Investigating organic fertilisers' ability to mineralize during the first month of plant propagation

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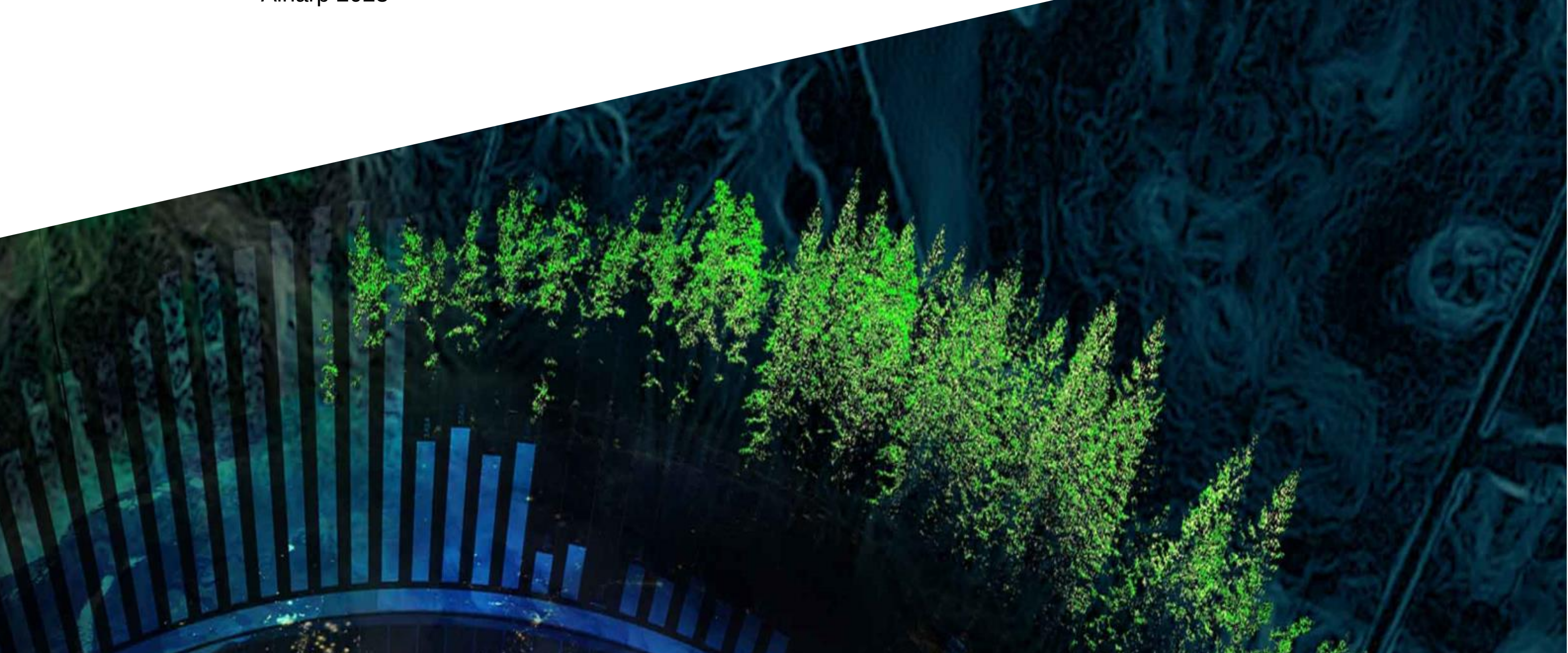

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Abstract

There are many forms of organc fertilizers produced and sold in the EU, and it can be difficult to assess which ones are the best in regards of nutrient content and the rate of mineraliztion. Two separate trials were conducted to assess the mineralization rates of three different organic fertilizers, available for private customers, on the Swedish market. One cow manure mix, one algae-based product and a solid fraction of biogas digestate were the tested fertilizers. The trials revealed that there were many differences in nutrient content and plant availability of said nutrients in the fertilizers. Analyses of the fertilizers' contents showed both several high values of some elements, as well as some completely depleted valuable elements. It was concluded that the cow manure fertilizer performed best of the treatments, in respect of mass of the model plant. The Algomin fertilizer and the biogas digestate fertilizer had more substrate nutrient content than the cow manure fertilizer, but it did not reflect in the size of the tomato plants grown in those treatments.

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1. Introduction

Organic fertilizers can be difficult to describe as a homogenous thing, since they are often composed of highly varying ingredients and compounds. For example an organic fertilizer can be composed of algae, molasses, blood, bones, plant residue and various animal manures and sold in the EU as organic fertilizer, as long as they reach the minimal standards determined by the EU council (EU, 2019, Sunarpi et al., 2021). Having such a high variance in ingredients for mixing a fertilizer causes the content of such fertilizer to be unpredictable, especially for the buyer.

When planting seedlings it is important to have the right amount and the right kind of fertilizer, and to apply it at the right time to ensure the new plants health and establishment (Moller and Schultheiss, 2015). If any of these points are lacking, the result could be an unhealthy plant. In some vegetable production there can be a short growing season and the requirements for the fertilizer to be precise and on time is high in those cultivations (Moller and Schultheiss, 2015). A short growing season also creates a demand for a high input of fertilizer during a short period.

Knowing what fertilizers to add and at what time could be challenging, since some of the nutrients can be bought in a different form than the plants mainly utilize, for example the different forms of nitrogen. According to Subbarao et al. (2006) most plants can utilize both nitrogen in the form of nitrate (NO_3^-) and ammonium (NH_4+), but the nitrate form is often preferred and easier utilized, in some stages of the plants development (Subbarao et al., 2006). Many commercial fertilizers contain nitrogen in its ammonium form. The ammonium nitrogen have to be nitrified before becoming easier plant available, and this process is ongoing in soils and fertilizers, where the nitrogen is often in a constant flux, Subbarao et al. (2006), often changing chemical form. When using store bought fertilizers for planting seedlings its important to know how much nitrate is available and also how much more nitrate will be made available in the near future, from the nitrification of ammonium.

When deciding wich organic fertilizers to use in a cropping area it can be hard to make an informed choice, since according to Moller and Schultheiss (2015) many organic fertilizers used in Europe, and sold under EU legislation, contain widely varied ammounts of nutrients, and sometimes excessive ammounts of heavy metals and other harmful contents. This is often not declared by the retailer or in the list of components.

In this project, the nutrient content, the mineralization rate and nitrification of the tested fertilizers will be assessed.

2. Background

2.1 Organic fertilizers

There is a high diversity of organic fertilizers on the market aimed at cultivating everything from vegetables to lawns and ornamentals.
These fertilizers can be composed of anything degradable such as manures, digestates, food industry derivatives, compost, or blood, hooves, bones and hairs from animal industry (EU, 2019).

Organic fertilizers, and especially animal organic fertilizers, have been reported by Gao et al. (2023), in a meta-analysis, to increase both the quality and the yield of tomatoes, compared to control treatments using mineral fertilizers.
To be considered a solid organic fertilizer within the borders of the EU the product needs to meet the following requirements (EU, 2019): At least 1% of mass is total nitrogen (N), 1% of mass is total phosphorus pentoxide (P) and 1% of mass is total potassium oxide (K). The sum of these three macro nutrients needs to be at least 4% of the products mass. At least 15% of the products mass needs to be organic carbon (C org). The product needs to be solid and contain at least one of the declared primary nutrients; Nitrogen (N), phosphorus pentoxide (P) or potassium oxide (K).

Since many organic fertilizers contain vastly varying compounds and degradables, (Moller and Schultheiss, 2015, EU, 2019, Gao et al., 2023) the predictability of when a fertilizer is considered to be suitable for a certain cultivation, is uncertain. There are many factors at play and it makes the usage of organic fertilizers difficult.

For organic commercial production it is common to use manure from chicken, cow, pig, and earthworm, to fertilize and amend the soil (Gao et al., 2023).

2.1.1 Algae extracts

Algae fertilizer products can be used for cultivation. There are various algae based fertilizer products available in stores, aimed at private customers and hobby growers. There could be a possibillty to expand the usage of these products if they prove to be useful for commercial production.

According to Sunarpi et al. (2021), the use of a small amount of brown algae extract in tomato production can decrease the need for inorganic fertilizers by up to 50%. The different algae used in these products have been reported to contain both plant growth hormones and macro-micro essential elements, in addition to the high nutrient value for the crops (Sunarpi et al., 2021). These products and algae extracts have interesting attributes that could see further development (Sunarpi et al., 2021), for example some extracts that increase growth and chlorophyll content, some that increase the yield of rice plants and some that increase the NPK absorption of tomato plants. This kind of product is rather new on the private market, compared to other types of fertilizer. Some attempts have been made in the Baltic region to utilize the brown algae for fertilizing purposes, with some success in both root elongation and promotion of growth (Bikovens et al., 2017).

2.1.2 Biogas digestate

Using biogas digestate as a fertilizer is favorable since it is part of a larger circular economic system.
Digestate from biogas production can be used as a fertilizer in food production (Koszel and Lorencowicz, 2015). It is derived from agricultural production waste, food waste, slaughter and urban greenery maintenance. According to Chiew et al. (2015) it was decided that in Sweden, 40% of all food waste should be recovered and reused as energy by 2018. Biogas production and the digestate that derives from it is a large part of the solution for managing this goal.
The product can be in liquid, solid or granular form (Prask et al., 2018), and can be used in both field production and in hydroponics, as a fertilizer and as soil amendment. The digestate is produced by introducing the previously mentioned biodegradable residues to an anaerobic environment, digesting it, while releasing biogas. According to Jurgutis et al. (2021), the selling of biogas digestate can increase the biogas plants income and the usage in cultivation can increase the nutrient densisity on low-fertility lands. The control of pH in cultivation using biogas digestate have been reported to be difficult, both in pots (Tampio et al., 2016), and in hydroponic systems (Lind et al., 2021). It is reported that biogas digestate can have a high variance in pH, reaching up to pH 9,05 (Torres-Climent et al., 2015).

Some attempts have been conducted to evaluate production of tomatoes with solid digestate as a part of the substrate (Bergstrand et al., 2020). It was then concluded that the nutrients present in the biogas digestate was sufficient enough to make biogas digestate a good candidate for greenhouse production.

