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Research report on compost quality and its potential for improving Nitrogen availability and soil microbial activity

Persons involved in the research at AU Food

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1. Introduction:

Approximately 65% of soil in the EU is considered degraded, with the loss of soil organic carbon (SOC) being a significant contributor to this degradation. Although Denmark generally has fertile soils, SOM is declining and at least 10% of the soil is critically low in SOM (Greve et al., 2022). Increasing SOC is crucial, especially as climate change scenarios predict rising temperatures, which exacerbate SOC loss through accelerated decomposition.

Applying compost is an effective strategy to enhance SOC. Research has demonstrated that compost application can increase SOC in both short- and long-term scenarios across various climatic regions. Additionally, compost provides essential macro- and micronutrients for plants and boosts soil biological activity. However, the impact of compost on soil quality depends heavily on the feedstock used to produce it. For example, compost made from animal manure typically has a higher nutrient content that is more readily available to plants compared to compost derived from park and garden waste.

With the green transition strategy emphasizing sustainability, there is a growing need to develop plant-based fertilizers to reduce dependency on livestock systems. In Denmark, garden and park waste (GPW) is an abundant resource that can be utilized as a plant-based compost feedstock. However, GPW compost generally has lower nutrient content compared to compost made from feedstocks rich in green materials. To enhance the quality of GPW compost (high nutrient content and overall effectiveness), incorporating nutrient rich green materials, such as grass-clover and vegetable crop residues can be a strategy which needs to be investigated further.

Objective of the Experiment:

The primary aim of this experiment was to evaluate the quality of GPW compost and its effectiveness in improving nitrogen availability and stimulating microbial activity. This was assessed with and without the addition of easily decomposable green materials, such as grass and vegetable crop residues during an open air composting system.

1. Experimental setup:

1.1. Feedstock collection and composting

The primary feedstock used for composting is GPW, which was collected from Kredsløb Affaldenergianlæg, Lisbjerg, Denmark. Grass clover was collected from organic 2nd year grass clover field and vegetable waste (a mixture of carrots, celeriac and potatoes) from Marienlyst Gartneri, Harlev, Demnark. Three compost piles were made in three replicates: (1) Garden and park waste compost (GPW), (2) Garden and park waste mixed with grass at 3:1 ratio (GPW+G), and (3) Garden and park waste mixed with vegetable crop residues at 3:1 ratio (GPW+G)

Composting was conducted for 6 months without turning, and the temperature in each pile was monitored during the composting process with temperature probes (Martin Lishman product code: CQ / MTM10BLÅ / CP). Representative samples were collected to measure the bulk density and major nutrient compositions at the start of the composting and end of the composting process. Both the feedstock and the compost samples were analyzed for standard compost parameters at an external accredited laboratory (Agrolab Group) in Germany using standard compost analysis ISO protocols.

1.2. Incubation experiment

Composite soil samples were collected from the 0–25 cm layer of Aarhus University's experimental field (AU Auning, 56°45'N, 10°33'E) at Gammel Estrup, Denmark. The sandy soil contained 2.0% organic C, 16.2 mg kg^{-1} total mineral N, and had a pH of 6.5 ($CaCl_2$). Samples were sieved (4 mm) to remove stones and improve homogeneity.

The experiment included four treatments: unamended control (CTR), GPW compost, GPW mixed with grass compost (GPW+G), and GPW mixed with grass compost (GPW+V), applied at 40 tons fresh weight ha^{-1} based on standard grower practices. Soil (337,8 g dry equivalent) was mixed with the corresponding compost amounts and placed in polyvinyl chloride tubes (radius = 3,2 cm, height = 12 cm), adjusted to a bulk density of 1.5 Mg m^{-3} and 50% water-filled pore space. The amount of compost was calculated based on the surface area of the PVC tubes.

A total of 72 tubes (4 treatments × 3 replicates × 6 sampling times) were incubated at 17°C for 120 days. Water content was maintained at 50% WFPS by replacing moisture loss. Destructive sampling was conducted on days 0, 7, 24, 69, 90, and 120 to analyze nitrogen mineralization dynamics, and microbial activities.

