes, 2022). The Norwegian market finds it difficult to replace peat, as substitutes do not fulfil the demands for peat-free growing media (Brod and Haraldsen, 2017). A complete replacement of peat requires more testing across different plant cultures and further research on the mixing rates of alternatives materials. These mixing rates may help address challenges such as excessively high pH levels, high cation exchange capacity, and issues related to structural homogeneity (Brod and Haraldsen, 2017).

To support the Norwegian transition for existing and future growers to the new organic regulation, a project consortium was established, comprising NIBIO, NORSØK, NLR

(Norwegian Agricultural Extension Service) and a reference group of business. The project, titled "Organic greenhouse cultivation in soil for Norwegian conditions" focuses on the most common crops, which are cucumber and tomato. It is presumed that the transition will be more successful if material and methods are accessible to growers–adaptable, applicable, low-tech, and inexpensive. Furthermore, the utility may be met in both small-scale and large-scale gardener enterprises. Measurements of the soil biome can illustrate abundance, diversity, food web structure, and community stability. The criteria for indicators should ideally: 1) be sensitive to management changes over time, 2) correlate well with beneficial soil functions, 3) effectively illustrate ecosystem processes, 4) be comprehensive and useful to growers, and 5) be easily applicable and inexpensive (Doran and Zeiss, 2000). Using locally sourced materials may also reduce transport cost and build confidence among growers. This forms the basis for the choice of materials and methods.

MATERIALS AND METHODS

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

The experimental layout for three growing media consisted of 63% soil, 10% biochar, and 27% of either compost, solid digestate or peat, measured by volume. The mixtures were placed in open box constructions measuring 0.8×0.8×8 m, with planted culture on top, at a density of 2.43 cucumber plants m^{-2}. Experimental design included two replications and comparation of two varieties and mixture with and without mulch. Plant growth, nutrient status, fluctuations, and yield were measured through the period. Regarding nutrients, soil samples were taken at the start, in the middle, and at the end of the growing cycle and analysed using Spurway analysis. In addition to solid fertilisation applied before the start of the growing cycle, liquid fertilization was applied via drip irrigation. Each plant had in average 1.5 drip providing 2 L h^{-1}. Fertilizer was OPF containing 7-2-3 NPK. Average irrigation m^{-2} day^{-1} was 1.5 L $plant^{-1}$, which resulted 0.49 g N day^{-1}. The pH levels were respectively 6.9 in the compost, 6.6 in the solid digestate and 6.4 in peat. During the first experiment, the mean temperature was 22.3°C, the relative humidity was 63.6%, and the mean CO_2 level was approximately 775 ppm.

Methods for describing soil life focused on assessing the content of organic matter. Ingredients such as compost, solid digestate, peat, and biochar contributed organic matter to the growing media. For each mixture, the organic matter content was estimated by loss on ignition (LOI). This is a widely used method but lacks a universal standard protocol (Hoogsteen et al., 2015). The following procedure was used: from each mixture, 2 kg of soil were sampled from the upper layer of 10 to 12 plots. From this portion, three samples of 200 g each were dried at 60°C for 48 h, and the dry matter measured. From each of the three repetitions, approximately 17 to 22 g of particles smaller than 2 mm in diameter were taken out. The samples were then dried at 550°C for 3 h. After drying, they were weighted, and the average loss of weight from the original sample was calculated as a percentage. For Norwegian conditions, adjustments based on clay content are recommended (Pommeresche et al., 2019). In this context, the samples were not adjusted for clay content because they consisted of anthropogenic mixture. In Scandinavian soil, it is assumed that mould constitutes approximately 50% of organic matter (Petersen, 1994; Pommeresche and Rittl, 2022).

Not all organic matter is available or exposed to the microbiome in the soil. The microbiometer method was used to measure microbial carbon available to the microbiome and determine whether the microorganisms are either fungi or bacteria, based on a standardized colour scale. The level of microbial carbon was considered low at 200 µg C g^{-1} soil and excellent at 800 µg C g^{-1} soil, according to the test provider. The Solvita® CO_2 test indicated the respiration of the soil biome, which was compared to a standardized colour scale.

Feeding habits were measured using bait lamina sticks. Bait lamina sticks are PVC sticks with 16 holes (1.5 mm diameter and 5 mm distance) filled with 70% cellulose powder, 27% wheat bran, and 3% activated carbon for microbial consumption. This method was developed in Germany in the 1990s and is used, among other purposes, in agroecosystems to describe soil improvement (Kratz, 1998). The amount consumed over time (1, 2, 3 weeks) indicated the activity of microorganisms in the upper soil layer. Ten sticks for each mixture were evenly placed, with half in soil with silage mulching and half 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, where 27% of the area has only 6% organic matter (Laghu et al., 2018). The Norwegian average is also high compared to agricultural land situated further south in Europe and to the critical level for plant cultivation, which is at least 3-4% organic matter (Lal et al., 2015). A Danish empiric study suggests 7-8% mould is good for greenhouse growing media (J. Søllingvrå Jensen, pers. commun.). When the content of organic matter is 13-15%, it is considered equivalent to 7% mould according to Scandinavian assumptions. Dutch data stated that when mould exceeds 8% in greenhouse production, one may face nutrient loss, too-high EC, and issues with woodlice and millipedes (Van der Wurff et al., 2016).