According to Koszel and Lorencowicz (2015), the use of biogas digestate in horticulture is fully viable, as long as local legislation allows it. Since it is a relatively new product, it has not been thoroughly investigated in some countries and is not counted as equal to other fertiliers.

2.1.3 Cow Manure

Cow manure is widely used around the world and it is often mixed with other organic and degradable matter to create a good composition of nutrients and soil amendments for the crop to grow in. The fact that store bought cow manure is often a mix of many things makes it hard to generalise as a fertilizer. It can contain everything from chicken, sheep, pig and horse manure to plant ash, activated carbon, yeast, food waste, compost and many other things (Moe, 2017, EU, 2019, Utami et al., 2019).
The content can therefore vary widely when looking at different organic cow manures, and so can the nutrient content. For example, the NPK-values can change a lot in the fertilizer just by a small change in the ratio between cow manure and chicken manure (Utami et al., 2019), and these two manures are the most common manures in commercial organic cow manure. Using cow manure in this trial is interesting since it can both act as a organic control, where the mineral fertilizer control is not organic, and because it is one of the most widely used fertilizers in the EU (EU, 2019).
The cow manure is according to Moe (2017) and Utami et al. (2019), a good source of nutrients up until a point in production when the nutrients can deplete. Cow manure is also according to Yunilasari et al. (2020) and Goncalo et al. (2020), used as a soil amendment for both soil structure and for restoring ruined soils. According to Zhang et al. (2020), mixing cow manure with soil also helps in maintaining the bacterial microbiota in soils, which can be damaged by for example the use of mineral fertilizers.

2.2 Mineralization of nitrogen (N)

The mineralization of nitrogen is an important part of soil fertility and occurs naturally in soils continuously. The process is complex and involves various life forms, such as fungi, bacteria and actinomyces (Kitchen, 2001). They collectively break down different forms of organic matter in soils to compounds that are plant available, or possibly instead become gaseous, leach out from the cropping system or become immobilized in the soil. The ratio of carbon to nitrogen matters in respect to when it occurs in the soil, and if there is a flux between the different forms of nitrogen. The soils' carbon content matters a lot. If the carbon-to-

nitrogen (C:N) ratio in the soil is above 30:1 (McLaren and Cameron, 1996), the microbes in the soil absorbs the nitrogen and makes it immobile. If the C:N ratio instead is less than 25:1, decomposition releases mineralized ammonium, as carbon is removed from the soil as for example carbon dioxide. Mineralization is the opposite of immobilization. To become fully plant available the minerals thereafter have to be nitrified, since the main source of plant nitrogen is in the form of nitrate (Subbarao et al., 2006), for most crops.
The bacteria responsible for the natural nitrification is of the generas *Nitrobacter* and *Nitrosomonas* (Daims et al., 2016). The *Nitrosomonas* is the genera that generally oxidise ammonium to nitrite. The *Nitrobacter* is the genera that oxidise nitrite to nitrate. Within the generas there are plenty of species that are important to the nitrogen cycle. The nitrification process and the bacterium responsible for it is most active in warm, mosit and aerated soils, with a pH of 6 and above.

Having too much ammonium nitrogen or nitrate nitrogen in a soil or substrate meant for cultivation could pose various problems.
Plants that are subject to ammonium toxicity will according to Barker and Corey (1991), develop chlorosis, necrosis, leaf deformities and have a stunt in growth. Large ammounts of ammonium N in the soil will also have phytotoxical features. The same applies to plants that are subject to nitrate toxicity, the symptoms will be similar. It has also been reported by Puritch and Barker (1967), that tomato plants' chroloplats will change and break down during ammonium toxicity. The plants will also have decreased photosynthetic qualities and chlorophyll loss.

2.3 Mineralisation of phosphorus (P)

Phosphorus in the form of phosphates is one of the most important macro nutrients for biological growth and health on earth. In plants, phosphorus play a role in for example cell division, photosynthesis, metabolism and transport of nutrients within the plant (Behera et al., 2014). Phosphorus have been estimated to be 0,2% of most plants' dry weight.

The natural oxidation of phophorous is an ongoing process in soils and is an important cycle for life on earth. Phosphorus in its pure form, in soils are insoluble and not plant available, both in its mineral form and its organic forms. The phosphorus needs to be solubilized according to Khan et al. (2007) and Behera et al. (2014), in order to become phosphates that are plant available, and that is done mostly by phosphate solubilizing microbes, mostly bacteria from the generas *Pseudomonas*, *Bacillus*, *Rhizobium* and fungi from generas *Penicillum*, *Aspergillus* and *Fusarium*. This microbial life release enzymes called phosphatases that are crucial to the solubilization of phosphate. Other mechanisms

that solubilize phosphorus in the soil are organic acids, for example lactate, oxalate and acetate.
The pH plays a large role in the mineralization of phosphorus according to Khan et al. (2007), and the regulation of the different organic and inorganic acids in soil contribute to the acceleration or deceleration of the process. The pH should according to Khan et al. (2007), be around pH 6-7 for the phosphorus to be mineralized, and a high presence of ammonium in the environment can sometimes lead to a decrease in phosphorus solubilization.

2.4 Measurements of mineralization

When measuring the mineralization and solubilazation of phosphorus, a couple of ways are used. One of them is according to Behera et al. (2014) isolating colonies of the model bacteria and surrounding them with insoluble minerals mixed with Bromophenol Blue. There will be a yellow halo formed around the colonies when they solubilize the mineral, lowering the pH in the process, because of the released organic acids.

Another way to measure the mineralization is the widely used Spurway analysis, where the plant available nutrients in the soil or substrate is analysed (Bergstrand, 2021, Mattila and Rajala, 2022).

The buried bag method is also a way to test N mineralization in field (Sullivan, 2020). It consists of digging up soil to fill empty bags before the sowing starts, to bury the bags after the planting is done. The bags should be made out of material that lets some oxygen and carbon dioxide to pass through it. The bags will stay in the same conditions as the rest of the soil during the season, and at any time during the season, bags can be dug up and analyzed for comparision with the rest of the soil in the field to determine the net mineralization of the soil on the field.

There are according to Frerichs et al. (2020), also ion-selective electrodes available to measure ammonium/nitrate content, for example (Thermo Orion Standard Ammonia Electrode, Thermo Electron corporation, USA; Feld-pH-Meter, pH/cond 340i, Xylem Analytic Germany Sales GmbH & Co. KG, WTW, Weilheim, Germany). They proved to be efficient in pot cultivation.

The crop N uptake from a Zero N plot is also a method for determining the mineralization of a soil (Sullivan, 2020). This method requires a crop to be cultivated without any added soil amendments, N fertilizers and any other N inputs during a season. The crop N content is measured at the end of the season, using the crops tissue N concentration and the crops dry weight. This method has proven to be useful and successful in areas with enough rainfall to make most residual N leach away from the previous season. If the residual N is leached away, the N found in the plant tissue consists of mostly mineralized N from the current year.

2.5 Project aim

The aim of this project is to examine the properties of different organic fertilizers when it comes to mineralization, nitrification, and lastly, nutrient content in the fertilizer. With knowledge in fertilizers' properties comes better efficiency in utilization of organic fertilizers.

A trial will be conducted to determine the mineralizing properties and the nutrient content of three different organic fertilizers sold on the Swedish consumer market; Algomin, solid fraction of biogas digestate and cow manure. A mineral fertilizer will be the control.

2.6 Research questions

- How predictable is the mineralization rate of nutrients in these fertilizers?
- Will the mineralization of the nutrients be affected by a change in climate between the two trials?
- Are these fertilizers suitable for cultivation, in regards of mineralization?

2.7 Hypotheses

- The mineralization rates will be higher in the second trial, because of a greater amount of light and heat.
- The biomass analyses will show that the plants grown with the commercial mineral fertilizer will be the largest.

3. Materials and methods

3.1 Fertilizers and treatments

Two separate trials were conducted, one in late winter and the other in early spring 23.02.15 – 23.03.10 & 23.04.13 – 23.05.5. They were done in a green house with climate control. There were two short trials to get data on differences in results under different climatic conditions. Tomato, *Solanum lycopersicum* 'Dasher', seeds were sown two weeks prior to transplanting. They were sown in vermiculite and grew their first two weeks in a set daily temperature of between 18 and 20 °C, before transplanted. Watering was done from above when the top substrate was dry. The substrate was never allowed to dry out completely.

The fertilizers used were three different organic products, certified by Swedish KRAV to be used in ecological cultivation.
Algomin Gröna Fingrar Vegansk Näring (Hasselfors Garden), vegan product made from brown algae extract, 5% bio char and 5% lime. Indicated NPK value at 4-1-5. KRAV-certified. 20g of Algomin L^{-1} of substrate.

A solid fraction of biogas digestate (Gasum Jordberga AB, Klagstorp, Sweden) was used. Before digestated, the average yearly input is 34% recirculated bio fertilizer, 30,9% water, 21,2% residues from food industry, 13,5% farmed crops, residues from cereals and vegetable biproducts, 0,4% iron chloride. Indicated NPK value at 5,8-0,9-3,5. KRAV-certified. The digestate is a biproduct of biogas production. 150g digestate L^{-1} of substrate was used.

A cow manure mix from Simontorp (Weibulls) was used. It contaied 80% peat, 10% cow manure and 10% chicken manure. KRAV-certified. Indicated NPK values at 1660 mg L^{-1} total nitrogen (N), which of 154 mg L^{-1} is nitrate. 20 mg L^{-1} phosphorus (P) and 250 mg L^{-1} potassium (K). 300g cow manure mix L^{-1} substrate was used.

A mineral fertilizer was used as a control. The fertilizer used in the first trial was Stroller Blå. Pellets with indicated NPK value at 12-3-15. For the second trial Yara Mila PROMAGNA was used as control, with an indicated NPK-value at 11-5-18.

Each of the fertilizers were mixed with natural, untreated peat (Rölunda), and then limed (Magnedol) until it reached an acceptable pH. For the cow manure and the biogas digestate 4 g L^{-1} were enough to reach 5,8 pH. For the mineral fertilizer and the Algomin treatments 8 g L^{-1} was used to reach a pH of 5,5. To measure the pH, 30g of substrate was mixed with 100 ml distilled water and shaken for one hour. A pH meter was then used to determine the pH values.
The aim for all treatments were a value of 800 mg N L^{-1} of substrate (Bergstrand et al., 2020), at the start of the trials. The value of 800 mg N L^{-1} was calculated without taking the fertilizers' other nutrients into account.