1.2.1. Mineral N analysis

Mineral N (NH4+ and NO3-) was measured in the suspension extracted from 100 g fresh weight of soil with 200 ml 1 M KCl after shaking for one hour at Agrolab group in Germany. Net N mineralization was calculated as a difference in total mineral N at the start and end of the incubation experiment.

1.2.2. Enzyme activities

Dehydrogenase enzyme activity (DHA) was measured at AU-Food using a modified method from our previous study [Gebremikael et.al., 2015]. Moist soil (5 g) was incubated with 2 ml of 3% 2,3,5-triphenyl tetrazolium chloride (TTC) and 2 ml of 0.1 M Tris-buffer (pH 7.8) at 37°C for 24 hours. After incubation, 20 ml of ethanol was added, and the samples were shaken (125 rpm) for 2 hours, then filtered (Whatman No. 5). The intensity of 1,3,5-triphenyl formazan (TPF) in the filtrate was measured at 485 nm using a Cary 60 UV-Vis Spectrophotometer. Measurements were performed in duplicate with a blank.

2. Results and discussion

2.1. Compost quality parameters

All the three composts show statistically comparable values (p>0,05) on most of the parameters measured to assess the compost quality, except for the pH and P2O5, where the GPW compost show different values compared to the one mixed with grass or vegetables [Table 1]. The GPW compost becomes more alkaline (pH 7,67) compared to the mixed feedstock compost piles.

Table 1: Compost properties (mean± sd/se, n=3) determined at the end of the composting process

Parameters	Unit	Mean (n=3)			Standard deviation			Standard error			p value (one way anova)
		GPW	GPW+g	GPW+v	GPW	GPW+g	GPW+v	GPW	GPW+g	GPW+v	
Density	g/L FW	867	920	913	92,38	51,96	70,24	53,33	30,00	40,55	
Dry matter	% FW	60,6	60,5	60,9	3,1	3,5	1,5	1,8	2,0	0,85	0,97
pH CaCl2		7,7	7,5	7,5	0,06	0,10	0,06	0,03	0,06	0,03	**0,035**
EC	µs/cm	282,0	268,7	220,0	22,0	23,7	40,3	12,7	13,7	23,3	0,094
OM	%DM	20,3	17,2	18,6	2,7	1,5	1,9	1,5	0,9	1,1	0,27
TOC	%DM	10,0	8,5	10,8	0,77	1,3	0,93	0,45	0,72	0,54	0,077
TN	%DM	0,56	0,55	0,57	0,03	0,08	0,04	0,02	0,05	0,02	0,928
CN ratio		17,8	15,5	19,1	1,5	0,4	2,9	0,9	0,2	1,7	0,136
P2O5	% DM	0,23	0,30	0,28	0,02	0,02	0,01	0,01	0,01	0,00	**0,004**
K2O	% DM	0,41	0,50	0,38	0,03	0,09	0,03	0,02	0,05	0,01	0,076
MgO	% DM	0,27	0,33	0,29	0,02	0,05	0,01	0,01	0,03	0,01	0,094
NH_4^+-N	mg/kg FW	47,8	33,3	47,5	9,2	23,7	5,6	5,3	13,7	3,2	0,451
NO_3^--N	mg/kg FW	12,5	43,0	6,2	7,6	30,0	2,1	4,4	17,3	1,2	0,093
NH_4^+-N:NO_3^--N		5,9	1,8	8,0	5,1	2,3	2,0	3,0	1,4	1,2	0,161
Total mineral N	mg/kg FW	60,4	76,3	53,7	13,8	6,3	7,3	8,0	3,7	4,2	0,069
Total mineral N	mg/kg DW	99,1	126,7	88,3	18,5	15,1	13,4	10,7	8,7	7,8	0,058

Mixing the GPW with grass (GPW+g) and vegetable (GPW+v) waste significantly increased the P concentration by about 33% and 24%, respectively. However, the nutrient content, particularly N of all the three composts is generally very low (<0,57% DM) compared to composts made from other feedstocks such as municipal waste compost (1,2-1,9% DM) (Diacono et al., 2024). Mixing GPW with grass generally tends to enhance the plant macronutrient content (NPK) compared to compost made solely from GPW or compost produced by mixing GPW with vegetable residues **(Figure 1)**, indicating the potential of mixing GPW with grass to improve the nutrient content further.