Solvita respiration tests indicated greater biological activity in the mixture with compost compared to the others, showing a colour scale closer to the highest value. Results are presented in Table 1, with deviations ranging from 42.6 to 71.9 CO_2 ppm s^{-1}. This may be attributed to the maturing process, which promotes microbial activity. However, this activity declined in the following year, except in the mixture with solid digestate (Table 1).

Table 1. Respiration from microbiome indicating biological activity (ppm CO_2 S^{-1}) in 2022 and 2023. Data average of 3 measurements from 10 subsamples in each mixture taken in the middle of the growing cycle.

Mixtures	Respiration (ppm CO_2 s^{-1})	
	2022	2023
Compost	62.9	49.6
Solid digestate	57.3	58.2
Peat	51.3	41.5

Microbiometer tests revealed similar levels of fungi and bacteria across the three mixtures, with higher fungi than bacteria (62, 60, 60% fungi). The following year, this disparity became more pronounced, with overweight fungi (74, 74, 68%) as shown in Figures 1 and 2. While solid fertilizers may provide a relatively higher proportion of fungi than bacteria, both solid and liquid fertilizers were applied.

The incorporation of organic matter, such as biochar, solid digestate or farmyard manure, in Norwegian potato cultivation did not show any significant difference between these treatments either (R. Pommeresche and T. Rittl, pers. commun.). A distribution of 50:50 between fungi and bacteria in organic greenhouse management is possible by adding or preferring solid fertilizers, as showed by Danish empiric research. Feeding fungi with lignin will promote the release of certain nutrients that support fruit development rather than vegetative growth (J. Søllingvrå Jensen, pers. commun.).

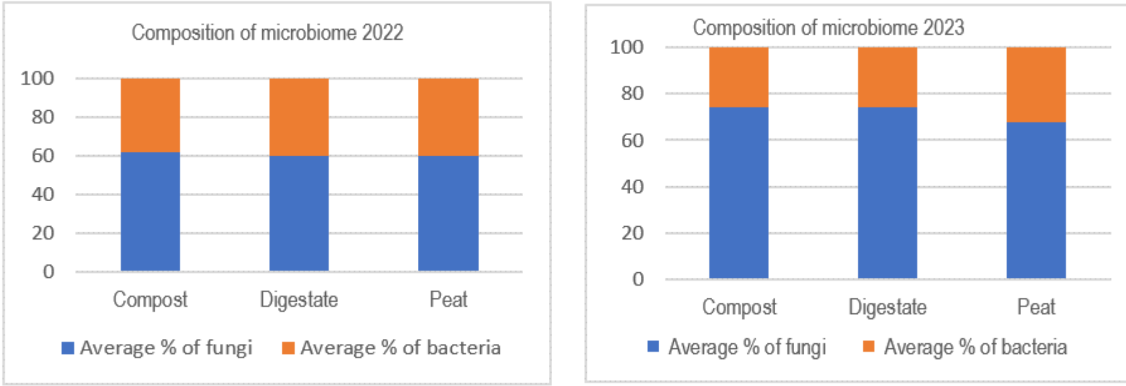

Figure 1. Composition of microbiome with distribution of fungi and bacteria in the mixtures 2022 and 2023. Number of samples = 3.

Figure 2. Comparing effect of mulching on microbiomes feeding habits did not come clear in May 2022, repetition in 2023 gave a clearer picture of positive effect of mulching.

A limitation of this type of measurement of fungi is that it does not indicate the species or group of fungi, such as pathogens, decomposers or mycorrhizas. Conducting DNA/RNA analysis is expensive and rare. In Norway, one can refer to an experiment at NIBIO Apelsvoll, but no difference between fungi diversity or quantity were correlated with crop rotation or organic versus conventional management over a long-term period (Pommeresche and Rittl, 2022). Similarly, Swedish greenhouse experiments failed to correlate diversity in microbial species with management strategies involving more or less crop rotation and co-cultivation. However, the inclusion of cruciferous species augmented diversity, particularly with regard to mycorrhizal fungi (A.K. Rosberg, pers. commun.) Trials involving an increased number of cultures in greenhouse did not lead to a greater diversity of fungal cultures (Rosberg and Alsanius, 2022), even though a meta-analysis indicated that a shorter crop rotation of less than five years can impact diversity (Venter et al., 21016 in Rosberg and Alsanius, 2022).

The levels of microbial carbon available for the microbiome were close to excellent in the three mixtures. Data from a Norwegian potato experiment that added similar organic amendments did not reach the same level, possibly due to different temperature regimes (Table 2).

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

Table 2. Microbial carbon available for microbiome in present experiment in cucumber and potato cultivation. Samples and subsamples in *a* = 3 provided from 10 subsamples in each mixture; *b* = samples from 4 places in Norway with 10 subsamples per each. No statistical analysis was performed.