3.2 Analyses

3.2.1 Substrate solution nutrient analyses

Once a week during the trials, lysimeters with ceramic tips, Rhizon soil moisture sampler (Eijkelkamp Agriresearch Equipment, Giesbeek, the Netherlands), were put in the chosen pots and left for 24 hours. Liquid was extracted and collected with 6 ml vacuum tubes (BD Vacutainer, Becton, Dickinson and Co, Franklin Lakes, NJ, USA).The liquids were then collected and stored in a freezer until further analysis. When analyzation was due, the liquid was thawed and used with test kits Hach Lange GmbH (Düsseldorf, Germany) according to the manufacturers instructions. LCK340 for nitrate (NO_3-N), LCK349 for phosphate (PO_4-P) and LCK303 for ammonium (NH_4-N). Nutrient amounts were examined in a Hach Lange DR 3900 spectrophotometer for the nitrate/phosphorus/ammonium content results. When using the kit for phosphorus, Lange LT200 was used for the heating process. The results were presented in mg L^{-1} for all tests.

3.2.2 Spurway analasys of substrate

Substrate samples were sent to the laboratory at LMI AB (Helsingborg, Sweden) for a Spurway analysis, at the end of both trials. The results from the Spurway analysis was used to verify the values measured with the spectrophotometer and substrate liquid samples. Additionally several other nutrients in the substrate were assessed and observed with the Spurway analysis, potassium, magnesium, sulphur, calcium, manganese, boron, iron, sodium and aluminium.

3.2.3 Leaf area measurements

The leaf area of each harvested plant was measured. Every above ground part, except the main stem, was measured with a LI-3100C (Li-Cor Biosciences GmbH Bad Homburg, Germany).

3.2.4 Chlorophyll content measurement

To measure chlorophyll content, the Apogee Instruments MC-100 Chlorophyll Concentration Meter was used. The measurements' values were accounted for in Chlorophyll Content Index (CCI).

3.2.5 Statistics

The statistical analyses were performed using Minitab statistical software (release 16; Minitab Inc., State College, PA, USA). The data was analyzed using Tukey's One way analysis of variance (ANOVA).
Microsoft Excel was used for graphs.

4. Results

4.1 Substrate solution nutrient analysis

4.1.1 Nitrate

The nitrate levels varied widely between treatments and also between the two trials.

The nitrate level were by far the highest in the cow manure treatment (Figure 1), during the whole trial, up to the last measurement where the nitrate had depleted from that treatment, and the Algomin and the biogas digestate contained the significantly highest concentration of nitrate. The cow manure and mineral fertilizer treatments had the lowest concentration and did not differ significantly from each other.

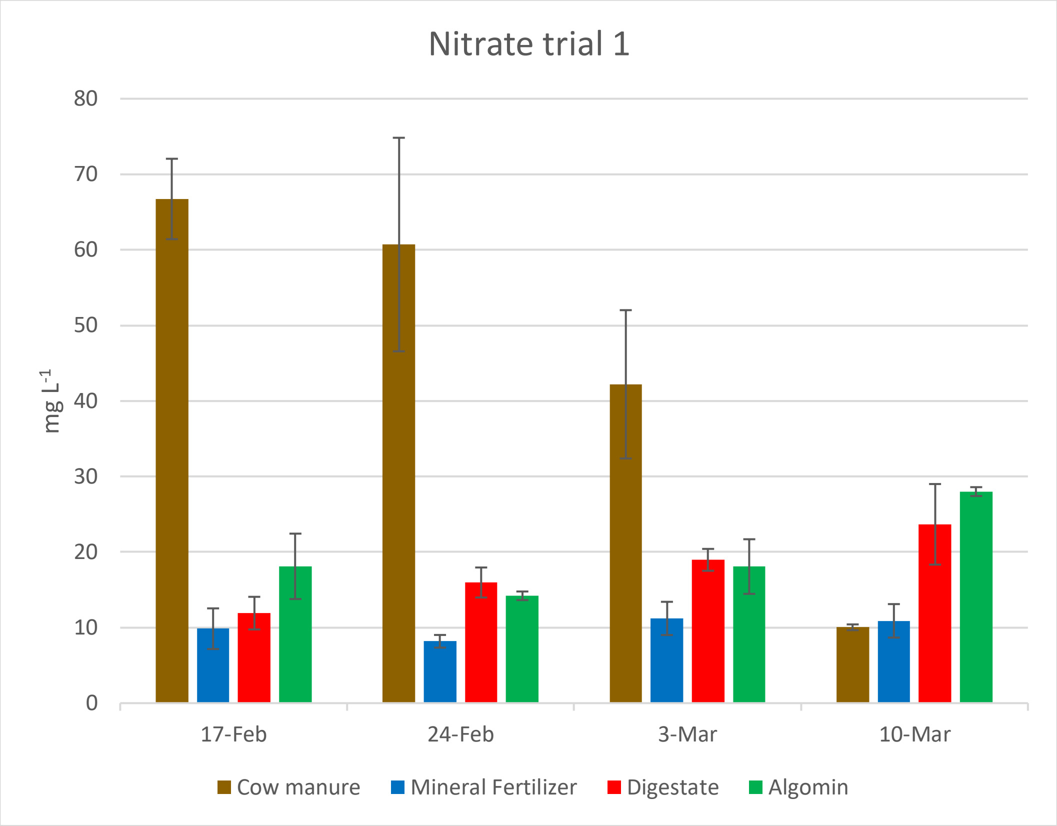

Figure 1. Substrate content analysis. Nitrate content, trial 1. N=3. Mean values. Treatments: ***Brown****: Cow manure.* ***Blue****: Mineral fertilizer.* ***Red****: Biogas digestate.* ***Green****: Algomin.*

Trial 2.
In the second trial, the mineral fertilizer started with a significantly greater amount of nitrate than the other treatments (Figure 2). The second week of measurements, the cow manure treatment increased its nitrate content to be significantly higher than the biogass digestate and Algomin treatments, but lower than the mineral fertilizer. The third and fourth weeks, the cow manure reached equal nitrate rates as the mineral fertilizer, while the other two treatments had a much lower nitrate content.

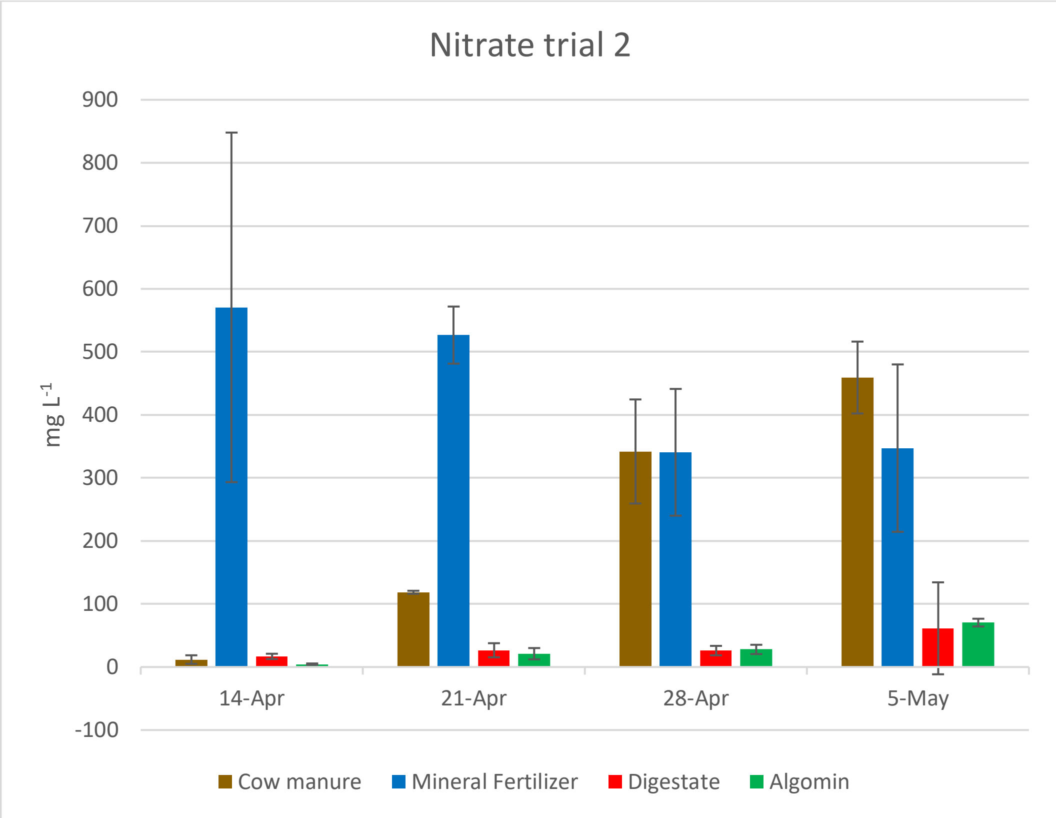

Figure 2. Substrate content analysis. Nitrate content, trial 2. N=3. Mean values. Treatments: ***Brown****: Cow manure.* ***Blue****: Mineral fertilizer.* ***Red****: Biogas digestate.* ***Green****: Algomin.*

4.1.2 Ammonium

Trial 1.
The first week the mineral fertilizer treatment had a significantly higher ammonium content than all other treatments (Figure 3). The same was true for week 2. Week 3, the mineral fertilizer still had a much higher ammonium content than biogas digestate and the cow manure treatments, and higher, but not significantly towards the Algomin treatment. The cow manure treatment had almost no traces of ammonium left at the third and fourth week, and the Spurway analysis did not report any presence of ammonium or nitrate left in the substrate at week four.