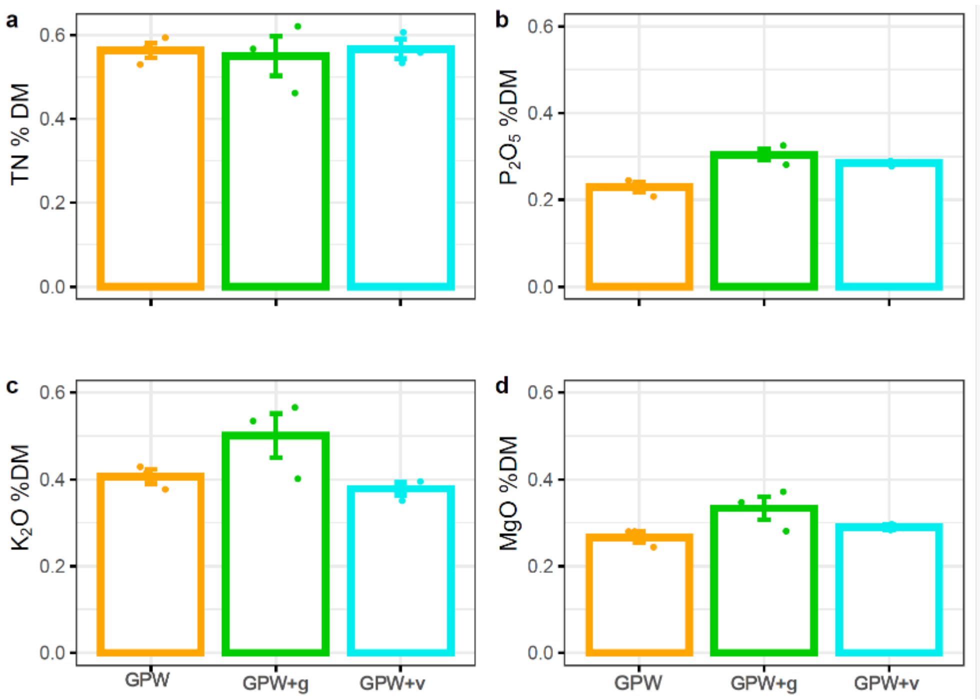

Figure 1: Mean (n=3) plant macronutrient concentration in the compost at the end of the composting process. Values are % in dry matter for total N (a), P2O5 (b), K2O (c) and MgO (d)

All the three composts have electrical conductivity (EC) of 220-282 µs/cm indicating low salt content which is good for plant growth. The C: N of all the three composts lie in the standard C: N range (15-19:1) for matured composts of good quality compost further indicating the suitability of using the composts in agriculture. Other parameters such as oxygen uptake rate that evaluate the maturity of the compost were not determined in this experiment. The NH_4:NO_3 ratio of the composts, particularly those made from GPW alone and GPW mixed with vegetable residues, was significantly higher (6-8:1) compared to the ratio typically observed in mature composts (<0.16:1). This indicates that the composts were not fully matured at the time of sampling, highlighting the need to extend the composting duration. However, a plant phytotoxicity test was conducted on one of the GPW compost piles at 25% and 50% compost content. The test yielded a consistent result of 86% in both cases, suggesting that the compost does not exhibit phytotoxic effects and is safe for plant growth.

2.2. Microbial activities

Dehydrogenases are intracellular enzymes involved in the microbial oxidation of organic substances under aerobic conditions and have been used to measure overall microbial activities in soils [Gebremikael et al., 2020]. Increased DHA is considered as an indicator of the activities of living microbial communities and soil biological quality. The application of all the three composts in soil resulted in significant increase in DHA throughout most of the incubation period (Figure 2), indicating the potential of the composts in improving soil microbial activities. This is in line with the existing knowledge that microbial communities in soil are generally limited in C and the application of organic amendments such as compost stimulates their growth.

