

**Theses of Doctoral (Ph.D.) Dissertation**

**Development and Evaluation of Organic-Based  
Nutrient Supplements Under Controlled and Field  
Conditions**

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## **1. BACKGROUND AND OBJECTIVES OF THE DOCTORAL DISSERTATION**

In recent decades, the problem of overpopulation has become an increasingly central concern globally. Alongside this, the future of agriculture faces a key challenge: preparing to effectively manage the environmental changes and extremes brought about by climate change. The non-site-oriented, unbalanced nutrient supplementation practices of past decades, along with increasing climatic anomalies and extremes, have led to soil degradation, a decrease in organic matter and nutrient content, and deterioration of water management properties.

Based on all of this, one of the biggest challenges today and in the future is to ensure the availability of high-quality, nutrient-rich, and abundant animal-based food. In connection with this, a global trend observed in recent decades has been a shift in livestock farming in favour of poultry farming. Currently, the most significant problem facing the poultry sector is that the accelerated, high-capacity food production cycle generates a large amount of manure, which, without processing, is unusable and, considered waste.

The primary objective of my doctoral research is to further develop natural, organic matter-based soil and plant conditioners derived from manure produced by large-scale poultry farming, using appropriate transformation and supplementation processes. These products aim to improve soil organic matter management, enhance nutrient availability, and improve the soil's physical, chemical, water management, and biological properties by enhancing and, in many cases, reactivating soil life.

In my experiments, I used fermented, supplemented, and pelletized chicken manure (Bio-Fer Natur Extra: NEX), which I improved with superabsorbent polymers (SAPs, hydrogels) and bentonite clay mineral. The effectiveness of the developed products was tested through soil analysis and water management studies.

Based on these, my main objectives were as follows:

- To develop and test prototype products through product development that can be effectively used in the production of safe and high-quality food raw materials and that may be suitable for commercial distribution.
- To examine the effects of the developed prototype products and composites in laboratory (soil incubation), pot (model), and field experiments, including operational observations and soil and plant analytical studies.
- To use the results of the research in precision agriculture and to expand knowledge on the production of environmentally friendly, high-quality food raw materials. I aimed to achieve my goals while also reducing the amount of waste generated during poultry farming.

## **2. MATERIALS AND METHODS**

The following materials were used in my experiments:

- Fermented and supplemented chicken manure (Bio-Fer product line: Natur Extra (NEX))
- Bentonite
- Superabsorbent polymers (SAPs)

To test the effects of the developed prototype composite products, I selected three different soil types typical of Hungary:

- Brown forest soil (Pallag), Lamellic Arenosol
- Calcareous chernozem soil (Látókép), Calcic Chernozem
- Non-specific (drifting) sandy soil (Debrecen), Aeolic Arenosol

I conducted my laboratory aerobic soil incubation and pot experiments at the Water and Environmental Management Institute of the Faculty of Agricultural and Food Sciences and Environmental Management at the University of Debrecen, while the field experiments were carried out at the University of Debrecen, Agricultural Research Institute at Pallag.

### **Soil, plant, and fruit analysis during the experiments**

The analysis of the experiment samples was conducted at multiple locations:

- Soil and leaf analysis: Agricultural Instrument Center, University of Debrecen
- Soil, leaf, and fruit analysis: Water and Environmental Management Institute, University of Debrecen
- Determination of antioxidant content: Institute of Agrochemistry and Soil Science, University of Debrecen

#### **2.1. Methodological description of soil incubation experiments**

I initially tested the effects of the prepared composites in aerobic soil incubation experiments.

During my research, I planned and carried out three soil incubation experiments to test the effects of the developed composites (Table 1). In all experiments, I used dried, sieved soil with a fraction <2 mm.

**Table 1.** Summarized table about soil incubation experiments

Experiment	Soil (amount) (g)	SWHC (%)	Period of experiment (month)	T (°C)	Replicates	Number of pots
I.	Debrecen, Pallag (200)	60	1	25	3	40
II.	Pallag, Látókép (100)	40 and 60	1	25	3	96
III.	Pallag (500)	40 and 60	4	25	3	144

### I. Soil incubation experiment

In this experiment, in addition to the two previously introduced additives, I also applied a new one, Aegis, to further improve the properties of the NEX product. For the one-month incubation experiment, I used 200 g of dried humus-rich sandy soil (Pallag). I placed the capsules 2 cm deep into the soil. One capsule was placed in each pot, and each treatment was applied in three replications at a water-holding capacity (SWHC) level of 60% (Table 2).

**Table 2.** Applied treatments in the I. soil incubation experiment

Treatments	Composite treatments (N:S:B ratio)
Control NEX	90.0 : 0.5 :9.5
Control NEX-Aegis (A)	90.0 : 1.0 :9.0
	90.0 : 1.5 :8.5
	90.0 : 2.0 :8.0

In the experiment, the soil layer in each pot was split in two layers and soil samples were taken from these layers after weeks 2 and 4.

**Table 3.** Applied treatment codes in the I. soil incubation experiment

<b>Treatments</b>	<b>Treatments</b>
<b>Deeper layer</b>	<b>Upper layer</b>
A – Control NEX	B – Control NEX
C – Control NEX A	D – Control NEX A
E – 90.0 : 0.5 : 9.5	F – 90.0 : 0.5 : 9.5
G – 90.0 : 1.0 : 9.0	H – 90.0 : 1.0 : 9.0
I – 90.0 : 1.5 : 8.5	J – 90.0 : 1.5 : 8.5
K – 90.0 : 2.0 : 8.0	L – 90.0 : 2.0 : 8.0

Note: The numbers in the table indicate the N:S:B ratios.

## II. Soil incubation experiment

In this incubation experiment, I used two different additives to improve the properties of composted poultry manure, Stockosorb as SAP and bentonite as clay amendment. The composites were tested on two different soil types: brown forest soil with sandy texture (Pallag) and chernozem soil (Látókép).

**Table 4.** Applied treatments in II. soil incubation experiment

<b>Treatment code</b>	<b>SWHC</b>	<b>NEX (powdered)</b>	<b>SAP</b>	<b>Bentonite</b>
	<b>%</b>		<b>mg</b>	
40 C (Control)	40	75	-	-
40 NEX	40	75	0.0375	7.5
60 C (Control)	60	75	-	-
60 NEX	60	75	0.0375	7.5

Soil samples were incubated at controlled moisture content (two soil water holding capacity levels (SWHC=40% and 60%)) for 28 days at 25°C. Each treatment included three replicates for 96 samples (Table 4).

## III. Soil incubation experiment

In this incubation experiment (Table 5), I used two different SAP additives: Stockosorb (S) as the synthetic additive, and Zeba (Z) as the organic-based additive. I examined the effects of

the composites on sandy brown forest soil from Pallag. The four-month aerobic incubation was conducted under controlled moisture conditions (SWHC = 40% and 60%).

The arrangement of the capsules was the same as in the previous experiment, but with an increased soil mass (500 g). Each treatment included three replications and four sampling points (monthly).

In the incubation experiment, I applied six treatments. Besides the absolute control (C), five treatments were set up and applied, which can be divided into three groups:

- KT (contained only fermented chicken manure),
- S group (contained fermented chicken manure and S in two different doses – S1 and S2),
- Z group (contained fermented chicken manure and Z in two different doses – Z1 and Z2).

In the treatments, the NEX:SAP ratios were 90:1:9 and 90:2:8, respectively. The amount of chicken manure remained constant in every treatment (Table 5).

**Table 5.** Applied treatments in III. soil incubation experiment

Treatments	Doses (mg/500g soil)			
	NEX	Bentonite	S	Z
<b>C</b>	-	-	-	-
<b>CM</b>	450	-	-	-
<b>S1</b>	450	45	5	-
<b>S2</b>	450	40	10	-
<b>Z1</b>	450	45	-	5
<b>Z2</b>	450	40	-	10

The main objective of the experiment was to study the effects of the products on N mineralisation. Therefore, in this experiment, I determined the total carbon (TC) and total nitrogen (TN) content of the soil, as well as the mineral nitrogen (MN) content and the C/N ratio of the soil. From the cumulative MN, I also calculated the potentially mineralizable nitrogen (PMN) content, and the net mineralization ratio (NMR) and net nitrification ratio (NNR).