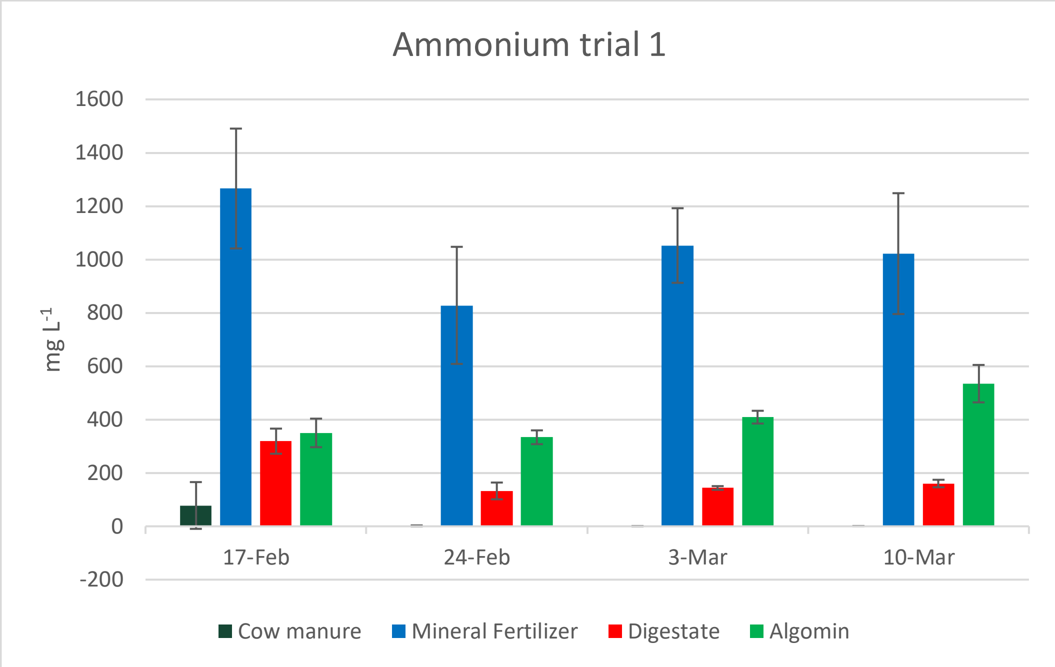

Figure 3. Substrate content analysis. Ammonium content, trial 1. N=3. Mean values. Treatments: ***Brown****: Cow manure.* ***Blue****: Mineral fertilizer.* ***Red****: Biogas digestate.* ***Green****: Algomin.*

Trial 2.
In measurement 1, there was no significance between treatments, even though the values varied a lot (Figure 4), and the mineral fertilizer contained more than 10 times more ammonium in the substrate than the cow manure treatment did.

At the second measurement, the mineral fertilizer had the significantly highest content of ammonium, while the Algomin treatment had the second highest rate, also significantly compared to the digestate and cow manure treatments. The biogas digestate and the cow manure had similar values to each other.
During week 3, the Algomin and the mineral treatments changed, and the Algomin had a significantly higher ammonium content than both the cow manure and the biogas digestate treatments. The cow manure treatment contained very little ammonium at this point.
At the last week, the ammonium levels of the mineral fertilizer and the Algomin treatments were equaly high and also significantly higher than both the other treatments. The cow manure treatment contained only traces of ammonium at this point.

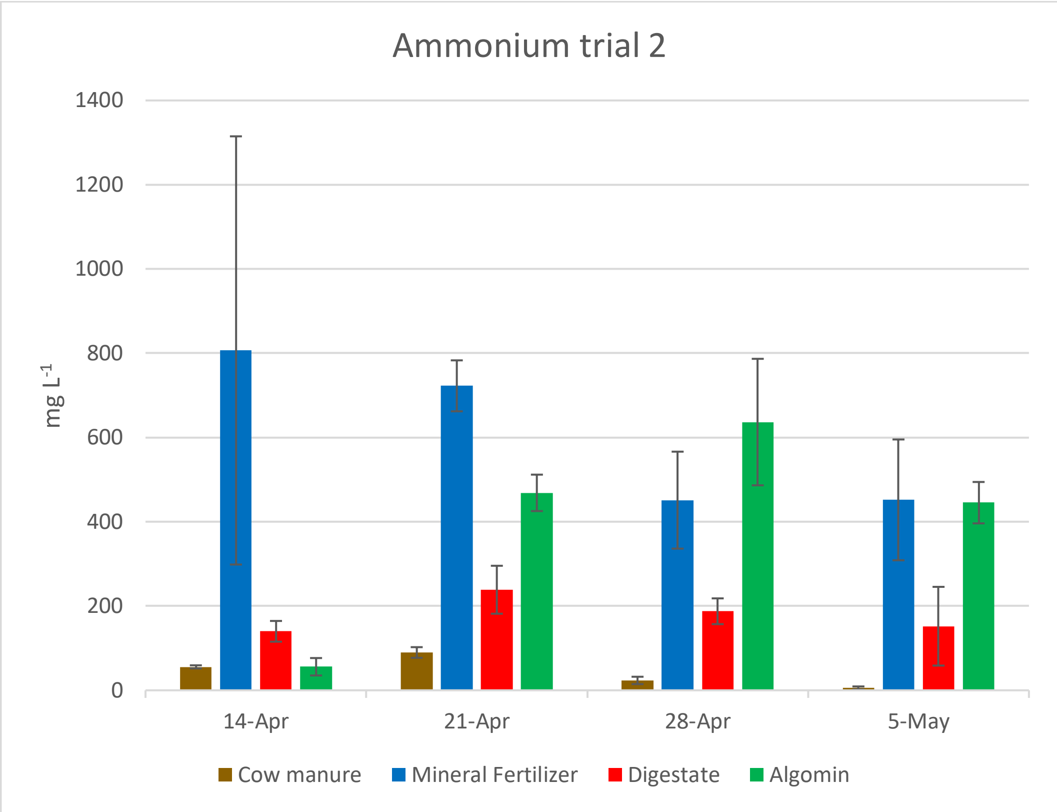

*Figure 4. Substrate content analysis. Ammonium content, trial 2. N=3. Mean values. Treatments: **Brown**: Cow manure. **Blue**: Mineral fertilizer. **Red**: Biogas digestate. **Green**: Algomin.*

4.1.3 Phosphate

Trial 1.

At the start there was only one treatment differing from the others in content of phosphorus and that was the cow manure treatment (Figure 5). It had significantly lower phosphorus values than the other three treatments.

At week 2 and 3, the mineral fertilizer had a significantly higher phosphorus content than both the Algomin and the cow manure, but not the biogas digestate treatment. The cow manure treatment had a much lower content than the mineral and digestate treatments, but not compared to the Algomin.

At the last week the mineral treatment still had a much higher phosphorus content compared to the cow manure and the Algomin, but not compared to the biogas digestate. The cow manure treatment still had a very low phosphorus content compared to the other treatments.

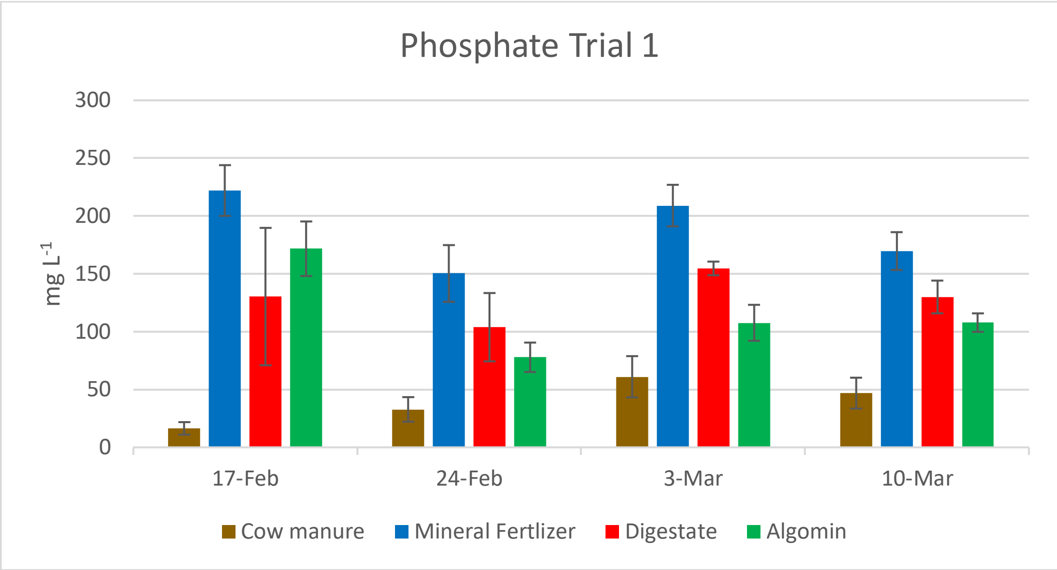

Figure 5. Substrate content analysis. Phosphate content, trial 1. N=3. Mean values. Treatments: ***Brown****: Cow manure.* ***Blue****: Mineral fertilizer.* ***Red****: Biogas digestate.* ***Green****: Algomin.*

Trial 2.
Measurement 1 showed that the mineral fertilizer had a significantly greater content of phosphorus than both the cow manure and the biogas digestate (Figure 6). The Algomin was somewhere in the middle and did not differ much from the other treatments.
Week 2, the biogas digestate had an increased value, compared to the previous measurement and was significantly higher than both the cow manure and the Algomin, but still significantly less than the mineral fertilizer, in phosphorus content. The cow manure and the Algomin had similar results.
In week 3, the biogas digestate and the cow manure treatments had equal results and were not different from each other, but had significantly lower phosphorus content than the mineral fertilizer and higher than the Algomin treatment.