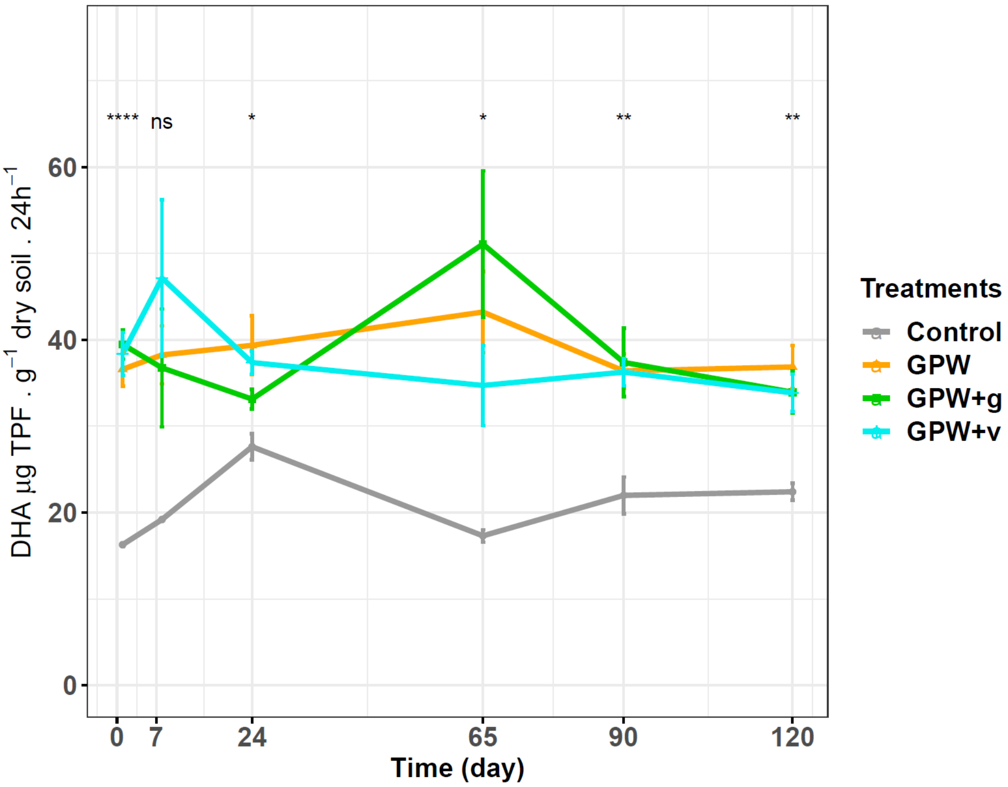

Figure 2: Dehydrogenase activities (DHA) over time during the 120 days of incubation experiment. The error bars refer to the standard error of the mean (n = 3). Significant differences between treatments at each sampling date are shown as ns ($p>0.05$), $p<0,05$ (*), $p<0,01$(**), $p<0,001$(***).

In the current experiment, DHA over time stayed more stable in GPW compost application compared to the GPW mixed with grass or vegetable, suggesting differences in labile C content in the compost. Despite the similar total organic carbon application rates (2.06–2.60 tons/ha) across all three compost treatments, the observed peaks in dehydrogenase activity (DHA) in the mixed feedstock composts at Day 7 (D7) and Day 65 (D65) (**Figure 2**) can likely be attributed to the response of r-strategist microbes, primarily bacteria, to the availability of labile carbon from the added grass and vegetable residues. However, despite these differences in DHA peaks, no significant difference was observed between the GPW compost and the mixed feedstock compost. This suggests that additional green material may be required to achieve a significant increase in DHA. It is important to highlight that the results demonstrate that the application of GPW compost alone significantly enhances soil microbial activity compared to the control.

2.3. Potential N mineralization

Like the DHA, the application of all the three composts increased the N mineralization (ammonification) process during most of the incubation time **(Figure 3)**. Such increase in the mineralization process following the composts application shows the continuous mineralization of organic N from the composts. The results also generally show that while the ammonia concentration decreases over time, the nitrification process increases. However, compost application did not significantly increase nitrate accumulation in the soil, except during the initial stages of incubation, which is attributed to the existing mineral nitrogen in the applied compost at the start of the incubation. The total mineral nitrogen (NH_4-N + NO_3-N) also showed similar trend like the nitrate N concentration.

