ECOCYCLES
ISSN 2416-2140

OPEN ACCESS
Scientific journal of the
European Ecocycles Society

Ecocycles, Vol. 9, No. 3, pp. 1-9 (2023)
DOI: 10.19040/ecocycles.v9i3.329

RESEARCH ARTICLE

Effects of organic composite fertilizer on soil nitrogen status and mineralization

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Abstract – A short-term soil incubation experiment was set up to obtain information to clarify the effect of our developed organic composite fertilizer on soil nitrogen mineralization. The composite was designed to have beneficial effects on the properties of chicken manure and to improve soil water management properties in addition to organic matter replenishment. In the incubation experiment, two different additives, bentonite, and super absorbent polymer, were used to enhance the properties of fermented chicken manure. Developed prototype products were tested in a four-week-long soil incubation experiment in two typical Hungarian soils: brown forest soil with a sandy texture and chernozem soil at two different water capacities (40 w/w % and 60 w/w %). Soil pH, and inorganic nitrogen forms, like nitrate and ammonium, were measured weekly. Furthermore, the potentially mineralized nitrogen and net mineralization rate were calculated. The applied composite was not affected the soil pH significantly in the examined period. The soil nitrate and ammonium ratio was changed during the incubation as the ammonium content in the soil decreased while nitrate content increased continuously throughout the experiment. This suggests that the incubation experiment successfully monitored the delicate balance of soil nitrogen forms. It was found that the chernozem soil type had a higher mineralization potential compared to brown forest soil due to its higher nutrient and organic matter contents. Moreover, our results pointed out that soil moisture content did not significantly affect the mineralization process. The amount of mineral nitrogen, generated per week can be described by a linear relationship for both soil types and water regimes. The composite product showed efficacy in promoting mineralization processes, particularly in soils with low nutrient status and mineralization potential.

Keywords – Organic fertilization; Soil incubation, Nitrogen mineralization

Received: July 7, 2023 Accepted: August 22, 2023

INTRODUCTION

The positive effect of soil organic matter (SOM) on crop yields has long been known due to its ability to supply plants with nutrients (King et al., 2020). The importance and role of organic fertilization have increased in the last years across Europe due to the steady decline in soil organic matter and deteriorating water management conditions. Panagos et al. (2013) reported that 75% of EU croplands having less than 2% organic carbon and almost half of the European arable areas have suffered from low SOM content (Yigini and Panagos (2016).

To improve SOM, usage of agrarian co-products (mostly animal manures) is frequented in sustainable agriculture practices due to their low cost, easy supply, rich in nutrients for plant and soil health, and re-participate in the material cycles in nature (McGrath et al., 2010; Materechera, 2010). Chicken manure (CM) is regarded as an excellent source of organic matter supplied in agriculture because globally, the chicken industry is a large and expanding agro-based sector and produces enormous amounts of co-products.

Consequently, the chicken industry generates millions of tons of potentially hazardous waste annually, and if not managed in an environmentally friendly and cost-effective manner, it can lead to significant environmental issues (Sharpley et al., 2007). Although CM is considered as a hazardous waste and contributes to environmental problems through intensive production, the use of CM has traditionally been prevalent in agriculture due to its high nutrient content.

The utilization of CM can enhance crop yield, and it can also remediate and/or improve the physical and chemical properties of the soil (Haga, 1999; Cordovil et al., 2005; Bolan, et al., 2010; Masarirambi et al. 2012; Ravindran et al., 2017). It increases the abundance and diversity of microorganisms, particularly in sandy soil, which benefits plants by enhancing water and nutrient availability (Kaiser et al., 2009).

Moreover, its application fits well with the aims of Green Deal. A central element of the Green Deal is the need to move towards a more sustainable system of agricultural production that minimizes farming's environmental footprint. The development and use of bio-based fertilizers to protect the environment are among the issue that has been widely researched. Therefore, the issue of how chicken manure affects soil health and different processes (e.g. N mineralization) has been studied for years.

Chicken manure alone, however, may not provide sufficient nutrients and conditions (Amanullah et al., 2010). It is therefore important to supplement it with materials that may improve its properties and, when used together, improve the water management properties of soils. Therefore, our research aimed to develop and test products that effectively improve the water-holding capacity of soils by adding commercially available fermented chicken manure, creating conditions that are more favorable for example, mineralization processes.