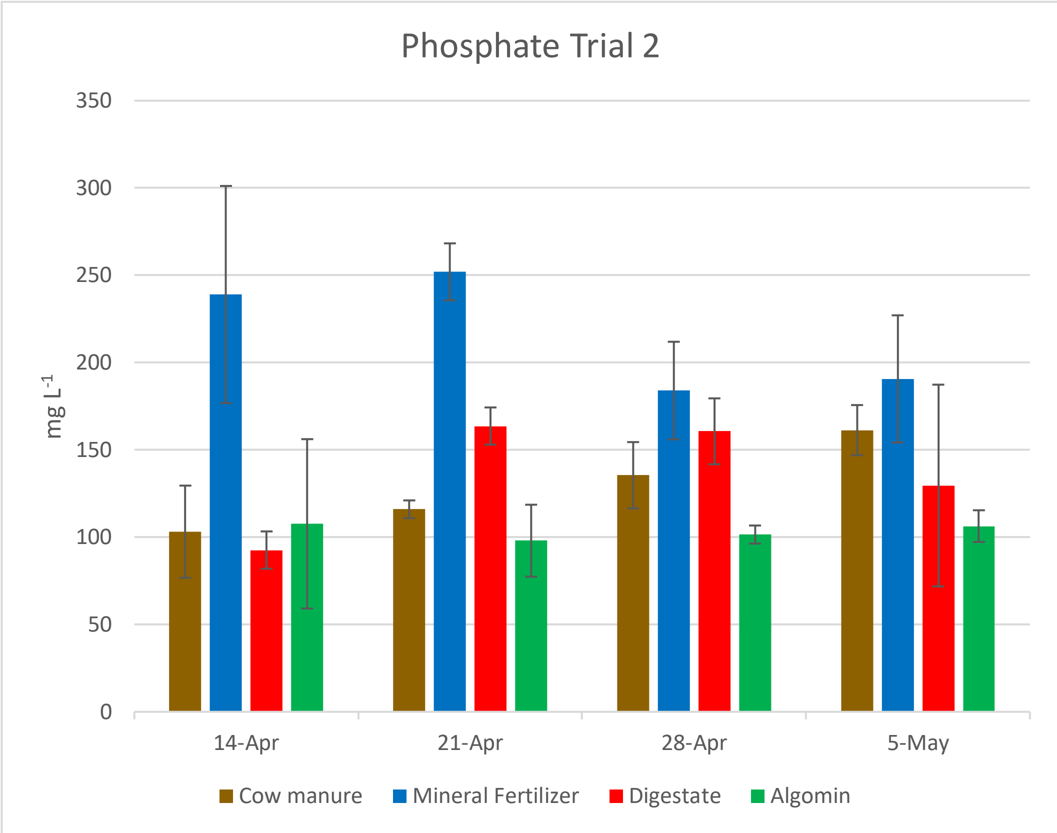

*Figure 6. Substrate content analysis. Phosphate content, trial 2. N=3. Mean values. Treatments: **Brown**: Cow manure. **Blue**: Mineral fertilizer. **Red**: Biogas digestate. **Green**: Algomin.*

The final week the values had equaled out and none of the values were significant from one another. The mean value of phosphorus content only varied from 106,37 to 190,7 for all treatments.

4.2 Leaf area

The leaf area measurements showed that the cow manure treatment had significantly larger foliage (Figure 7), than the other treatments throughout the whole test, except for the last measurement, where the digestate treatment caught up in size.

For the second trial (Figure 8), there were no significant size difference between cow manure, digestate or the control treatments, at the start of the experiment. At week 2 there was a significant difference between the cow manure treatment and the Algomin and digestate treatments, where the cow manure treatment were larger. The cow manure and control did not significantly differ. At the end of the trial, the cow manure and the mineral fertilizer control treatments were by far the largest, the Algomin treatment significantly worse than both of them, and the digestate treatment somewhere inbetween, not differing significantly from either Algomin or the control treatment.

The mineral fertilizer had the significantly smallest plants in the first trial but not in the second trial. The Algomin treatment had the smallest plants, only significantly in the first week but not significantly in the other two measurements.

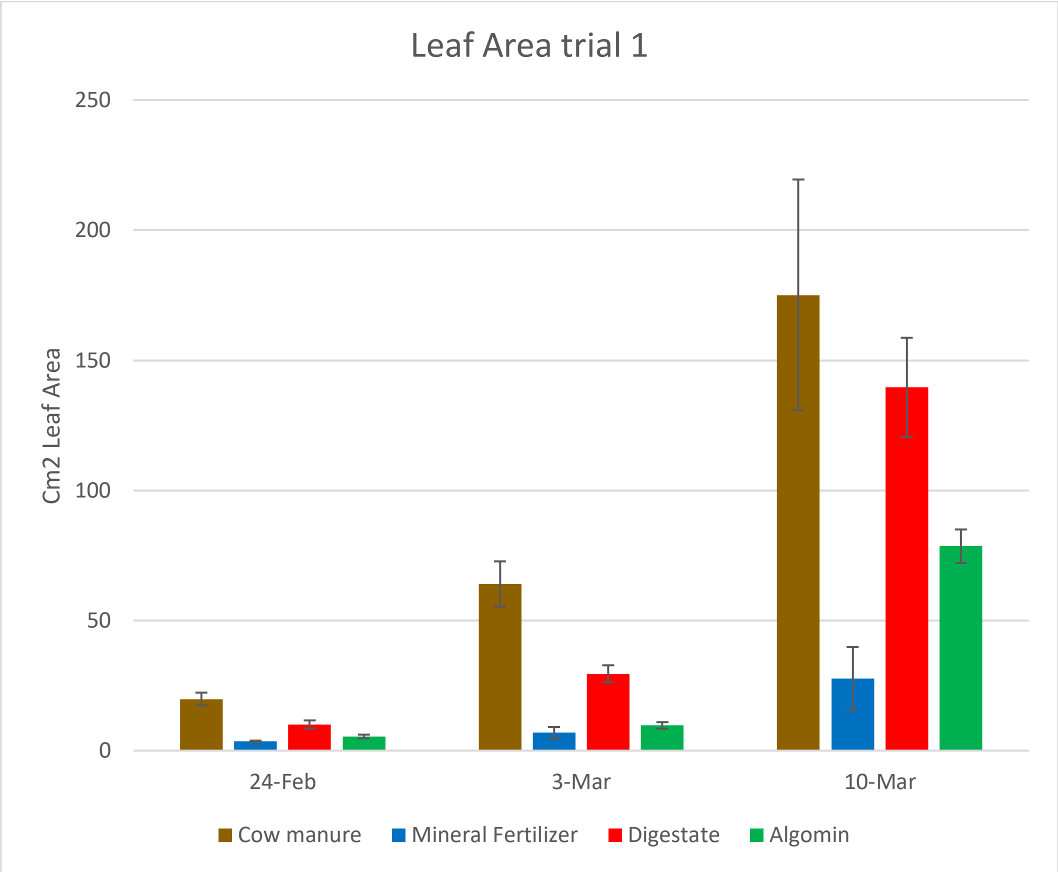

Figure 7. Leaf area measurement. Trial 1. N=3. Mean values. Treatments: ***Brown****: Cow manure.* ***Blue****: Mineral fertilizer.* ***Red****: Biogas digestate.* ***Green****: Algomin.*

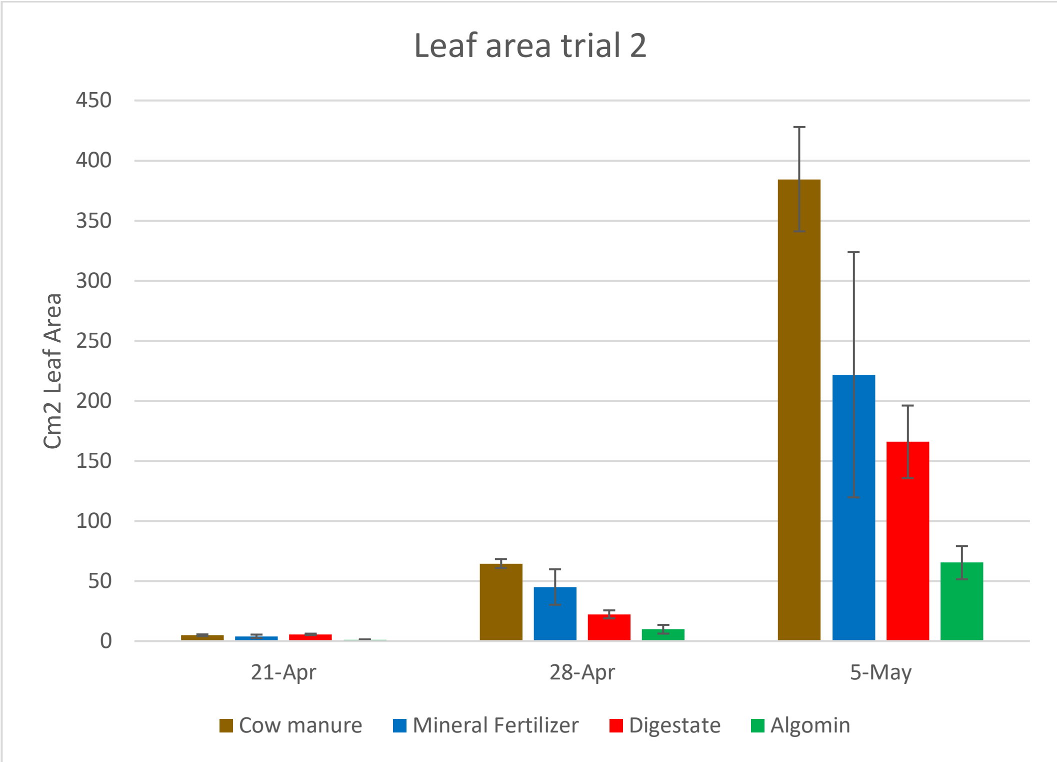

Figure 8. Leaf area measurement. Trial 2. N=3. Treatments: Mean values. ***Brown****: Cow manure.* ***Blue****: Mineral fertilizer.* ***Red****: Biogas digestate.* ***Green****: Algomin.*

4.3 Chlorophyll content

Trial 1.
The Algomin treatment had the significantly highest chlorophyll content index (CCI) in both measurements (Figure 9). The mineral fertilizer had the significantly lowest CCI in trial 1, measurement 2. Otherwise the treatments did not differ significantly in trial 1.