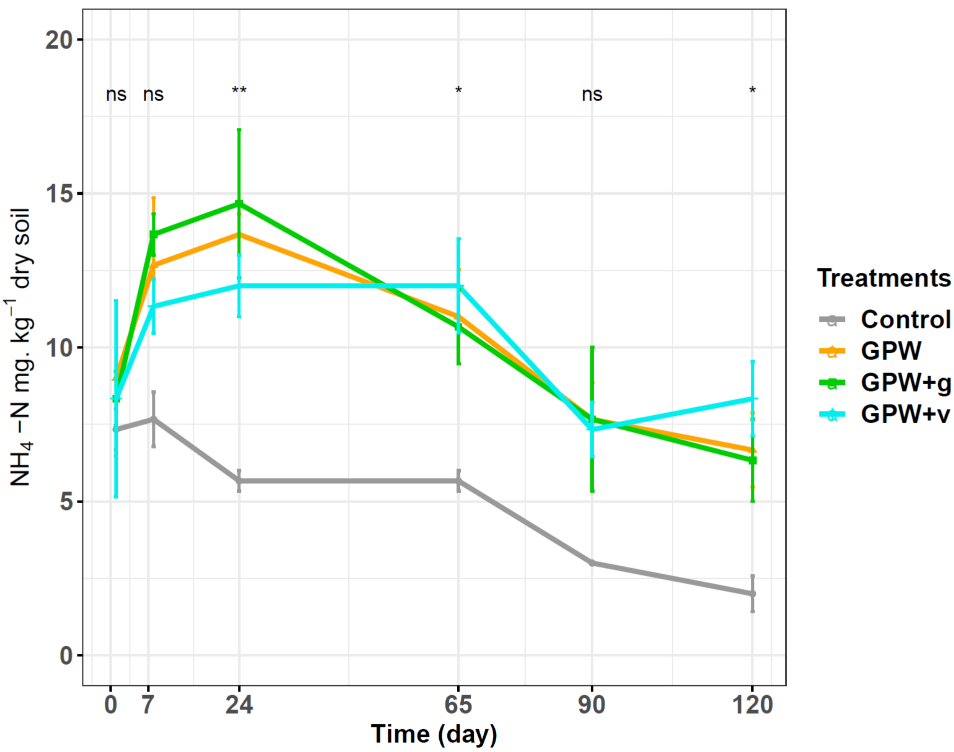

Figure 3: The dynamics of NH_4^+-N concentration over time during the 120 days of incubation experiment. The error bars refer to the standard error of the mean (n = 3). Significant differences between treatments at each sampling date are shown as ns (p>0.05), p<0,05 (*), p<0,01(**), p<0,001(***).

All the composts resulted in net mineralization (calculated as total mineral N at the start and at the end of the incubation), with the highest increase was recorded in the GPW compost (87%±34), followed by GPW+g compost (46%±19) and GPW+v (44%±29). However, there was also a net mineralization in the unamended control (77%±18), which is higher than both composts with mixed feedstocks, and showing the potential of the native soil organic matter to N availability. The net mineralization results account for the change only at the beginning and end of the incubation and does not show the dynamics during the entire incubation period.