To achieve our objectives, we used two soil additives (superabsorbent polymer (SAP) and bentonite) to improve the properties of fermented chicken manure and to create an organic-based composite.

These soil amendments were chosen because of the growing interest in the use of SAPs to solve agricultural problems related to soil water management in recent decades (Buchholz and Graham, 1998; Abd EI-Rehirn et al., 2004). Recently, the use of SAPs in agriculture has demonstrated several benefits for soil amendments, reducing the usage of nutrients, saving soil water content, and minimizing the negative impacts of water stress (Elshafie and Camele, 2021).
They have been successfully applied as soil amendments to improve the physical properties of soils by increasing water-holding capacity and/or nutrient retention of soils (Abd EI-Rehirn et al., 2004; Burke et al., 2010 Brave and Nnadi, 2011).

Bentonite is also widely known in agriculture as a natural soil amelioration. Its application enhances the pH, cation exchange capacity (CEC), steadiness of aggregates, nutrient retention, and capability, improves water use efficiency, increases soil water-holding capacity, utilizes ability, and accordingly improves agricultural yield (Gill et al., 2004; Kátai et al., 2008 and 2010, Tállai, 2009; Mi et al., 2020; Hussain et al., 2022).

Traditionally, the N mineralization potential of various materials, such as manures, composts, and soils, has been estimated through laboratory incubation (Hadas and Portnoy 1994; Abbasi et al., 2001). As the rate and timing of manure application as nitrogen (N) fertilizer depends on the N-releasing capacity of manures. The amount of N potentially mineralized from manures is a crucial factor when determining the appropriate application rate to meet N requirements for optimal crop production. Therefore this research focused on testing organic based composite in an incubation experiment, applied two different soil types and moisture levels. The main objective of present study was to investigate the effect of composite on soil nitrogen status and mineralization and to evaluate the effects of composite on potential rates of mineralization and nitrification, providing valuable insights into the potential use of this composite as organic N sources in farming systems.

MATERIALS AND METHODS

To study the effects of fertilizer composite on soil nitrogen mineralization, an aerobic incubation experiment was set up. For incubation, 75 mg composted chicken manure (CM), 7.5 mg bentonite, and 0.0375 mg super absorbent polymer (SAP) were mixed with 100 gr soil samples in the whole volume and put in a special glass tube (Nagy, 2010). The CM was a Bio-Fer product (Natur extra (NEX)), as raw material, produced by Baromfi Coop Ltd. The main components of NEX are shown in Table 1.

Table 1. Main chemical characteristics of Bio-Fer Natur Extra product

Component	Value	Component	Value
Nitrogen (w/w%)	5.50	Fe (mg kg^{-1})	545.00
Phosphorus (P_2O_5) (w/w%)	3.00	Mn (mg kg^{-1})	374.00
Potassium (K_2O) (w/w%)	2.50	Mo (mg kg^{-1})	3.66
Ca (w/w) %	6.00	Zn (mg kg^{-1})	367.00
Mg (w/w) %	0.50	Cu (mg kg^{-1})	53.30
S (w/w %)	1.00	Moisture content (w/w%)	12.00
B (mg kg^{-1})	31.40	pH	7.20

Source: https://bio-fer.hu/bio-fer-natur-extra/

In the incubation experiment, two different additives were used to enhance the properties of fermented CM. A cross-linked acrylamide and potassium polyacrylate copolymer, Stockosorb was used as an SAP (EVONIK Nutrition &Care GmbH). Furthermore, bentonite was used as a clay mineral, consisting predominantly of smectite minerals, usually montmorillonite (Axis Bentonit Ltd.).

The composite was tested at two different typical Hungarian soil types. One is brown forest soil with a sandy texture (Pallag, Lamellic Arenosol) and another is chernozem soil (Látókép, Calcaric Fluvisol). Soil samples were incubated under controlled moisture conditions (at two water capacity levels (40% and 60%)) at 25ºC, for 28 days.

The incubation temperature was 25°C because it represented the mean temperature of tested soils during the growing season and higher temperatures can promote the decomposition of organic matter by different microbial communities not normally active at 5 to 25°C, providing a spurious estimate of potentially available N (Sharifi et al., 2007).