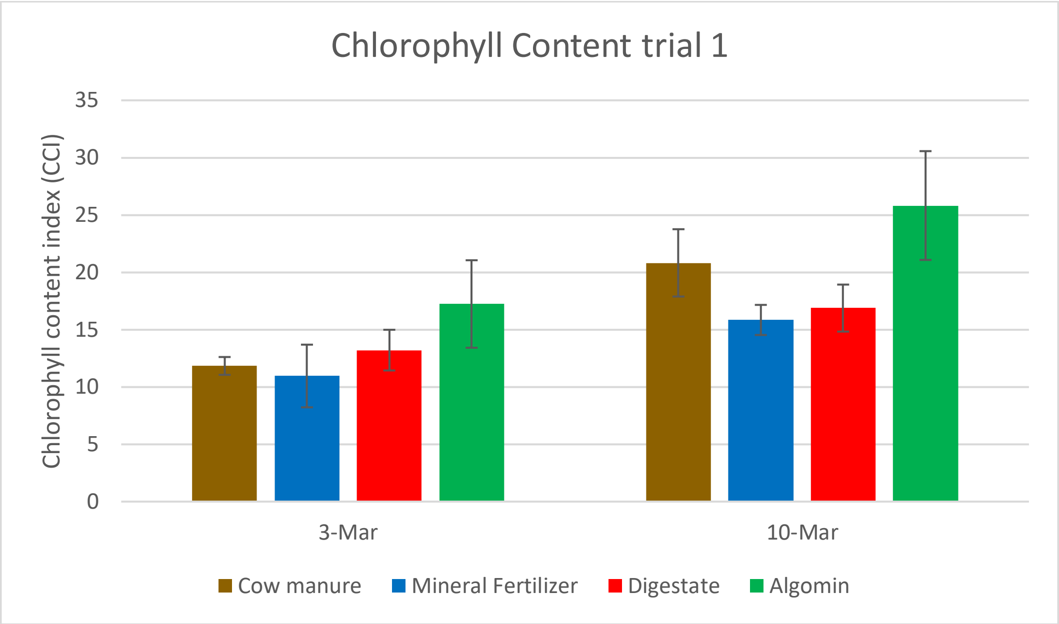

Figure 9. Chlorophyll content. Trial 1. N=3. Mean values. Treatments: ***Brown****: Cow manure.* ***Blue****: Mineral fertilizer.* ***Red****: Biogas digestate.* ***Green****: Algomin.*

Trial 2.
In the first measurement, the Algomin and the mineral fertilizer differed significantly from the cow manure and the digestate treatments, but they did not differ between each other (Figure 10). The Algomin and the mineral fertilizer had the highest CCI.

In the second measurement, the only significance was that the mineral fertilizer had a higher CCI than both the digestate and the cow manure treatments.
The two trials combined, the Algomin had the highest CCI, sometimes significantly and sometimes not, but always in the top.

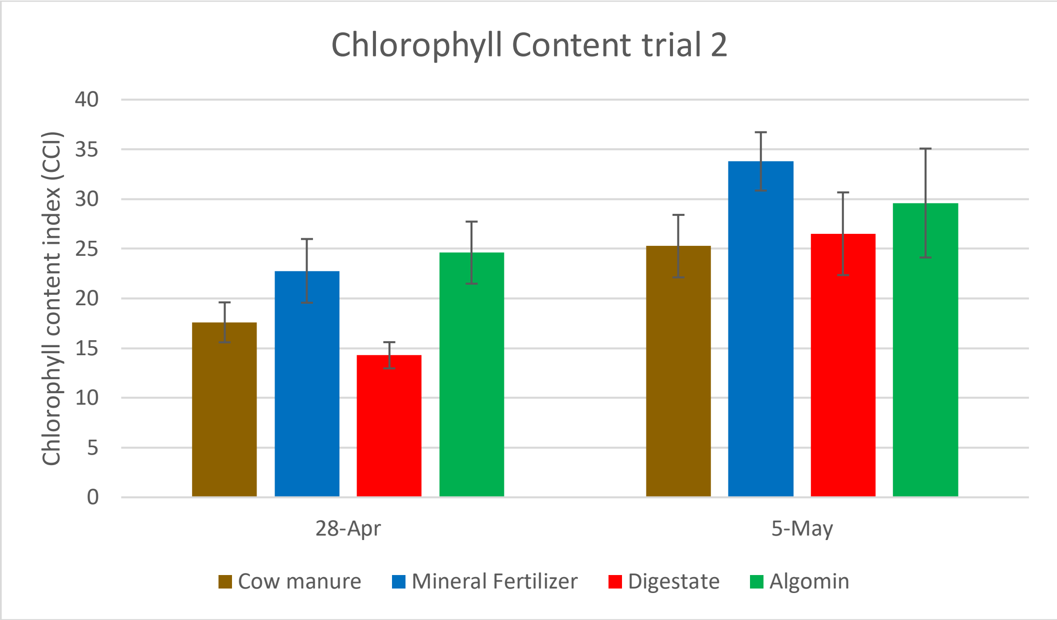

Figure 10. Chlorophyll content. Trial 2. N=3. Mean values. Treatments: ***Brown****: Cow manure.* ***Blue****: Mineral fertilizer.* ***Red****: Biogas digestate.* ***Green****: Algomin.*

4.4 Fresh and dry weight

Trial 1.

The fresh weight from the cow manure treatment was significantly higher than the other treatments in measurement one (Figure 11 & 12). The digestate treatment was also significantly higher than both the Algomin and the mineral fertilizer treatments.

In terms of dry weight, in the same measurement, the cow manure treatment was still significantly the highest, and the mineral fertilizer one was the lowest, while the other treatments did not differ.

In the second measurement, the cow manure fertilizer treatment was the highest, the digestate was the second highest, and the other two treatments had weights not significantly different from oneother. This was true for both fresh and dry weight.

In the third measurement, fresh weight showed that the cow manure treatment was significantly higher than both the Algomin and the mineral fertilizer treatments. It did not differ enough from the biogas digestate treatment to be significant. The biogas digestate treatment differed from the mineral fertilizer significantly but not from the other two treatments. The mineral fertilizer treatment had by far the lowest weights. Looking at the dry weights of the same plants, the cow manure treatment was the only one significantly higher than all the other three.

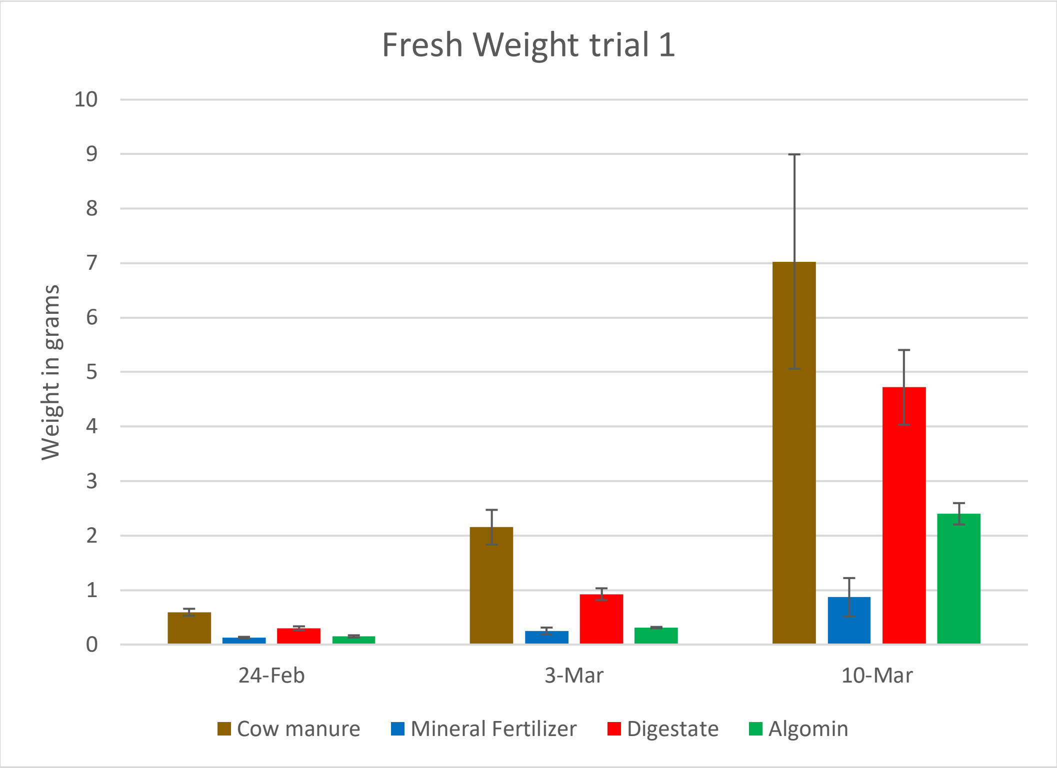

*Figure 11. Fresh weight in grams. Trial 1. N=3. Mean values. Treatments: **Brown**: Cow manure. **Blue**: Mineral fertilizer. **Red**: Biogas digestate. **Green**: Algomin. N=3*

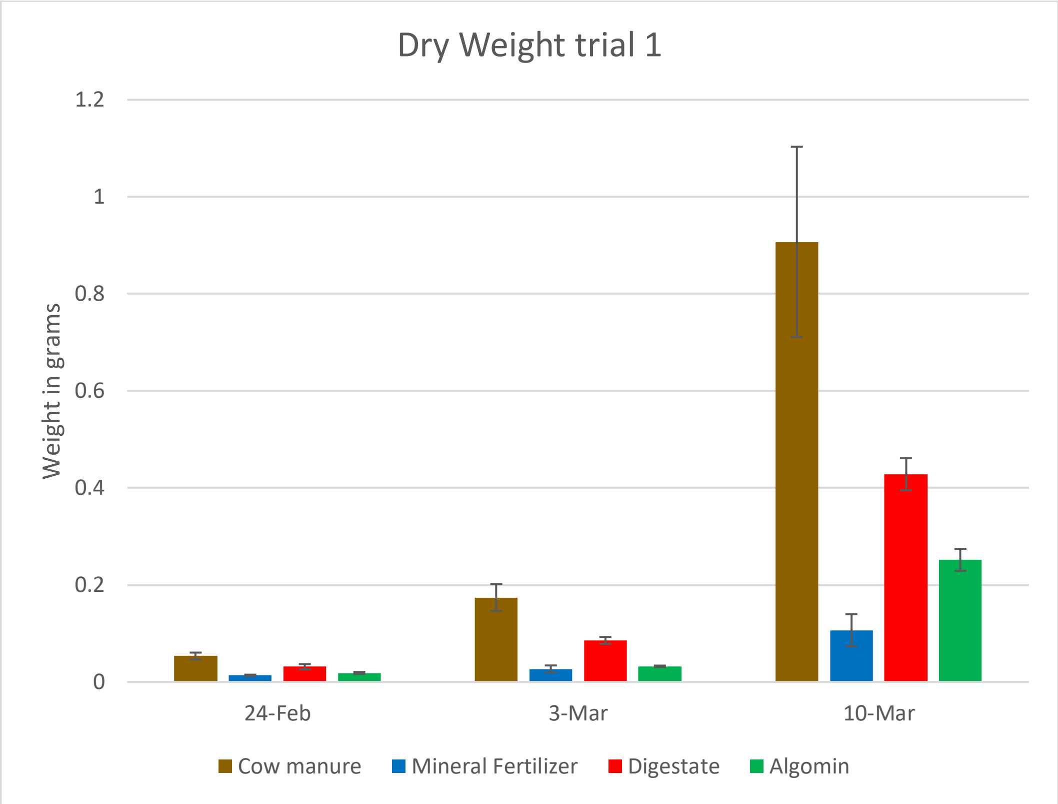

Figure 12. Dry weight in grams. Trial 1. N=3. Mean values. Treatments: ***Brown****: Cow manure.* ***Blue****: Mineral fertilizer.* ***Red****: Biogas digestate.* ***Green****: Algomin.*

Trial 2.
Measurement 1 showed that in both fresh and dry weight, the cow manure and the biogas digestate were significantly higher than the Algomin treatment (Figure 13 & 14). The mineral fertilizer did not differ enough from either of the other treatments to be significant.