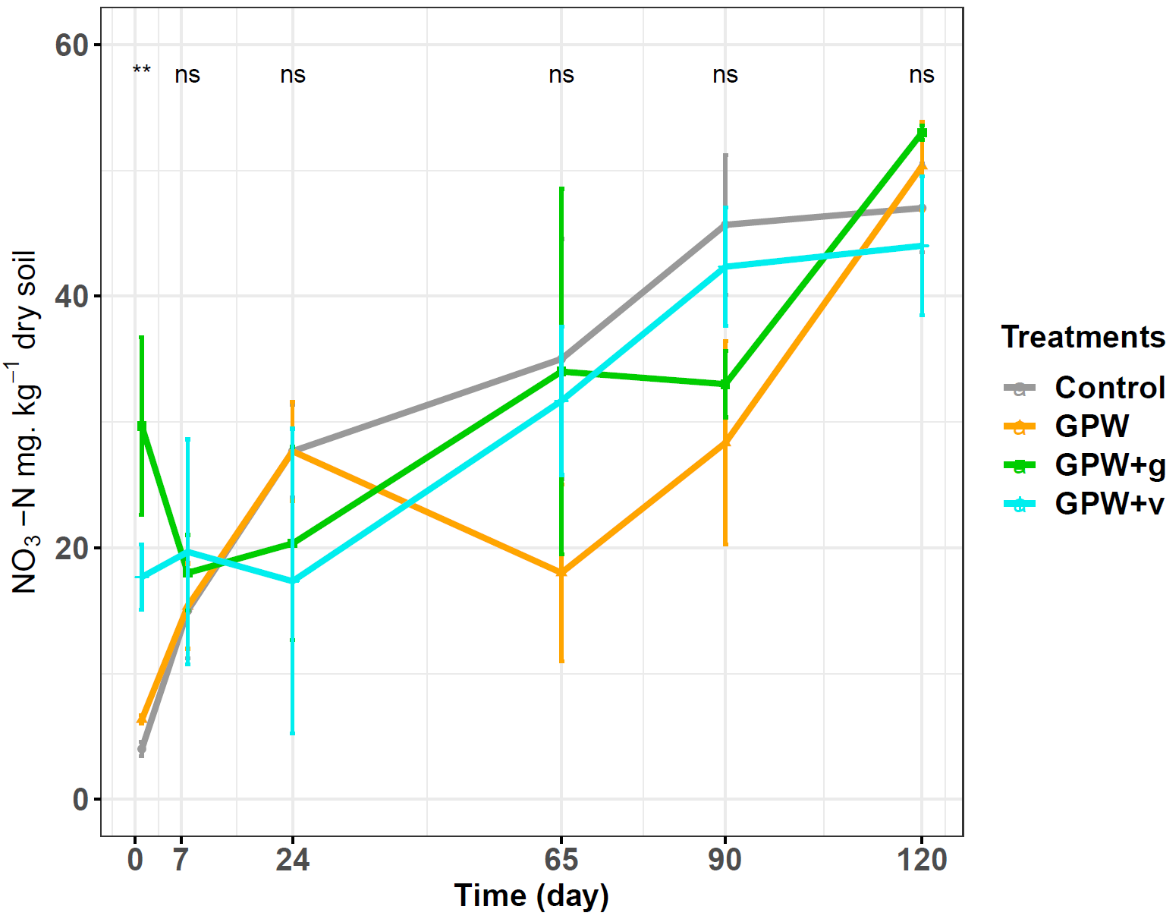

Figure 4: The dynamics of NO_3^--N concentration over time during the 120 days of incubation experiment. The error bars refer to the standard error of the mean (n = 3). Significant differences between treatments at each sampling date are shown as ns (p>0.05), p<0,05 (*), p<0,01(**), p<0,001(***).

In contrast to our expectation, none of the three composts applied significantly improved mineral N availability compared to the unamended control. This can be primarily attributed to the lower total N content (0,55-0,57%) in all the three composts compared to composts from other feedstocks as mentioned above. At the rate of 40 ton FW compost ha^{-1} application, the initial plant available N (total mineral N) supplied through the compost was also very limited (2,15-3,06 kg N ha^{-1}) and there was no clear indication of net N mineralization from the organic N during the incubation period, as total mineral N in the composts were not statistically different than the control **(Figure 5)**. Moreover, the high microbial activity observed following compost application likely led to nitrogen immobilization, where mineral nitrogen is assimilated into the microbial biomass. It is also important to highlight that the variation in total mineral nitrogen availability throughout the 4-month incubation period was substantial, leading to no significant differences either among the compost treatments or between the composts and the unamended control.