## 2.2. Methodological description of small pot experiments

In the second phase of my research, I carried out small pot experiments to study the effects of the composites on tomato in 2021 and cucumber in 2022. The length of the experiment was four months. In my experiments, I mixed the fermented poultry manure (BioFer Natur Extra) as a raw material with superadsorbent polymers (synthetic (SAP1-Stockosorb) and organic (SAP2-Zeba)) and clay paste (Bentonite) in different doses (Table 6).

**Table 6.** Applied treatments in small pot experiments (2021-2022)

<b>Treatments</b>	<b>Manure</b>	<b>Bentonite</b>	<b>Stockosorb</b>	<b>Zeba</b>
<b>(g/3 kg soil)</b>				
<b>K</b>	0	0	0	0
<b>KT</b>	10	0	0	0
<b>S1</b>	10	5	3	0
<b>S2</b>	10	5	6	0
<b>Z1</b>	10	5	0	1.8
<b>Z2</b>	10	5	0	2.7

I investigated the effect of the own developed soil improvement composites on the biomass mass, plant pigment content (chlorophyll and carotenoid content) and water utilization of the cultivated plant. The number of pots used in the experiments was 36-36 per experiment for each crop (tomato: 1 tracer x 6 treatments x 3 replicates x 2 soil types x 1VK level = 36 pots; cucumber: 1 tracer x 6 treatments x 3 replicates x 1 soil x 2VK level = 36 pots).

In the tomato experiment I used one water capacity level (VK=60%), while in the cucumber experiment I used two water capacity levels (VK=60% and VK=70%), The adjusted moisture content of the soils was ensured by daily irrigation with distilled water. In the experiments, I used sandy loam (Debrecen) and brown forest soil (Pallag).

## 2.3. Methodological description of field experiments (Pallag)

The trials were carried out in the orchard of the University of Debrecen's Institute of Horticultural Sciences at the Pallag Experimental Station. The orchard was planted in 2011 with a row spacing of 1 m and a row spacing of 4 m. The trees were grafted on M9 rootstock, and trained to slender spindle with a height of 3.5 m (CSIHON et al., 2021). In the experiments, I used the apple cultivar 'Pinova' (*Malus domestica* Borkh.) (Table 7).

**Table 7.** Treatments at Pallag (2021, 2022)

Treatments	Doses (kg/tree)		
	NEX	Bentonite	SAP
<b>K</b>	-	-	-
<b>KNEX</b>	2	-	-
<b>B1</b>	2	0.5	-
<b>B2</b>	2	1.0	-
<b>S1</b>	2	-	0.1
<b>S2</b>	2	-	0.2
<b>BS1</b>	2	0.5	0.1
<b>BS2</b>	2	1.0	0.2

Each treatment has five trees. The experiment was set up in May 2021 after flowering and fertilisation was repeated in May 2022.

In addition to my treatments, the entire plantation received the following annual dose of fertilizer: 200kg/ha Yara Crop Care N:P:K (11:11:21) applied in two equal doses in March and June, plus additional N supplementation at 100 kg/ha in the form of Péli salt. Before application, pelleted chicken manure (Bio Fer NEX) was ground and mixed with the additives. I placed the mixture in the soil at a depth of 20 cm on either side of the trees at the drip line, 50-50 cm from the trunks. Throughout the experiment, soil, leaf and fruit samples were taken regularly to test the effectiveness of the applied formulations.

#### 2.4 Statistical analysis

Statistical analyses were carried out using R software in R Studio user environment (version 4.1.3) using R studio agricolae package. I used (Shapiro -Wilk) test for normality of data. The effects of different treatments were detected using single and multivariate analysis of variance (Duncan, Kruskal - Wallis test SD= 5%). To determine significant differences in the parameters tested (SOC, SON, NO<sub>3</sub>-N), I used Spearman Rank - type correlation analysis (SD=5% and SD=10%) with Statgraphics 18 software.

### **3. RESULTS**

#### **3.1. Results of preliminary experiments**

I began my research by producing composite products with appropriate ratios based on the physical properties of the base material and additives. To do this, I had to determine the exact mixing ratios, which were established by the manufacturer recommendations and the preliminary test experiments I conducted.

The results of my preliminary experiments can be summarized as follows:

- The ratio of each component was determined by their physico-chemical properties, application dosages, and effectiveness.
- In my experiments, fermented chicken manure was considered as the base material, and therefore its proportion was 90%.
- Based on the results of the preliminary experiments, the most effective ratios were as follows: bentonite at approximately 8-9%, and super absorbent polymers at 1-2%.
- From the results, I concluded that the encapsulated form is the most suitable for soil incubation experiments.
- The results indicated that super absorbent polymers should be applied not on the soil surface, but rather at a deeper layer, at least 2-20 cm deep (depending on the type of experiment and test plant). Surface or near-surface application leads to soil layer bulging, surface fragmentation, and a decline in the effectiveness of the composites.
- My results highlighted that the assembled composites are suitable for the prolonged cultivation of seedlings, even for several weeks.

#### **3.2. Results of soil incubation experiments**

It can be concluded that the pH value ranged between 7.20 and 7.45 after the second week, and between 6.10 and 6.50 after the fourth week in the first incubation experiment. During the experiment, the soil pH slightly decreased in all treatments. My results also indicate that treatments containing a higher dose of super absorbent polymers (SAP) more effectively reduced the soil pH. This can be explained by the fact that SAP is able to bind not only water but also soluble nutrient ions (SITU et al., 2023). The soil EC varied between 180 and 230 mS/cm after the second week, while at the end of the experiment it ranged between 130 and 180 mS/cm, showing a slightly decreasing trend. My results suggest that the treatments reduced soil EC compared to the control by the second week. However, this effect diminished by the

end of the experiment, with no significant difference in soil EC between the control and treated samples in any layer. The results indicated that the soil nitrate content ranged between 25 and 65 mg/kg after two weeks, and between 20 and 60 mg/kg by the end of the experiment.

I observed that the additives positively influenced the vertical distribution of nitrate ions, protecting them from leaching. This effect can be particularly beneficial in sandy-textured soils, where the vertical movement of nitrate ions is significant, as it ensures a higher directly available nitrate content in the root zone, the primary nutrient uptake zone (SISTANI et al., 2008).

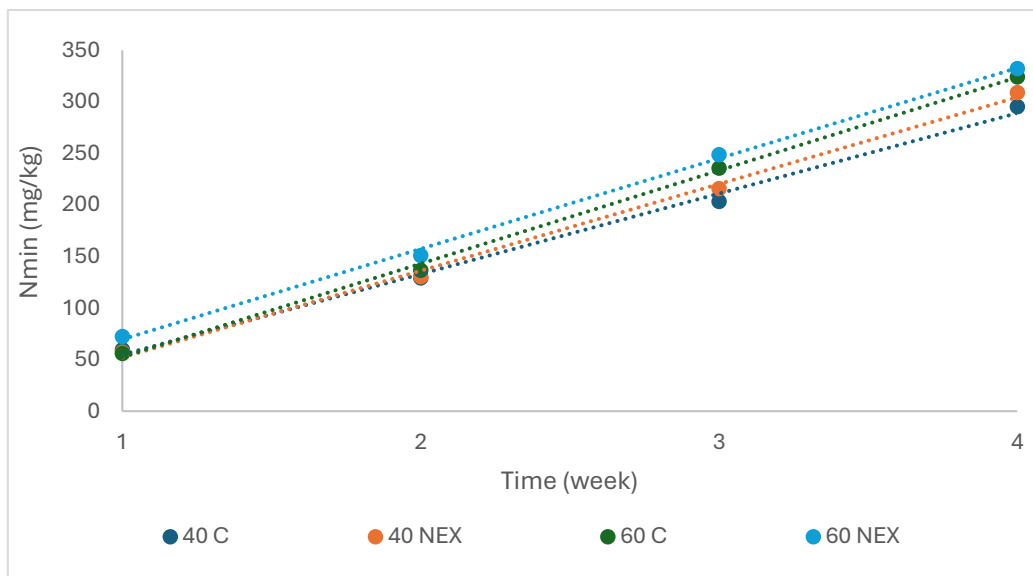
The treatments slightly increased the soil ammonium content compared to the control, but this effect was not significant. The soil ammonium content remained largely unchanged during the incubation period. It was also observed that the nitrate content of the soil was approximately five times that of the ammonium content throughout the experiment. This suggests that nitrate was the dominant N form during the experiment, and mineralization processes were not hindered under the applied moisture conditions.