In measurement 2, both the fresh and dry weight showed that the cow manure and mineral fertilizer treatments were heavier than the Algomin ones. Only the cow manure treatment had higher weight than the biogas digestate treatment.

Measurement 3 showed that the cow manure treatment were significantly higher that all other three treatments in fresh weight. The other ones did not differ enough from each other to be significant.
Looking at the dry weight on the same plants showed a small difference from that, where the cow manure and the mineral fertilizer treatments were close in weight, but still significantly different from the Algomin treatment. The mineral fertilizer treatment and the biogas digestate one had differences but not large enough to be significant.

Combined results for the four weeks of the second trial showed that the cow manure treatment were significantly larger than the other plants, while the Algomin treatment contained the significantly smallest plants.

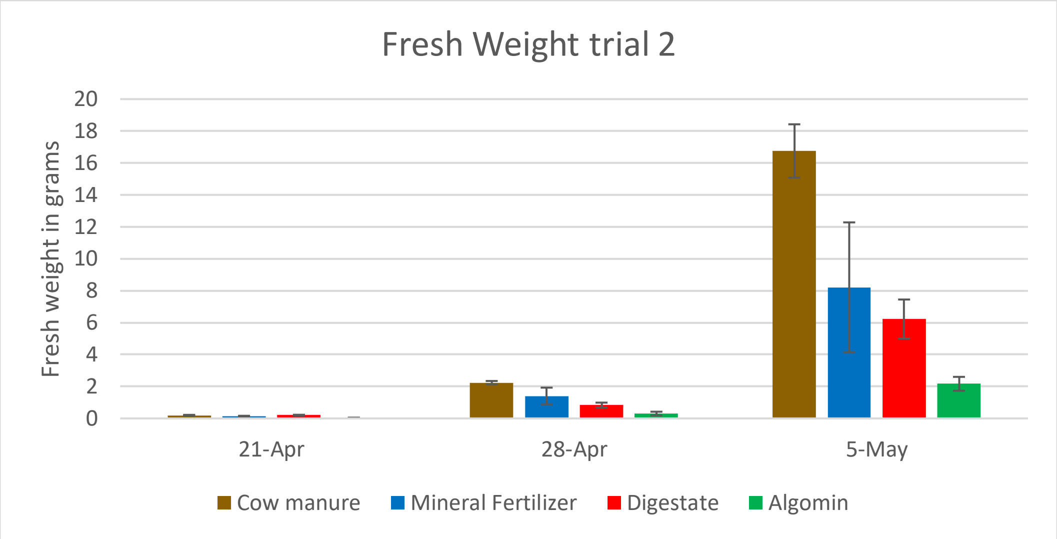

*Figure 13. Fresh weight in grams. Trial 2. N=3. Mean values. Treatments: **Brown**: Cow manure. **Blue**: Mineral fertilizer. **Red**: Biogas digestate. **Green**: Algomin.*

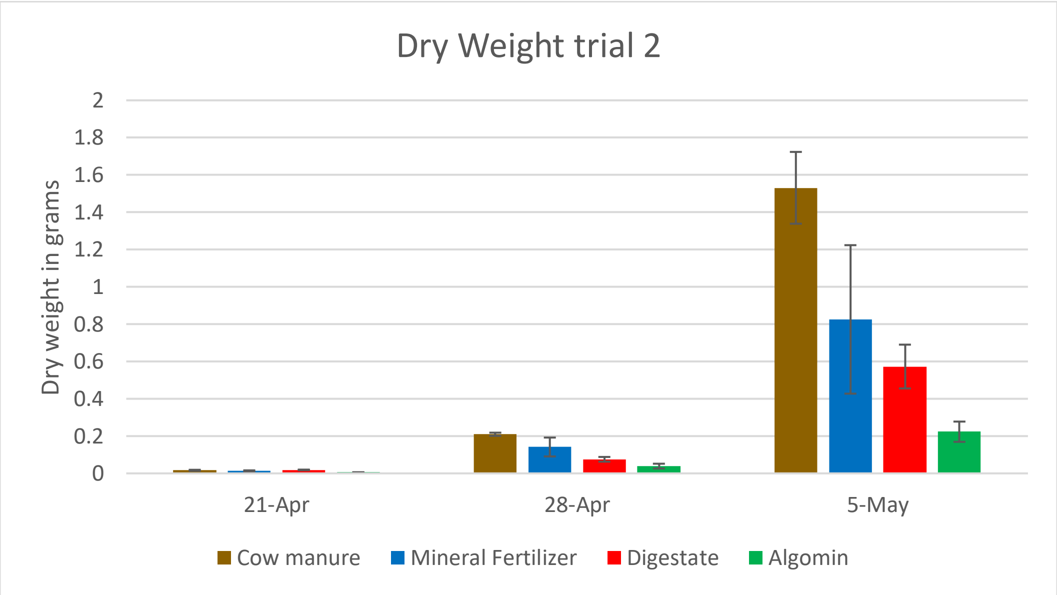

*Figure 14. Dry weight in grams. Trial 2. N=3. Mean values. Treatments: **Brown**: Cow manure. **Blue**: Mineral fertilizer. **Red**: Biogas digestate. **Green**: Algomin.*

4.5 Spurway analysis

The results from the Spurway analysis (Table 1 & table 2), showed that the cow manure contained high values of sodium, between 120-180 mg L^{-1}, in both treatments. The other treatments also contained sodium but in a lesser extent. The other results confirmed the results received from the spectrophotometer regarding nitrate and ammonium. The ammonium was absent from the cow manure treatment in both trials, but contained a high amount of nitrate in the second trial (Table 2).

The analysis showed that both the Algomin treatment and the mineral fertilizer treratment contained high amounts of potassium and sulphur, in both trials. The mineral fertilizer also contained excessive amounts of manganese and boron in the second trial (Table 2), but not excessive in the first trial (Table 1).

The biogas digestate appears to have a low content of every tested type of mineral, except potassium and iron, in the first trial (Table 1). In the second trial it did not have high values in those minerals either (Table 2).

The results for phosphorus/phosphate from the Spurway analysis were in content of phosphorus, not in phosphate and cannot be properly compared to the results of phosphates from the spectrophotometer.

Table 1. Spurway analysis results from trial 1, regarding content of macro and micro nutrients, showed as mg L^{-1}. Standard deviation of treatments. The numbers are mean values. Samples taken 23.03.10. N=3.

	Cow manure	Cow manure st.dev	Mineral fertilizer	Mineral fertilizer st.dev	Biogas digestate	Biogas digestate st.dev	Algomin	Algomin st.dev
Nitrogen	0,00	0,00	560,00	120,28	130,00	16,33	430,00	21,60
Nitrate-N	0,00	0,00	4,00	0,82	1,00	0,00	18,00	5,66
Ammonium-N	0,00	0,00	560,00	120,28	133,33	12,47	413,33	26,25
Phosphorous	60,33	6,24	96,33	24,80	55,67	6,13	70,33	4,03
Potassium	320,00	57,15	856,67	182,64	250,00	24,49	793,33	57,93
Magnesium	163,33	9,43	260,00	29,44	113,33	12,47	126,67	4,71
Sulphur	14,00	2,83	930,00	212,76	18,67	2,87	356,67	49,22
Calcium	523,33	44,97	300,00	37,42	163,33	9,43	153,33	12,47
Manganese	0,26	0,03	0,82	0,20	1,07	0,05	0,78	0,05
Boron	0,29	0,01	2,47	0,54	0,42	0,05	0,28	0,00
Iron	0,64	0,03	0,68	0,11	1,33	0,40	1,20	0,14
Sodium	150,00	21,60	39,33	4,50	49,33	11,90	74,33	5,44
Aluminium	1,00	0,00	1,80	0,16	1,07	0,09	1,13	0,12

Table 2. Spurway analysis results from trial 2, regarding content of macro and micro nutrients, showed as mg L^{-1}. Standard deviation of treatments. The numbers are mean values. Samples taken 23.05.5. N=3.

	Cow manure	Cow manure st.dev	Mineral fertilizer	Mineral fertilizer st.dev	Biogas digestate	Biogas digestate st.dev	Algomin	Algomin st.dev
Nitrogen	200,00	29,44	346,67	179,13	123,00	82,74	500,00	72,57
Nitrate-N	193,33	33,99	146,33	80,38	38,00	50,92	52,67	5,73
Ammonium-N	5,00	1,63	203,33	103,71	85,00	31,82	443,33	74,09
Phosphorous	186,67	12,47	120,00	56,86	84,67	53,32	109,33	22,53
Potassium	390,00	24,49	760,00	311,23	263,33	146,36	1013,33	197,54
Magnesium	200,00	8,16	270,00	49,67	127,00	32,63	163,33	20,55
Sulphur	14,00	1,41	446,67	193,45	15,00	7,26	486,67	119,54
Calcium	640,00	24,49	320,00	43,20	166,67	46,43	173,33	20,55
Manganese	1,12	0,14	6,93	2,19	1,33	0,29	1,05	0,10
Boron	0,34	0,03	1,63	0,47	0,50	0,20	0,28	0,00
Iron	0,30	0,05	0,68	0,07	1,17	0,17	1,63	0,45
Sodium	170,00	8,16	41,67	7,59	59,00	9,63	92,67	17,91
Aluminium	1,00	0,00	1,93	0,25	1,07	0,05	1,30	0,24

5. Discussion

Since the nitrate content was the highest in the cow manure during trial one, up until the last measurement, where it had depleted, it can be concluded that there was not enough nitrate in that treatment to sustain the plants for much longer than the trial endured. To strengthen this statement, we could look at the ammonium levels of the same treatment and see that also that element was depleted. While the other treatments still contained ammonium that could change form into nitrate (Subbarao et al., 2006), the cow manure did not. The same applies for the phosphorus in that treatment, it had been depleted.
The levels of all nutrients were low in the cow manure treatment, and to sustain the growth of those plants there would be a need to add more of both phosphorus and nitrogen, in both forms.