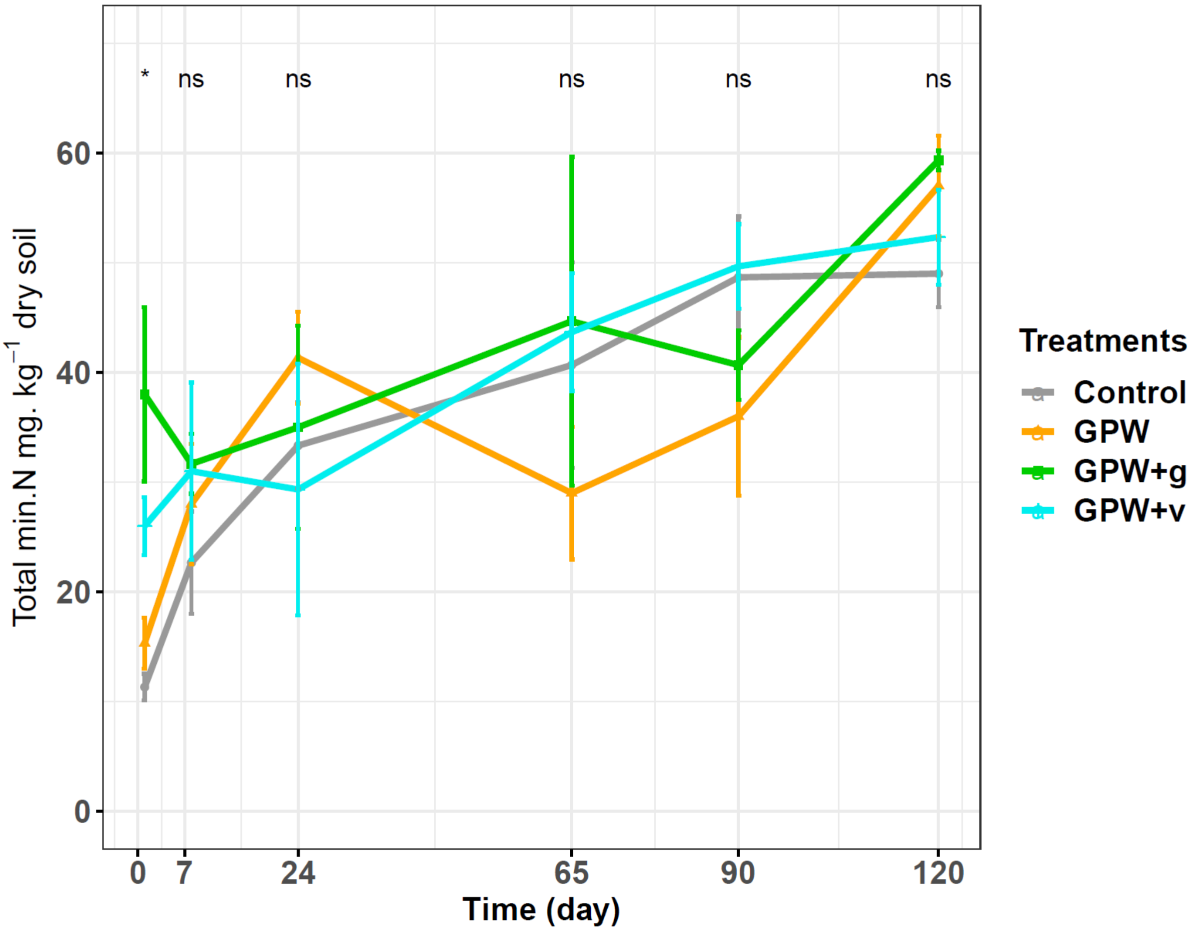

Figure 5: The dynamics of total mineral N concentration over time during the 120 days of incubation experiment. The error bars refer to the standard error of the mean (n = 3). Significant differences between treatments at each sampling date are shown as ns (p>0.05), p<0,05 (*), p<0,01(**), p<0,001(***).

3. Conclusions and outlook

The GPW compost demonstrates good quality on its own and is effective in enhancing soil health by boosting microbial activity. However, it does not appear to improve nitrogen availability in the short term compared to the unamended control. This suggests the need for supplementary application of readily available nitrogen fertilizers to address potential nitrogen limitations during plant growth. Mixing GPW with nitrogen-rich feedstocks, particularly grass, tends to enhance the nutrient content (N, P, K and Mg). However, further research is required to achieve a more significant improvement in nutrient levels, such as by increasing the proportion of grass or other vegetable waste materials in the mixture. Additionally, further studies are needed to assess the potential these composts for improving nitrogen availability in the plant-soil system under controlled and field conditions.

4. References:

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