The results of the second experiment indicated a significant difference in soil nitrate content between the two soil types. The nitrate content measured in the Látókép soil was approximately ten times higher than that in the Pallag soil, which can be explained by the differences between the two soil types. Initially, the nitrate content in the chernozem soil was ten times greater than that in the brown forest soil, but by the end of the experiment, this ratio decreased to three to four times. This suggests that the composite treatment had a more favourable effect on the soil with a lower nutrient supply.

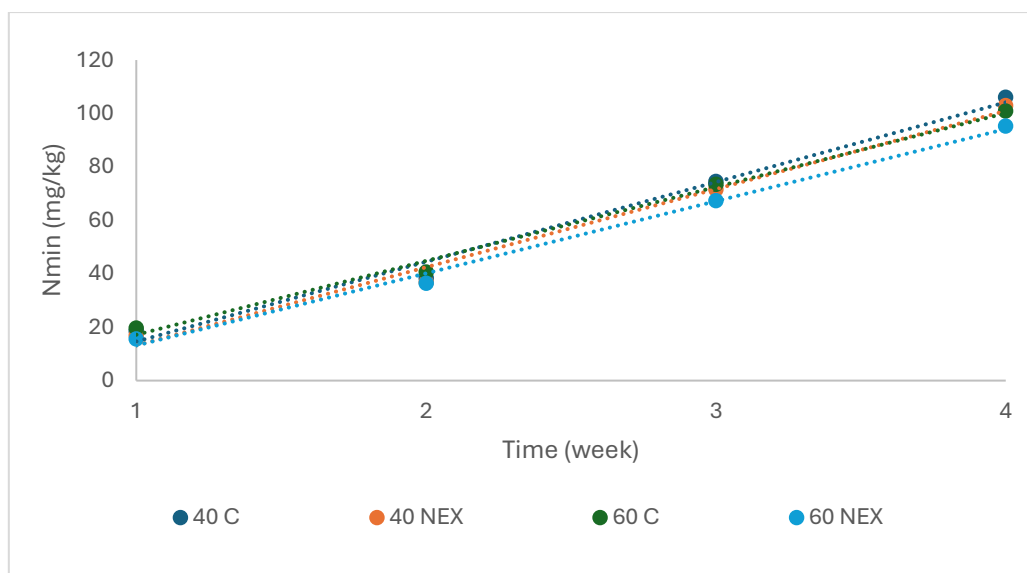
In this experiment, similar to the chernozem soil, the ratio between the two N forms is shifted in the brown forest soil during incubation, but the rate of the shift was smaller compared to the chernozem soil.

From the results the potentially mineralizable nitrogen (PMN) in the soils were determined according to FILEP and TÓTHNÉ, 1980a; b.

The rate of mineral N formation per week could be described by a linear relationship in both soil types during the examined period (Figures 1 and 2). Based on the results, it can be concluded that the chernozem soil has a greater mineralization potential than the brown forest soil, due to its higher nutrient and organic matter content (Table 8).



**Figure 1.** N<sub>min</sub> content during the incubation period at chernozem soil



**Figure 2.** N<sub>min</sub> content during the incubation period at brown forest soil

**Table 8.** Calculated PMN values at Látókép and Pallag soils

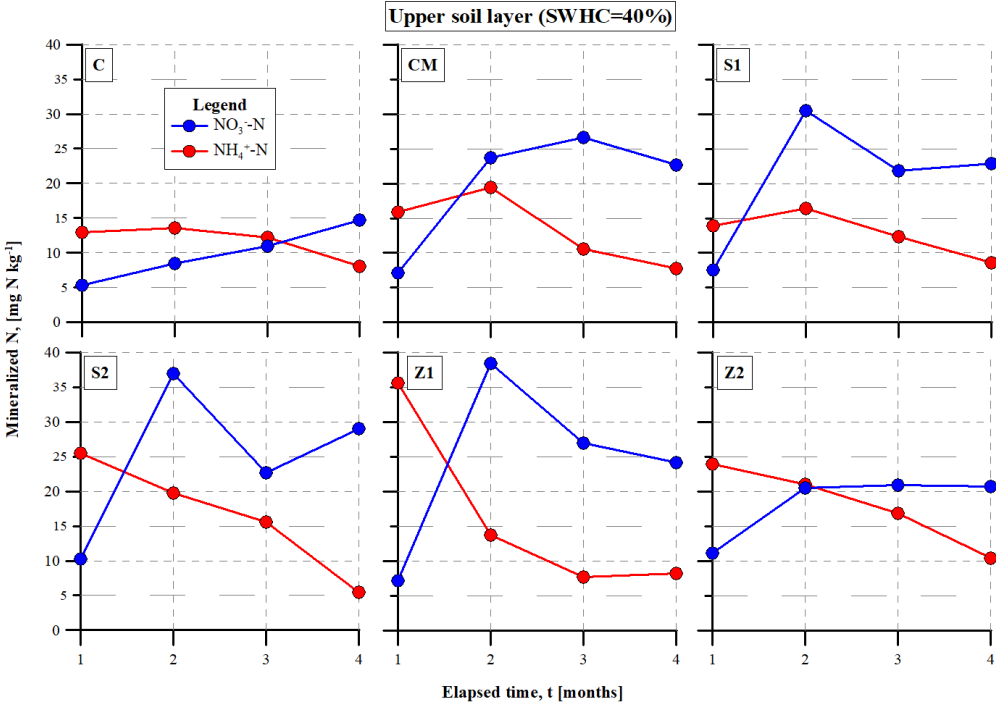
	Látókép soil	Pallag soil
Treatments	PMN (mg/kg)	PMN (mg/kg)
<b>40 C</b>	434 .78	114 .65
<b>40 NEX</b>	588 .24	188 .68
<b>60 C</b>	1000 .14	140 .85
<b>60 NEX</b>	1428 .57	256 .41

The application of the composite increased the PMN value in the brown forest soil by 64.5% to 82%, depending on the moisture content, and in the chernozem soil by 35.3% to 42.8%, depending on the moisture content. The results showed that the application of the composite effectively promoted mineralization processes in both soil types. The findings suggest that significant nitrogen mineralization can only be expected under optimal soil moisture conditions. The composite product proved to be particularly effective in soils with low nutrient levels and low mineralization potential, such as sandy-structured soils.

Based on the linear regression model, the net mineralization rate (NMR) was also determined. In the chernozem soil, the calculated NMR values were 1.14, 1.28, 1.15, and 0.38 mg N/kg soil/day for the 40 C, 40 NEX, 60 C, and 60 NEX treatments, respectively. In the brown forest soil, the calculated NMR values were 0.46, 0.52, 0.28, and 0.44 mg N/kg soil/day for the 40 C, 40 NEX, 60 C, and 60 NEX treatments, respectively.

The NMR value in the chernozem soil was 2.5 to 4 times higher than in the brown forest soil, except for the 60 NEX treatment. The NEX treatment generally had an increasing effect on NMR, except for the 60 NEX treatment in the chernozem soil.

Soil organic N content was re-measured at the end of the experiment. The content was 2100 mg/kg in the chernozem soil and 370 mg/kg in the brown forest soil. This means that 60% and 53% of the initial amount remained in the chernozem and brown forest soils, respectively, after one month of incubation.