	Results	MBC-C (µg C g^{-1} dw)
Organic amendment in present experiment[a]	Mixture with compost	776
	Mixture with solid digestate	752
	Mixture with peat	764
Organic amendment compared residual effect in potato cultivation[b]	Biochar + liquid digestate	392
	Solid digestate	434
	Farmyard manure	399
	Control	425

[a]Results from present experiment; [b]Results from Pommeresche and Rittl (2022).

Readings from the lamina bait sticks indicated that feeding habits in the mixture with compost started later than in the other two mixtures. Activity increased from the first to the second week in all mixtures. Comparing soil with and without silage mulch was challenging to interpret. The results showed that without mulch was as effective as with mulch in the mixture containing solid digestate and peat, but even better without mulch in the compost. A similar experiment involving silage mulch in the outdoor cultivation of onion and leek concluded that the feeding of microorganisms was stimulated by the added organic mulch. In that outdoor trial, it was also found to be challenging to compare the feeding activity indicated by the sticks. The outdoor results may have been influenced by variations in humidity and temperature. Notably, results from one of the five locations were consistent with the present study, where microbial activity was higher without mulch. The authors of the outdoor trial suggested that when soil content is over a certain level of organic matter, then the microbiome becomes indifferent to the sticks. While the effect of mulching did not come clear at once, they tested a nearby location for residual effects after mulching. Then it came clear that mulching does have a positive effect on microbial activity. In the cucumber greenhouse trial, the positive influence of mulching did not appear in the measurements taken in May for any of the three mixtures. Regardless of the mixture, the effects of mulching are illustrated in Figure 2. The readings from the third week were inadequate, as the consumption amount should be progressive. A repetition of measurements in the next trial provided a clearer picture of the positive influence mulching, as shown in Figure 2. This may be interpreted as a residual effect, similar to the results found in the trials with leek and onion.

Phosphorous (P) content was highest in the solid digestate and lowest in peat (data not shown). Using fresh animal manure can provide significant amounts of P (J. Søllingvrå Jensen, pers. commun.), and the bio-rest contains pig manure, while compost and peat do not contain animal manure. High levels of P in soil may negatively affect mycorrhiza fungi (A.K. Rosberg, pers. commun.).

Another indicator for biological activity in the soil could have been the decomposition of tea bags. This method is cheap and easy to apply and can be compared to other data (Tresch and Fliessbach, 2017). It was applicated in 2023 and compared to outdoor results from 7 places in Norway. Degradation of tea was less pronounced in peat mixture. It was difficult to distinguish effect of mulch. As expected, degradation in greenhouse goes faster than for outdoor conditions. For an enterprise plan aimed at improving soil health, it is essential to consider both strategy and indicator. Common to all production are four strategies: 1) conservation of soil and organic matter, 2) minimizing erosion, 3) balancing production and environment, and 4) optimizing the use of renewable resources. The following indicators might measure 1) organic matter and change over time, 2) surface properties and covering degree, 3) plant culture characteristics and nitrogen status and fluctuation, and 4) plant culture characteristics and economy (Doran and Zeiss, 2000). Economy is not within the scope here but will be highlighted in another outcome of the project.

CONCLUSIONS

Data on soil life – especially in greenhouses – are difficult to find. The data obtained from selected indicators for soil life are useful to a certain point. As mentioned, beyond simply stating the presence of fungi, it would have been beneficial to categorize fungi into decomposers, pathogens or mycorrhizae. For sound organic production, the presence of both fungi and bacteria is essential. A high proportion of fungi provides a stable growing media, which was the case in all three mixtures.

The chosen methods were found to be reliable, feasible, and economically reasonable. They demonstrated that the organic matter content was appropriate in all three mixtures, promoting good conditions for soil life. The respiration of the microbiome was close to excellent in all three mixtures. The effect of silage mulch was difficult to interpret, but in 2023, a positive effect became clearer. It seems that the microbiome does not feed on bait lamina sticks if the growing media supply them sufficiently.

The selected mixtures ensured healthy soil local recirculation and organic amendment. For long-term maintenance of healthy soil, longer time experiments are needed. To describe the soil pathogen suppression, methods other than those used in this study are needed. The chosen methods are suitable for farm-level management aimed at enhancing sustainability. Additionally, the tea bag index for biological activity could also be applied, although it was not measured in this study.

ACKNOWLEDGEMENTS

We thank the Norwegian Agriculture Agency for financial support and researchers, advisers and civil servants: M. Stubberud at Norwegian Food Safety Authority gave orientation about new European organic regulation at Ecological Congress February 6-8, 2023. J. Søllingvrå Jensen at the Danish advisory company, Grotek, held a lecture June 20, 2023 at our open seminar. Same did A.K. Rosberg at the Swedish Agricultural University about crop rotation and effect on soil microbiome and soil borne diseases. R. Pommeresche and T. Rittl provided us their presentation held at Annual Science Days for European Joint Programme on Soil in Riga, Latvia June 12-14, 2023: Assessing on-farm soil health indicators under Norwegian conditions.

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