Distilled water was used to adjust the water capacity level of the soil to avoid further nutrient addition. In the incubation experiment, four treatments were applied:
1.40 C - Control treatment at 40% soil moisture level
2.40 NEX - Natur extra and additives treatment at 40% soil moisture level
3.60 C - Control treatment at 60% soil moisture level
4.60 NEX - Natur extra and additives treatment at 60% soil moisture level

Each treatment had three replicates, resulting in 96 experimental units overall. Soil moisture content was adjusted daily, by adding distilled water to maintain the moisturized conditions.

Before incubation experiment, the initial chemical characteristics of soils were determined in the accredited laboratory of the Agrarian Instrument Centre of University of Debrecen.

Soil organic carbon (SOC) was measured by Walkley-Black method (Perkin-Elmer Analyst 300, MSZ-08-0210:1977). Soil organic nitrogen (SON) was calculated from the total nitrogen content determined by Kjeldahl method (VELP DKL 20, MSZ-08-0458:1980). Soil nitrate content was assessed spectrophotometric method (FOSS FIASTAR 5000, MSZ 20135:1999). Soil phosphorus (P), potassium (K), sodium (Na), magnesium (Mg), and micronutrients were analyzed using the ICP-OES method (Thermo Fisher iCAP 7400, MSZ 20135:1999).

The initial chemical characteristics of soils used in the incubation study are shown in Table 2.

Table 2. The chemical parameters of soils of Látókép and Pallag

Basic soil parameters	Chernozem soil	Brown forest soil
pH (KCl)	7.00	6.07
Water soluble salts (w/w)%	0.04	<0.02
Carbonate (w/w)%	1.73	< 0.10
SOC (w/w)%	2.85	0.89
P_2O_5 (mg kg^{-1}) (AL)	317.00	135.00
K_2O (mg kg^{-1}) (AL)	656.00	101.00
Nitrate (mg kg^{-1}) (KCl)	115.00	11.60
Ammonium (mg kg^{-1}) (KCl)	16.67	13.12
Magnesium (mg kg^{-1}) (KCl)	376.00	136.00
Manganese(mg kg^{-1}) (EDTA)	136.00	28.80
Zinc (mg kg^{-1}) (EDTA)	2.67	0.72
Copper (mg kg^{-1}) (EDTA)	5.59	0.60
SON (w/w)%	0.35	0.07

AL, KCl and EDTA are soil extractants according to the Hungarian standard (MSZ 20135:1999)

Soil basic parameters pointed out that both soils have neutral pH, which is optimal for plant growth. High carbonate content was measured in chernozem soil, while brown forest soil contains a lower amount of carbonate. Chernozem soil is richer in organic matter than brown forest soil. Soil N content is good at chernozem and low at brown forest soil. The total amount of soil N was 3632 mg/kg in chernozem soil and 725 mg/kg in brown forest soil. It means that the total N content of the soil was five times higher in the chernozem soil than in the brown forest soil. Soil P and K contents are high at chernozem and poor at brown forest soil. All micronutrients are larger amounts in chernozem soil due to the soil type. Soil chemical parameters pointed out that there are high differences in the nutrient status and supply at the two soils.
In the soil incubation experiment, two extractants were used for soil analysis. The pH was measured from the water

extractant by electrochemical method (WTW pH/cond 3320 SET2). Inorganic ionic nitrogen forms (nitrate and ammonium) were determined from 1M KCl extractant by photometric methods (PF 12 spectrophotometer). Measurements were done weekly. The mineralized nitrogen content (Nmin) of the soil was calculated from nitrate and ammonium contents. Furthermore, the potentially mineralized nitrogen (Npot) and net mineralization rate (NMR) were also, calculated.

The mineralization rate is proportional to the current amount of mineralizable N, and the process can be considered kinetically first order. The mineralization processes and the kinetics of N mineralization was studied based on Stanford (1973). In the 1970s, Stanford and co-workers (Stanford and Smith (1972), Stanford et al. (1973), and Stanford and Epstein (1974)) advanced the concept of potentially mineralizable N (Npot) and a related mineralization rate constant (k) for use in characterizing soil-available N. This theory assumed that organic nitrogen mineralization at optimum temperature and moisture content is following a first-order kinetics. Thus the first-order rate equation:

$-dN/dt = kN$

integrate from time 0 to t:

$\ln Nt - \ln N0 = -kt$

take antilogarithms: $Nt = N0e-kt$

Where Nt = mineralizable organic substrate remaining at time t. At time 0:

$Npot = N0e-k0 = N0$

The amount of inorganic N mineralized (Nmin) is defined as the difference between the amount of mineralizable organic N at time 0 and at time t:

$Nmin = N0 - Nt$

Thus:

$Nmin = N0 - N0e-kt = N0(1-e-kt)$

Where:

t – time of incubation, the other signs are seen in the text

According to this conception, the mineralized N (Nmin) can be calculated by summing the nitrate and ammonium content. Cumulative Nmin values were calculated week by week throughout the entire experiment.