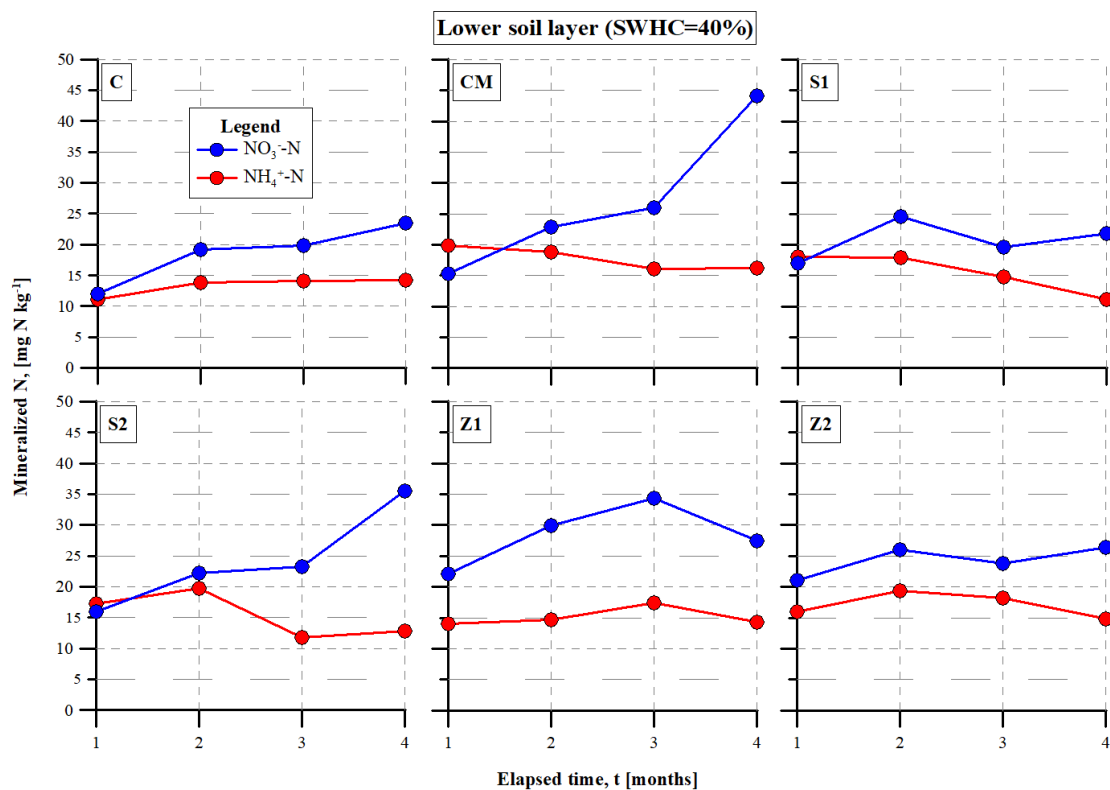


**Figure 3.** The effect of treatments on mineralized N forms (mg N/kg) in the upper soil layer (SWHC=40%)

The results of the third, four-month-long soil incubation experiment indicated that the soil  $\text{NH}_4\text{-N}$  content decreased, while the  $\text{NO}_3\text{-N}$  content increased in all treatments during the incubation period (Figures 3 and 4).

In general, the decreasing trend in  $\text{NH}_4\text{-N}$  concentration correlated with the increase in  $\text{NO}_3\text{-N}$  concentration during the incubation period. This indicates that the amount of two main inorganic forms of soil N highly correlated during the incubation, due to the advanced mineralization process (CALDERÓN et al., 2004). Furthermore, my results pointed out that the change in  $\text{NH}_4\text{-N}$  content between the two layers remained below that of nitrate, because the soil clay particles and the additives temporarily retained the ammonium ions at their cation exchange sites.

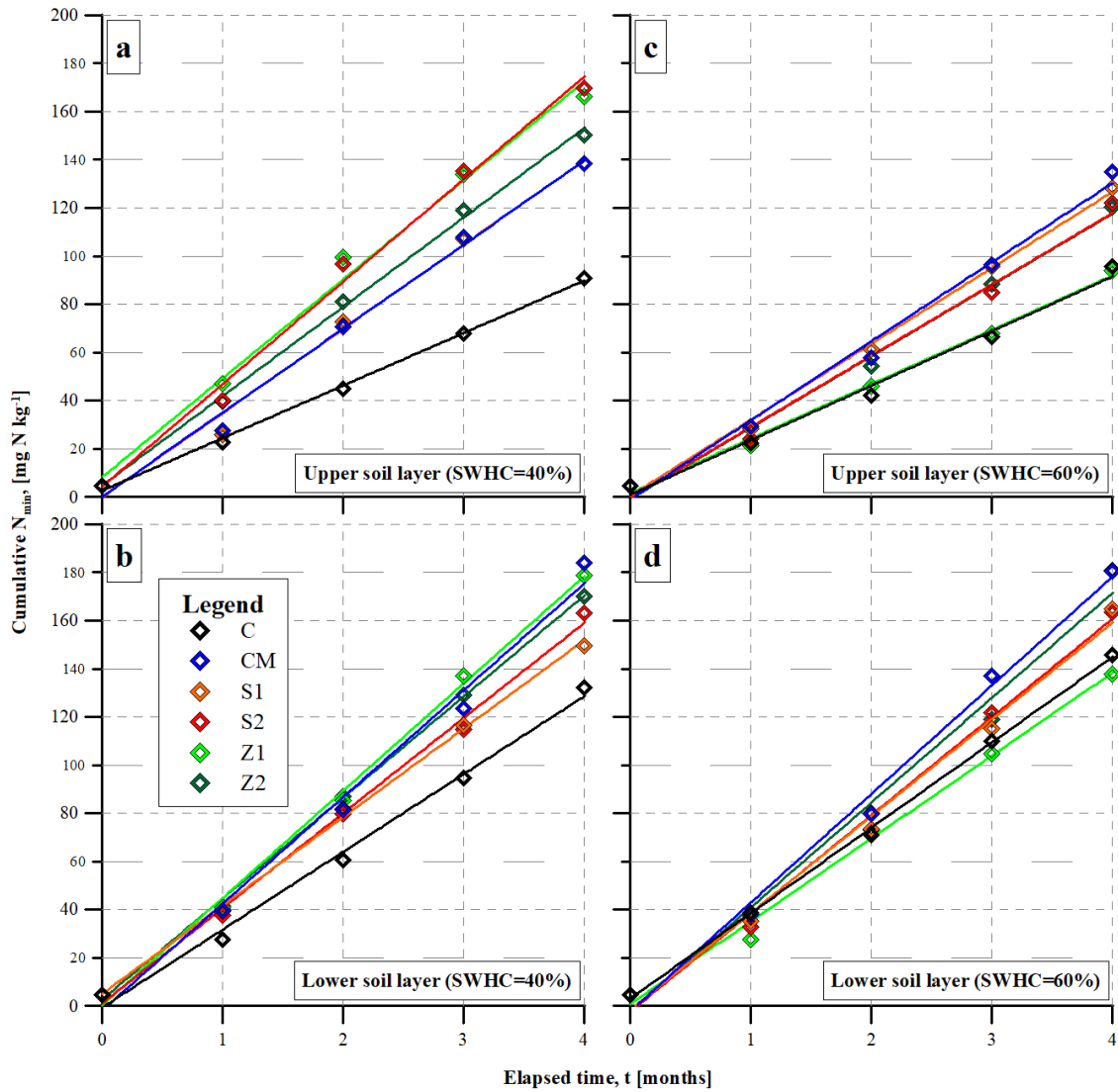
It can be concluded that a more significant treatment effect was observed at the lower water capacity level, suggesting that SAPs have more favourable effect under lower soil moisture conditions (ADJUIK et al., 2022).



**Figure 4.** The effect of treatments on mineralized N forms (mg N/kg) in the lower soil layer (SWHC=40%)

At the lower water capacity level in the upper layer, I observed 1.5 to 2 times higher Nmin content compared to the control, whereas at higher moisture levels, no such difference was

measured between the treatments and the control. The cumulative  $N_{min}$  values in all treatments reached 140-180 mg/kg compared to the control (90-130 mg/kg) at the lower water capacity level (Figures 5a,b).



**Figure 5.** Effects of the treatments on  $N_{min}$  in the entire incubation period

The results allowed for the estimation of the total mineralized N proportion in the soil across different treatments - essentially determining what percentage of the total nitrogen content was present in inorganic form. During the 112-day incubation experiment, the amount of mineralized N ranged between 8.14% and 15.63% (with an average of 11.92%). The presence of chicken manure and additives in the composite treatments significantly increased the amount of mineralized N (from 7.87% to 14.4-14.7%) in both moisture conditions and in both examined layers compared to the control (except for the Z1 treatment).

It can be concluded that the composites were more effective at lower water capacity in the treated layer. The S2, Z1, and Z2 treatments increased the amount of mineralized N by 2.7%, 2.4%, and 1% compared to the CM treatment, while S1 resulted in the same value. In the lower layer, the effectiveness of the CM and S2, Z1, and Z2 treatments did not differ from each other. The CM treatment was as effective as the composite treatments under higher moisture conditions. Moreover, there was no significant difference between the treatments, except for Z1, which resulted in the lowest values of 8.14% and 11.94% (Table 9).