In the second trial, there were not the same values of the cow manure treatment, as in the first, whereas it contained much more nitrate in the second run. The ammonium levels were still low. Why it contained that much nitrate could only be speculated about, since it was a duplication from trial 1, but as stated in the background, it is difficult to predict how much nutrients will be contained in a certain organic fertilizer, since it is often a mix of many things (EU, 2019, Gao et al., 2023). Perhaps the batch of fertilizer used in trial 2 contained more high-nitrate content, for example chicken manure (Utami et al., 2019), which should not be the case, since the content should be standardized and homogenous.
The Spurway analysis disclosed that the sodium levels were higher in the cow manure than in the other fertilizers. It reached between 120-180 mg L^{-1}, which is too high for tomato cultivation and could decrease yield, but increase quality of fruits (Agius et al., 2022) for a cultivation. Since the plants from this treatment were the largest and healthiest, it could be disregarded for the first month of cultivation.
It could also be concluded that the cow manure fertilizer does not have the same measured ammonium/nitrate ratio that was disclosed on the package description. Around 10% of the total nitrogen was supposed to be nitrate and the rest ammonium, which was not at all mirrored by either the spectrophotometer tests or the results from the Spurway analysis.
The fact that the cow manure differed greatly in the two trials suggests that there was not the same ratio of content in the used bags, and that the ingredients used to compose the product could differ between batches, for example a higher ratio of one of the used manures (Utami et al., 2019).

Although the cow manure offered the best start for the plants in both trials, it would not be ongoing for many weeks, since the ammonium and phosphate levels were lacking and the nitrate was non existant at the end of trial 1 (Figure 3-8). As described in the introduction, the cow manure is not only used as a nutrient source, but also sometimes as soil amendment.

The mineral fertilizer used in trial 1 and trial 2 were different, and that was visible in the measured values. The one used in trial 1 had very high values of ammonium and it caused what could possibly be phytotoxicity (Guo et al., 2021), as the plants looked sickly, small, sometimes chlorotic and necrotic, and had the lowest values when looking at the leaf area and the weights. It also showed in having the lowest CCI of all treatments. The ammonium levels were very high while the nitrate content stayed low throughout the treatment, which suggests that the ammonium in the substrate could not be nitrified for some reason, or did not have the time to do so. Since the mineral fertilizer was supposed to be the control, it had to be changed to another type for trial 2, to be a justified control that could compare to the other treatments.

The second mineral fertilizer used showed much higher nitrate levels and still high ammonium levels, which was visible when looking at the growth of the plants. The plants of that treatment were a lot larger than in trial 1, but still not the largest. The first mineral fertilizer used contained 12-3-15 NPK, while the second indicated to contain 11-5-18, but both the Spurway analysis and the spectrophotometer analysis suggested that the nitrate and ammonium ratio varied immensely between them.

The fact that the mineral fertilizer had such differences between the two trials suggests that fertilizing with the first one is not suitable for this type of cultivation. The two products are sold for the same target group and are declared to have the same area of usage, but the second one is better for this type of tomato cultivation. A product with a higher ratio of nitrate to ammonium would be preferable.

The Algomin treatments seemed to do well in the first trial, but perhaps because it was compared to the very bad mineral treatment. In the second trial it was by far the worst, combining leaf area and weight. The chlorophyll content of the Algomin treatments was the highest in both trials, which is usually an indicator of good plant health (Kurniawan, 2021), and the chlorophyll content of plants grown with algae extracts have been reported to increase (Sunarpi et al., 2021). It could be that the high ammonium levels and low nitrate levels in the fertilizer caused phytotoxicity and that is what caused the stunting in growth (Hachiya et al., 2021).

The biogas digestate was the fertilizer that never stood out, always in the middle and rarely significantly different from other treatments. It was never the worst, but also never the best. When examining the results from the Spurway analysis, it is clear that the biogas digestate is the fertilizer that contained the least measured nutrients in total, combining everything from beneficial macro nutrients to non-beneficial compounds like sodium and iron. Since the digestate is composed of organic plant matter and arrived to the test site in still visible lumps and parts, it is possible that there is more nutrients in it that is not fully digested and not readily plant available yet (Pausas and Bond, 2020). It is possible that the nutrients are not yet soluable.

In all of the fertlilizers, except the cow manure, it was observed that at the end of both trials there were still a large ammonium buffert left in the substrate that could last for a period of time, if the trials would keep running. This is if the nitrification would be ongoing, for the ammonium to become fully plant available as nitrate (Subbarao et al., 2006). The settings in the greenhouse chamber would in large part determine if this would happen, since the nitrification is, as described before, climate dependent (Subbarao et al., 2006).
Phytotoxicity could have affected some of the treatments and it is plausible that it is because of the high reported ammonium content (Guo et al., 2021). Perhaps the fertilizers should be diluted a bit more to reach the levels that the cow manure had during both trials, to get a good start. The calculation of 800 mg N L^{-1} was according to Bergstrand et al. (2020), and calculated as if the used fertilizer was a slow release fertilizer. Since the fertilizers used in this trial was not slow release fertilizers, it could have led to a too high concentration of nutrients in the substrate during the trials. This could be what caused possible phytotoxicity.

A cow manure mix shows to be a close to ideal starting fertilizer for tomato plants, but it needs to be added soon again, if not other fertilizer is added, for lasting effects. Since it is a mix of compounds (Moller and Schultheiss, 2015, EU, 2019), it is also highly unreliable, as visible in the results, for cultivation. The differences in nitrate levels between the two trials show that the cow manure is unpredictable, and makes fertilizing a hard task, with the risk of both overfertilizing and underfertilizing. The specifications on the bags does not correspond to the measured values of nutrients. There is a possibility that the analyses did not show the correct values for the measured elements, perhaps because of differences in water saturation level in the substrate, during sampling.

The watering of the plants could have been different between the two trials, since the first was conducted in Sweden, between February and March, and the second one was between April and May. There was a distinct difference in the climate of the growing chamber used for the trials, in regards of heat and sun light. The temperature of the chamber hovered around 18-20 °C during the first trial, with a few heat spikes around 23 °C, while during the second trial, there were only one day where the temperature was under 22 °C, and most of the days were around 24-25 °C. The pots were never allowed to dry out, but possible differences in water content of the substrate could mean different values of solubilized nutrients in the samples (Saidy, 2013). This would have to be investigated further if the trials would be replicated. Also, the increased substrate moisture in the first trial, and the fact that the substrate never dried out at all, caused fungus gnats to thrive among the pots (Katumanyane, 2020). This could be the reason to why the plants of the first trial took longer to establish, if the roots were being attacked.

Otherwise it could be the lower light exposure in the first trial compared to the second that caused the plants of the first trial to be smaller.

Why the cow manure treatment’s plants had more than double the size in leaf area and double the fresh weight, the second trial compared to the first one, could be because of the increased sunlight (Song, 2022), the warmer climate, less fungus gnats, but also because of the much higher dose of nitrate that was present in the soil. The same applies for all the treatments except the Algomin treatment, where the canopy size and weight was lower in the second trial than in the first.

Since the Spurway analysis and the spectrophotometer measured different forms of phosphorus the values cannot be properly compared. The values did not seem to correlate to each other.

If you don’t know the exact content of a fertilizer product, you cannot know exactly how much to use, when nutrients would be available, when to apply it and what you need to add to supplement it. This could make organic production more difficult to plan than conventional farming, where you could know for certain what your mineral fertilizer would do to your crop.

The hypotheses that the mineral fertilizer would be the best treatment, both in plant size and weight was wrong in the first trial, where it instead was by far the worst treatment in regards to growth and plant health. In the second trial it was part true, where it was a close contender to the cow manure treatment.

6. Conclusion

The cow manure mixed fertilizer was the best of the tried fertilizers for the first month of tomato cultivation, in regards to growth. There was a risk that the nutrients would be depleted after that time and that there would be a need for refilling the substrate with fertilizers, it was difficult to calculate with the high variance of organic fertilizer. The predictability of these fertilizers was difficult. Algomin fertilizer was not suitable for this kind of cultivation, it stunted the growth of the tomato plant, even though it contained plenty of nutrients.
Biogas digestate was good, in regards to substrate nutrient content, but it did not produce the healthiest or largest plants.

The change in climactic conditions in the two trials seemed to have a positive effect on the cow manure treatments plants' growth, but there were other factors that could be attributed to that, for example a higher concentration of nitrate. On the other treatments, the climactic factors did not make a big difference.

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Popular science summary

The mineralization and nitrification of nitrogen is an important part of soil chemistry and soil biology world wide, as it helps make the important nutrient plant available.
We wanted to see what happened mineralization-wise in substrates when using different forms of fertilizers, and what would happen in the substrates during different climatic conditions.

A study of three organic fertilizers was conducted in a green house chamber, from early to late spring, in the south of Sweden. The tested fertilizers were cow manure, an algae-based product called Algomin, and a solid fraction of residues from biogas production, called biogas digestate. These products are all sold as organic and as KRAV-products, which is one of the most well known sigills of enviromentaly friendliness and quality in Sweden. Tomato seedlings were planted in the different fertilizer treatments, and then later the grown plants were examined to see how they had been affected by the different treatments.

The trials were done in two different time periods to see if there would be any differences in mineralization when the growing chamber would be warmer, as it was suspected to be in the later spring time. The plants' mass increased with the increase in heat and sun light, but it could not be surely correlated to only those factors.

The cow manure treatment seemed to be the best start for the tomato plants since they were by far the largest. The plants grown in biogas digestate and the plants grown in Algomin were smaller and did not seem to be healthy. Differences in the mineral fertilizers used as a control, caused it to become unfit to as a control treatment.

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