Statistical Analysis

All the acquired information was evaluated and accurately examined using the ANOVA, and Fisher's least significant differences were calculated following a significant ($P \leq 0.05$) F test.

RESULTS

Soil pH

The pH values obtained during the experiment are presented in Table 3. The soil pH was near neutral in both soil types. The applied treatments did not significantly affect the soil pH during the examined period.

Soil pH values varied between 6.55 and 7.05 in the brown forest soil and 6.33 and 6.96 in the chernozem soil. During the four weeks, the pH values seemed to decrease slightly on both soil types. This finding is consistent with a previous study (Tóth et al., 2022) and contradicts the findings of Sarifuddin and Dewantari (2021). Additionally, similar results were observed at 40% and 60% soil moisture levels for the same soil type, indicating that the soil moisture level did not affect soil pH. Furthermore, the application of NEX (at 60% soil moisture level) resulted in the highest pH of both soil types at the end of the experiment.

Table 3. Effect of the treatments on soil pH

Weeks	1st	2nd	3th	4th
Chernozem soil				
40 C	6.82a	6.43a	6.54a	6.42b
40 NEX	6.96a	6.49a	6.49a	6.35b
60 C	6.56b	6.50a	6.42a	6.46b
60 NEX	6.61b	6.59a	6.33b	6.62a
Brown forest soil				
40 C	6.94a	6.61a	6.61a	6.84a
40 NEX	6.88a	6.67a	6.55a	6.72a
60 C	6.89a	6.59a	6.61a	6.79a
60 NEX	7.05a	6.54a	6.79a	6.88a

In each column, means followed by the same letter are not significantly different ($P<0.05$).

Soil nitrogen forms

Soil nitrate and ammonium results during the experiment are presented in Table 4 and Table 5.

Table 4. Effects of the treatments on soil nitrate content (mg/kg)

Weeks	1st	2nd	3th	4th
Chernozem soil				
40 C	37.25b	14.67b	66.92bc	85.33a
40 NEX	42.75b	21.08a	79.00b	84.92a
60 C	40.33b	16.58b	92.08a	82.08a
60 NEX	58.75a	16.00b	91.67a	77.83a
Brown forest soil				
40 C	3.11b	4.94b	24.40a	24.43a
40 NEX	4.04b	6.07b	21.94a	24.39a
60 C	5.07a	7.01a	21.54a	21.44a
60 NEX	6.09a	8.14a	21.33a	22.75a

In each column, means followed by the same letter are not significantly different ($P<0.05$).

Higher nitrate contents were observed in the chernozem soil compared to the brown forest soil, which can be attributed to the soil type and the higher nutrient content in the chernozem soil. Similarly, Sistani et al. (2008) observed significant differences among the soil types in their incubation experiment.

Initially, the nitrate content in the chernozem soil was ten times higher than in the brown forest soil. By the end of the experiment, this ratio has decreased to three to four times.

In the chernozem soil, the nitrate ion concentration decreased in the second week but then increased again. In the brown forest soil, the nitrate content showed a continuous increase, with a slight increment observed in the first two weeks. In the latter part of the experiment, the nitrate content in the brown forest soil significantly increased. NEX treatments had an overall increasing effect on soil nitrate content, although this effect was not significant in all cases. Abbasi et al. (2007) reported a similar trend in their study on the N mineralization potential of different manures in a laboratory incubation experiment.

Soil ammonium content was also measured during the incubation period. Obtained results are shown in Table 5.

Table 5. Effects of the treatments on soil ammonium content (mg/kg)

Weeks	1st	2nd	3th	4th
Chernozem soil				
40 C	22.67a	54.67a	7.25a	6.58b
40 NEX	14.50b	52.25a	6.50a	8.08a
60 C	15.67b	64.17a	7.08a	6.25b
60 NEX	13.83b	62.50a	6.25a	5.50b
Brown forest soil				
40 C	15.50a	14.83a	11.83a	7.00a
40 NEX	12.92a	13.83a	12.75a	7.00a
60 C	14.58a	13.93a	11.33a	6.00a
60 NEX	9.50b	12.68a	9.58a	5.25a

In each column, means followed by the same letter are not significantly different ($P<0.05$).