**Table 9.** Effects of the treatments on the mineralized part of the total N-content (%).

<b>Mineralized part of the total N-content (%)</b>				
<b>Treatments</b>	<b>SWHC=40%</b>		<b>SWHC=60%</b>	
	<b>Upper layer</b>	<b>Lower layer</b>	<b>Upper layer</b>	<b>Lower layer</b>
<b>C</b>	7.87 <sup>c</sup>	9.46 <sup>b</sup>	8.27 <sup>c</sup>	12.64 <sup>b</sup>
<b>CM</b>	11.99 <sup>b</sup>	12.88 <sup>a</sup>	11.70 <sup>a</sup>	15.63 <sup>a</sup>
<b>S1</b>	12.00 <sup>b</sup>	9.91 <sup>b</sup>	11.12 <sup>a</sup>	14.30 <sup>a</sup>
<b>S2</b>	14.70 <sup>a</sup>	11.26 <sup>a</sup>	10.57 <sup>a</sup>	14.18 <sup>a</sup>
<b>Z1</b>	14.41 <sup>a</sup>	12.36 <sup>a</sup>	8.14 <sup>c</sup>	11.94 <sup>b</sup>
<b>Z2</b>	13.01 <sup>a</sup>	11.53 <sup>a</sup>	10.42 <sup>a</sup>	15.67 <sup>a</sup>

There is no significant difference between values marked with the same letter (P<0.05).

Obtained results enabled the estimation of soil PMN and NMR values at different treatments (MAITLO et al., 2022). The calculated PMN and NMR values are shown in Table 10. The PMN values ranged from 54 to 232 mg N/kg depending on the treatments, water capacity level, and depth.

The lowest values were obtained in the control samples (54-70 mg N/kg). A more significant treatment effect was observed in the application layer at 40% water capacity level than in the lower layer, and at higher water capacity levels, in both layers. The higher dose of SAP in the composites (S2 and Z2 treatments) increased the PMN by 3-4 times compared to the control and CM treatment (Table 10). The Z1 treatment resulted twice as much PMN in the lower layer compared to the control. The S1 and Z2 treatments tripled the PMN in the lower layer compared to the control at higher water capacity level. Additionally, these treatments increased the PMN by 50 mg/kg compared to the CM treatment. However, in the upper layer at higher water capacity level, the CM treatment caused the highest PMN value (227 mg N/kg).

**Table 10.** Effect of treatments on calculated PMN, NMR, and NNR values (N mg/kg).

<b>Upper layer</b>							
<b>SWHC=40%</b>				<b>SWHC=60%</b>			
Treatment	PMN	NMR	NNR	Treatment	PMN	NMR	NNR
mg N/kg				mg N/kg			
<b>C</b>	54 <sup>c</sup>	2.41 <sup>c</sup>	0.38 <sup>c</sup>	<b>C</b>	70 <sup>c</sup>	2.41 <sup>c</sup>	0.63 <sup>b</sup>
<b>CM</b>	64 <sup>c</sup>	3.64 <sup>b</sup>	0.74 <sup>b</sup>	<b>CM</b>	227 <sup>a</sup>	3.37 <sup>a</sup>	0.92 <sup>a</sup>
<b>S1</b>	68 <sup>c</sup>	3.63 <sup>b</sup>	0.76 <sup>b</sup>	<b>S1</b>	139 <sup>b</sup>	3.31 <sup>a</sup>	0.82 <sup>a</sup>
<b>S2</b>	192 <sup>a</sup>	4.65 <sup>a</sup>	0.91 <sup>a</sup>	<b>S2</b>	71 <sup>c</sup>	3.05 <sup>b</sup>	0.74 <sup>b</sup>
<b>Z1</b>	103 <sup>b</sup>	4.70 <sup>a</sup>	0.87 <sup>a</sup>	<b>Z1</b>	147 <sup>b</sup>	2.44 <sup>c</sup>	0.59 <sup>b</sup>
<b>Z2</b>	232 <sup>a</sup>	4.11 <sup>b</sup>	0.68 <sup>b</sup>	<b>Z2</b>	76 <sup>c</sup>	3.04 <sup>b</sup>	0.78 <sup>a</sup>

<b>Lower layer</b>							
<b>SWHC=40%</b>				<b>SWHC=60%</b>			
Treatment	PMN	NMR	NNR	Treatment	PMN	NMR	NNR
mg/kg				mg/kg			
<b>C</b>	55 <sup>c</sup>	3.33 <sup>c</sup>	0.69 <sup>b</sup>	<b>C</b>	61 <sup>d</sup>	3.85 <sup>c</sup>	0.85 <sup>b</sup>
<b>CM</b>	89 <sup>b</sup>	4.51 <sup>a</sup>	0.99 <sup>a</sup>	<b>CM</b>	147 <sup>b</sup>	4.58 <sup>a</sup>	1.17 <sup>a</sup>
<b>S1</b>	54 <sup>c</sup>	4.08 <sup>b</sup>	0.76 <sup>b</sup>	<b>S1</b>	208 <sup>a</sup>	4.10 <sup>b</sup>	0.95 <sup>a</sup>
<b>S2</b>	81 <sup>b</sup>	4.16 <sup>b</sup>	0.89 <sup>a</sup>	<b>S2</b>	101 <sup>c</sup>	4.12 <sup>b</sup>	0.92 <sup>a</sup>
<b>Z1</b>	109 <sup>a</sup>	4.65 <sup>a</sup>	1.04 <sup>a</sup>	<b>Z1</b>	66 <sup>d</sup>	3.62 <sup>c</sup>	0.80 <sup>b</sup>
<b>Z2</b>	73 <sup>b</sup>	4.50 <sup>a</sup>	0.89 <sup>a</sup>	<b>Z2</b>	192 <sup>a</sup>	4.39 <sup>a</sup>	1.11 <sup>a</sup>

There is no significant difference between values marked with the same letter (P<0.05).

These results suggested that a significant correlation could be established between composite treatments and mineralization, and that at lower water capacity levels, the composite treatments were more effective in achieving maximum mineralization potential than other treatments.

It can be seen that the NMR values ranged between 2.4 and 4.7 mg/kg depending on the applied treatments, water capacity level, and depth. The lowest values were observed in the control (2.41-3.85 mg/kg). It can be concluded that the applied treatments significantly increased the NMR value compared to the control. The CM, Z1, and Z2 treatments had the greatest increasing effect on NMR in the lower layer at lower water capacity level compared to the control. At higher water capacity level, however, the CM and Z2 treatments resulted in the highest NMR value in the lower layer. In the upper layer, the most effective treatments were S2 and Z1 at SWHC=40%, and CM and S1 at SWHC=60%.

In addition to PMN and NMR values, the changes in NNR values was also studied (Table 10). The NNR values ranged between 0.38 and 1.17 mg/kg depending on the applied treatments, the water capacity level, and depth. The lowest values were observed in the control (0.38-0.85 mg/kg). Compared to the control, the treatments resulted in significantly higher NNR values in both soil layers at lower water capacity levels (except for S1). The S2 and Z1 treatments resulted in nearly two and a half times the NNR increase compared to the control, and the value increased by 20% compared to the CM treatment in the application layer at lower water capacity level. At higher water capacity level, the treatments caused significantly higher NNR values in both soil layers compared to the control (except for S2, Z1 in the upper layer and Z1 in the lower layer). However, the composites did not result in higher NNR values at this water capacity level compared to the CM treatment. This finding also pointed out that the composites are more effective in the mineralization process at lower water capacity level.

### **3.3. Results of small pot experiments**

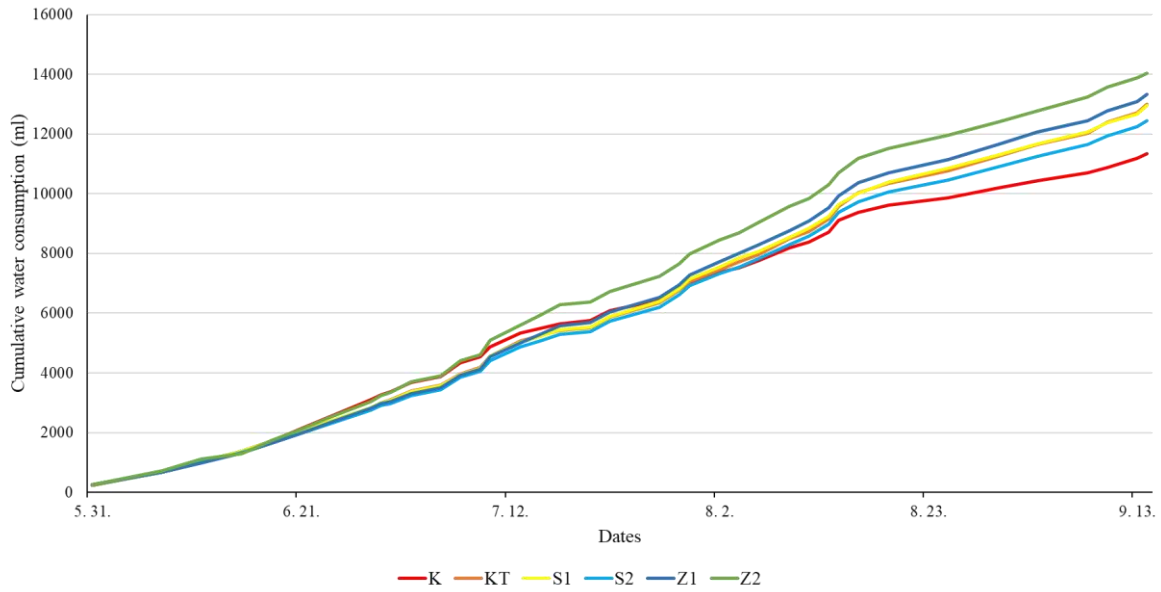
I paid special attention to test the developed composites as prototype products in small pot (model) experiments. I compared the effect of each composite treatment to a control treatment and a treatment receiving only chicken manure, and I examined how these treatments affected plant growth and some quality indicators in cucumber and tomato as indicator plants.