The soil type had a lesser effect on soil ammonium content compared to nitrate. In the chernozem soil, there was an initial increase in soil ammonium content, followed by a significant decrease. This trend is consistent with the results of nitrate measurements (Table 4.).

The decrease in ammonium concentrations corresponded to an increase in nitrate concentrations. The nitrate/ammonium ratio has changed from 3/1 to 11/1 by the end of the experiment. This suggests that the two forms of soil nitrogen, oxidized and reduced forms, changed coherently during the experiment, possibly due to an increasing mineralization potential. Similar to the chernozem soil, a shift in the ratio of the two nitrogen forms during incubation was observed in the brown forest soil, but the degree of this shift was lower compared to the chernozem soil.

Sistani et al. (2008) published a similar trend in a laboratory evaluation of the effect of broiler litter on nitrogen mineralization.

Nitrogen mineralization potentials of soils

The cumulative amount of mineralized nitrogen increased continuously during the examined period.

The weekly formation of mineral nitrogen can be described by a linear relationship for both soil types (Figure 1 and 2).

The equations and R values for these relationships are presented in Table 6, with R values exceeding 0.99 in all cases. These indicate that a linear regression model, regardless of soil type, can accurately describe the amounts of N_{min} during the incubation period.

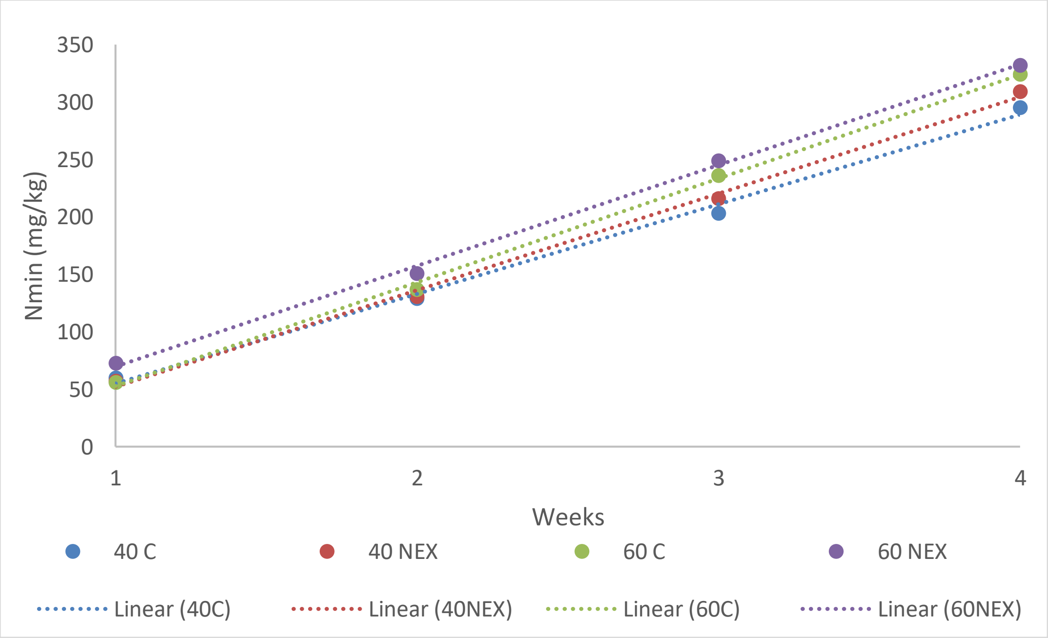

Figure 1. Amount of N_{min} during the incubation period in chernozem soil

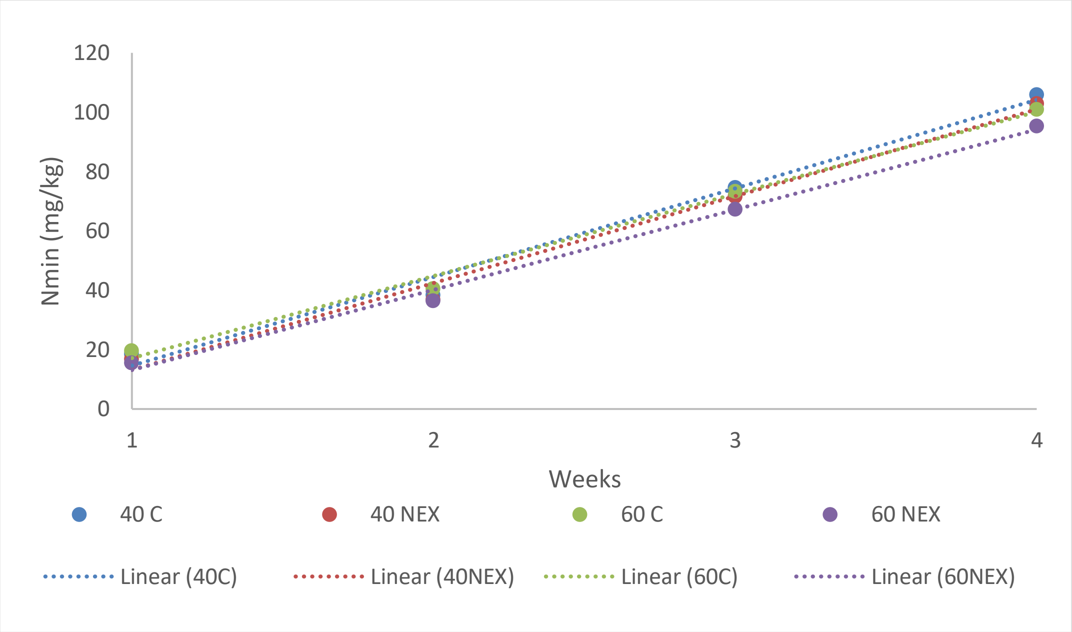

Figure 2. Amount of Nmin during the incubation period in brown forest soil

Higher water capacity levels led to higher Nmin content in the chernozem soil (Figure 1), while no significant differences were observed in the brown forest soil (Figure 2). Several authors (Appel, 1998, Griffin et al., 2002, Honeycutt et al., 2005) have reported results similar to our findings, where moisture did not affect mineralization.