#### **3.3.1. Results of small pot experiments with tomato**

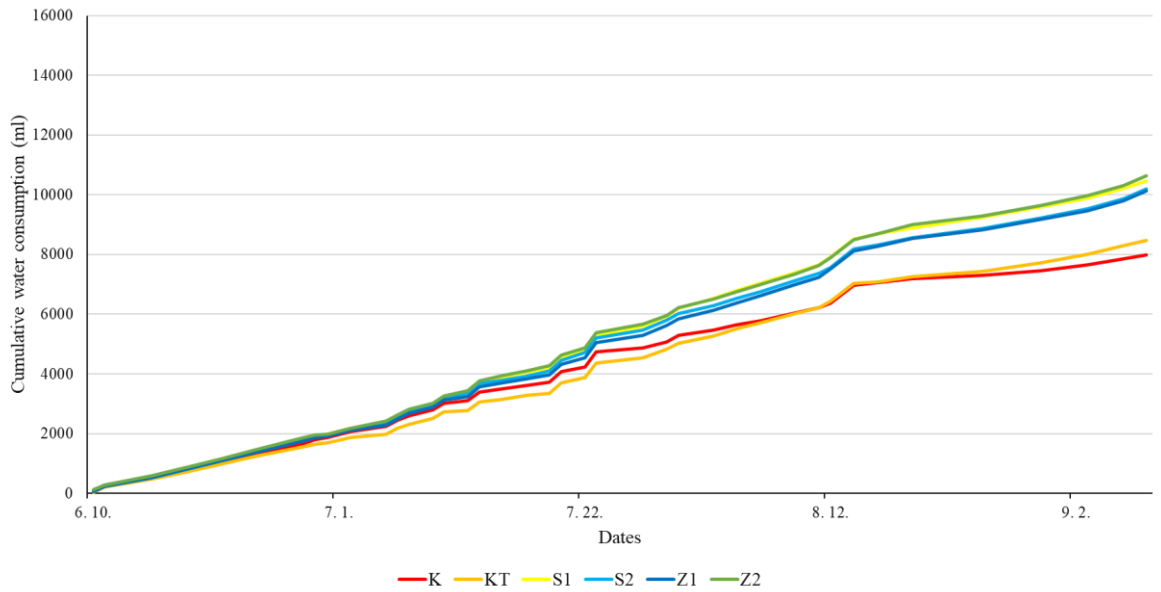
It can be concluded that the fermented chicken manure alone already increased water consumption on both soils compared to the control (Figures 6 and 7).

These results can be explained by the larger biomass mass of the tomato plants grown in these treatments. More developed plants require a greater amount of water; however, as I will later demonstrate, this increased water consumption per unit mass represents a smaller quantity since the rate of biomass mass increase exceeded the rate of water consumption increase.

Similar to the Pallag soil, the smallest cumulative amount of irrigation water was obtained in the control treatment at Debrcen soil as well. The treatment that received only manure slightly increased the amount of irrigation water. However, in composite treatments, the rate of increase was on average about 20-25% higher compared to the control and the chicken manure (KT) treatment.



**Figure 6.** Effects of the treatments on the amount of irrigation water at Pallag soil

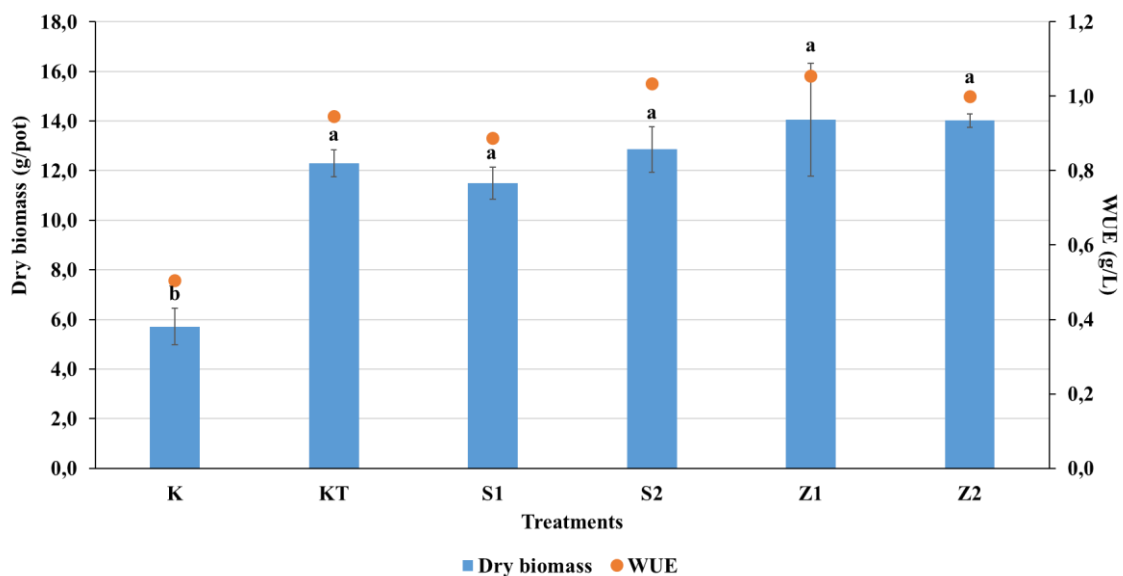


**Figure 7.** Effects of the treatments on the amount of irrigation water at Debrecen soil

Figure 8 shows the effect of the treatments on the dry matter mass of the tomato and its water use efficiency (WUE) at Pallag soil. The lowest value was obtained in the control treatment (5.7 g/pot), while the applied treatments resulted in more than double mass increase (11.5-14.1 g/pot). The highest values were obtained in the Z1 and Z2 treatments (14.1 and 14.0 g/pot), which were not significantly different from each other. This suggests that the treatments that received organic SAP had the greatest impact on increasing dry matter mass.

The figure also shows that WUE significantly increased as a result of the applied treatments compared to the control. The dry biomass mass obtained per unit of water increased from 0.5 grams to 0.9 - 1.05 grams. This represents an improvement of almost 100% in WUE, which seems very promising in the current very dry weather conditions.

In addition to WUE, the specific water demand of the plants was also calculated, which, compared to the significant dry matter surplus and water consumption data, resulted in a significant reduction in specific water demand and thus an increase in WUE. The specific water requirement decreased from 2 l/g to approximately 1 g/l, representing a 50% water saving. It means that the composite treatments were also able to further reduce the specific water requirement compared to the chicken manure treatment.

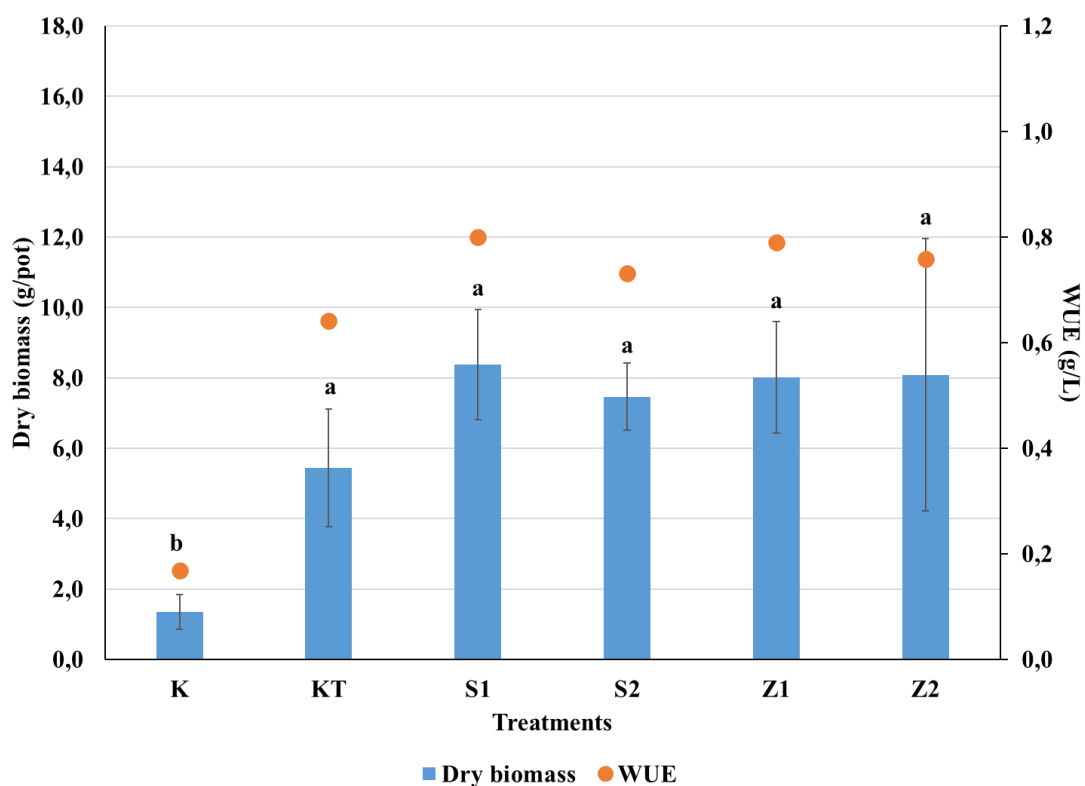


There is no significant difference between values marked with the same letter ( $P < 0.05$ ).

**Figure 8.** The effect of treatments on the dry matter mass and WUE of tomatoes on Pallag soil

Figure 9 shows the effect of treatments on the dry matter mass and water use efficiency of tomatoes on Debrecen sandy soil. It can be seen that for this soil, the control treatment also resulted in the smallest biomass mass (1.35 g/pot). The applied treatments led to a 3-5-fold increase in dry matter content (7.46-8.37 g/pot). The composite treatments further increased the dry matter mass of tomatoes by about 0.8-1.0 grams per pot compared to the treatment that received only chicken manure. There was no significant difference between the composite treatments, but all of them increased the dry matter mass of the tomato indicator plant compared to both the chicken manure and control treatments.

Similar to the data measured on the Pallag soil, WUE was also lowest in this experiment in the control (0.2 g/l). The treatments significantly increased WUE by approximately three to four times (0.6-0.8 g/l). It can be seen that compared to the chicken manure treatment, the composite treatments further increased water use efficiency by 0.2 g/l. This means that in the applied treatments, three to four times as much dry biomass mass was produced per unit of water compared to the control sample. These results are very promising for the use of composites, as they can help to achieve several times higher yields per unit mass of irrigation water. This could result in a significant yield increase under field conditions. Of course, my results must be supported by future experiments under small plot and field (greenhouse) conditions.



There is no significant difference between values marked with the same letter ( $P < 0.05$ ).

**Figure 9.** The effect of treatments on the dry matter mass and WUE of tomatoes on Debrecen soil

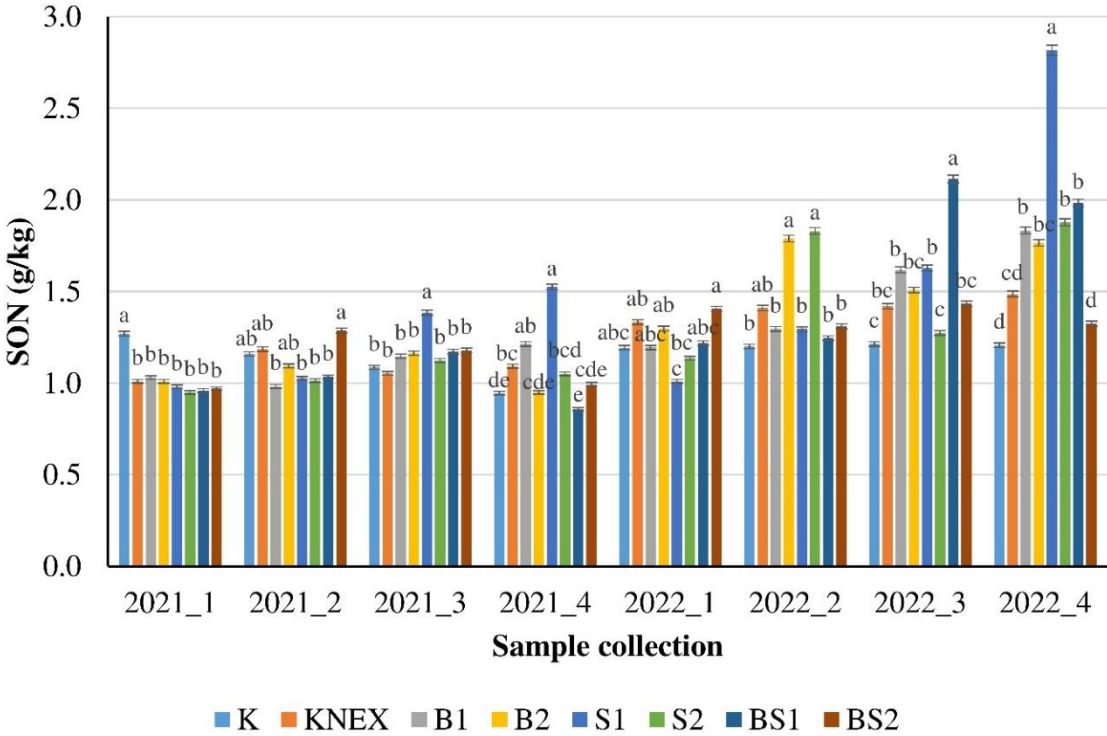
Today, when irrigation is becoming crucial for plant production, the use of so-called water saving techniques (which can save significant amounts of water) have particular importance. The significance of the results obtained is even more pronounced in water-demanding vegetable and fruit crops. In recent years, the drought summers and often precipitation-deficient spring and autumn periods have highlighted that meaningful (both quantitative and qualitative)

production is not possible for these plants without proper water management practices. It can be concluded that the products developed and applied in these experiments significantly reduce water requirements, increase water use efficiency, and result in larger, more attractive plants compared to both the control and treatments that received only chicken manure.

**3.3. Results of field experiment (Pallag)**

In my research, at the highest level, I also tested the effect of composites under field conditions. I conducted my experiment at the Pallag experimental site of the University of Debrecen in an apple orchard planted in 2011.

I tested the composite products in the orchard over two consecutive years. Based on soil analysis results, it can be concluded that by the end of the first year, the composites significantly increased soil nitrate content and affected the amount of soil organic carbon and nitrogen (WANG et al., 2013; ZHANG et al., 2022). Chicken manure and higher doses of composites increased soil organic carbon content by 4-9 g/kg. All treatments, except for the lower doses of bentonite and super absorbent polymer, significantly increased the soil organic nitrogen content (from 1 g/kg to 1.8-2.8 g/kg) compared to the control and chicken manure treatment ( $p < 0.05$ ) by the end of the second year (Figure 10).



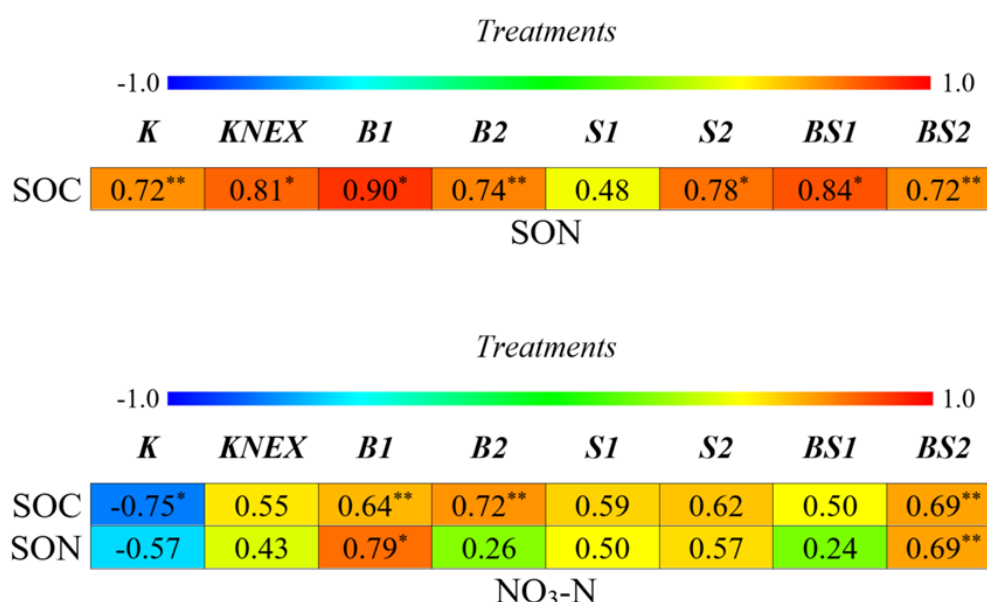
There is no significant difference between values marked with the same letter ( $P < 0.05$ ).

**Figure 10.** The effect of treatments on SON content at different sampling times.

Soil nitrate content continuously increased during the experiment from 8-10 mg/kg to 30-38 mg/kg in all treatments, except for the control, which remained at 8 mg/kg throughout. However, my results highlighted the importance of maintaining or possibly improving the appropriate C/N ratio, as the efficiency of nitrogen mobilization can only be increased at proper C/N ratio.

I found that the ratio of organic/inorganic nitrogen in the soil significantly changes due to the composite treatments, indicating that the composite treatments have a significant impact on nitrogen mineralization and mobilization. Since ensuring adequate nitrogen supply over an extended period (e.g., in perennial crops) is particularly challenging in soils with low nutrient supply and prone to leaching, the composites I developed, with their prolonged effect, may be suitable for providing the necessary nutrient supplementation under such conditions.

The correlations between SOC, SON, and NO<sub>3</sub>-N are shown in Figure 11 based on Spearman's rank correlation.



\*Statistically significant correlations at a 95.0% confidence level ( $p < 0.05$ )

\*\*Statistically significant correlations at a 90.0% confidence level ( $p < 0.10$ )

**Figure 11.** Spearman's rank correlations between SOC, SON, and NO<sub>3</sub>-N

I found a significant correlation at a 95.0% confidence level ( $p < 0.05$ ) between the SOC and SON parameters in the KNEX, B1, and BS1 treatments. In addition to the SOC and SON correlation, I examined the statistical relationship between NO<sub>3</sub>-N and SOC values. The results showed a significant negative correlation at a 95.0% confidence level ( $p < 0.05$ ) between NO<sub>3</sub>-N and SOC parameters in the control treatment, with a value of -0.75. All other treatments showed a positive correlation between NO<sub>3</sub>-N and SOC values (Figure 11). At a 90.0%

confidence level ( $p < 0.10$ ), statistically significant positive correlations between  $\text{NO}_3\text{-N}$  and SOC values were found only in the B1 (0.64), B2 (0.72), and BS2 (0.69) treatments. This suggests that in these treatments, the increasing organic matter content statistically significantly influenced and increased the nitrate content of the soils. A significant correlation between  $\text{NO}_3\text{-N}$  and SON values was found at a 95.0% confidence level ( $p < 0.05$ ) in the B1 treatment (0.79). Additionally, at a 90.0% confidence level ( $p < 0.10$ ), a significant correlation was found in the BS2 treatment (0.69).

The leaf analysis indicated that the composites effectively increased leaf N, K, Ca, and Mg content, while the treatments had no significant effect on leaf P content ( $p < 0.05$ ) (ALI et al., 2023). Furthermore, I found that all treatments (except for the lower dose of bentonite) significantly increased yield by an average of 14-63% during the study years, depending on the applied composite, compared to the control. Regarding the individual apple weight, the bentonite treatments increased the weight by 2% and 24% compared to the chicken manure treatment. On average, over two years, composite treatments (except for the lower dose of SAP) increased the titratable acidity of the harvested fruits by 26-43% compared to the control, and by 0.5-10% compared to the chicken manure treatment.

However, over the two-year period, significant differences were observed in the polyphenol content of the fruits between the years. Notably, higher polyphenol content was measured in the composite treatments in 2022. This is significant because the extreme drought conditions of 2022 decreased the polyphenol content in the control and chicken manure treatments, while increasing it in the composite treatments (except for B1 and BS2).

Based on my results, the developed composites are able for improving and enhancing soil nutrient supply, especially in sandy soils with low nutrient availability and poor water management, which are sensitive to improper nutrient management. This helps to mitigate the adverse effects of extreme weather conditions. At the same time, the recycling of manure, which is considered a potentially hazardous waste without processing and is a byproduct of large-scale poultry farming, is also taken into account. This contributes to the realization of sustainable agriculture and nutrient management. The developed composite products may be particularly effective in arid and semi-arid conditions, where the amount of precipitation during the growing season of various crops is particularly limited. In summary, the use of the composite products I have developed is recommended for improving soil properties in such locations where adequate nitrogen supply and/or mineralization processes are hindered for some reason, and where the soil does not have sufficient water retention capacity (typically soils with low nutrients and sandy texture).

#### **4. NEW SCIENTIFIC RESULTS OF THE THESIS**

1. During my product development work, I have developed new composite products containing fermented chicken manure (90%) as raw material, bentonite (8-9%) as additive and synthetic or organic based superabsorbent polymers (1-2%) to improve the composition of the commercially available fermented chicken manure product.

2. The results of soil incubation experiments indicated that the developed composite products effectively promote nitrogen mineralization processes in the soil, particularly in soils with lower nutrient supply. Depending on the moisture content, the application of the composites increased the potentially mineralizable nitrogen value by 64.5 to 82% in brown forest soil and by 35.3 to 42.8% in chernozem soil. The composites increased the amount of mineralized nitrogen by 1-3% during the four-month incubation period compared to the treatment that only received chicken manure.

3. Pot experiments confirmed the effects of the developed composite products on vegetable crops. In tomatoes, the treatments increased the dry mass weight by 2.5 to 5 times, while in cucumbers, the increase was 1.4 to 1.6 times. The use of these products increased the dry biomass per unit of water from 0.5 grams to 0.9-1.05 grams in tomatoes and from 0.58 grams to 0.8 grams in cucumbers. As a result, the amount of irrigation water required or the frequency of irrigation can be reduced in irrigated crops.

4. Field trials demonstrated that the developed composite products improved the nutrient supply capacity of sandy-textured brown forest soil. Higher doses of composites significantly increased the soil organic nitrogen content (from 1 g/kg to 1.8-2.8 g/kg) compared to the control and chicken manure treatments ( $p < 0.05$ ) by the end of the second year. Plant studies showed that composites positively affected the availability of macronutrients, as they significantly increased the nitrogen, potassium, calcium, and magnesium content in the leaves.

## **5. THE PRACTICAL USE OF THE RESULTS**

1. The composite products I developed can be used to effectively improve soils with low nutrient contents and poor water management.
2. The effectiveness of the developed composite products is mainly concentrated on the application depth, so it is recommended to adjust the application of these products to the root zone.
3. The effectiveness of the developed and tested products is greater under less favourable water supply conditions, so it is recommended to use them in areas where soils are sensitive to water supply problems and less able to retain precipitation in the root zone or are susceptible to leaching and leaching processes.
4. My experiments confirmed that the developed composite products have a positive effect on mineralisation processes in the soil, promoting these processes and thereby providing more significant amounts of mineral nitrogen for plants, especially in soils where nitrogen mineralization is hindered for some reason.
5. My experiments showed that the developed composite products are not in competition with the nutrient uptake by plants.

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## 7. PUBLICATION LIST



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### List of publications related to the dissertation

#### Foreign language scientific articles in Hungarian journals (4)

1. **Tóth, F. A.**, Tamás, J., Nagy, P. T.: Effects of fermented and supplemented chicken manure on the nutrient management aspects of an apple orchard.  
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**Total IF of journals (all publications): 7,908**

**Total IF of journals (publications related to the dissertation): 4,5**



The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

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