From the obtained results, the following equations were calculated (Table 6).

Table 6. Mineralization equations and R values of the treatments

	Equation	R value
Chernozem soil		
40 C	$y = 78.042x - 23.125$	0.9978
40 NEX	$y = 84.1x - 32.000$	0.9986
60 C	$y = 90.392x - 37.750$	0.9993
60 NEX	$y = 87.717x - 18.042$	0.9991
Brown forest soil		
40 C	$y = 29.849x - 15.217$	0.9937
40 NEX	$y = 29.264x - 16.087$	0.9943
60 C	$y = 27.662x - 10.503$	0.9966
60 NEX	$y = 27.011x - 13.868$	0.9971

Our findings have enabled the estimation of potentially mineralizable N (N_{pot}) in the soil. When mineralization is monitored over a very long (infinite) time ($t \rightarrow \infty$), Nt becomes equal to N_{pot}, representing the maximum mineralizable N.

If the reciprocal of the total N mineralized at different times (1/Nt) is plotted as a function of the reciprocal of time (1/t), the axis section of the line gives the approximate value of $1/N_{pot}$ as $1/N_{pot'}$.
The N_{pot} and the mineralization constant (k) were calculated according to Filep and Tóthné (1980a;b) (Table 7.).

Table 7. Calculated N_{pot} values (mg/kg) in chernozem and in brown forest soil

Treatments	Chernozem soil	Brown forest soil
40 C	434.78	114.65
40 NEX	588.24	188.68
60 C	1000.14	140.85
60 NEX	1428.57	256.41

Our results indicated that the chernozem soil type has a higher mineralization potential compared to the brown forest soil, primarily due to its higher nutrient and organic matter contents (Table 7.). The value of N_{pot} varied between 114.65 and 140.85 mg/kg in control, depending on the water content, in brown forest soil. In chernozem soil, the N_{pot} was 434.78 and 1000.14 mg/kg in the control, depending on the water content.

The application of composite increased the value of N_{pot} by 64.5 and 82% in brown forest soil depending on water content and by 35.3 and 42.8% in chernozem soil depending on water content. Results showed that the application of the composite was effective in promoting mineralization processes in both soil types. Obtained results suggest that significant nitrogen mineralization can only be expected at optimal soil moisture levels. The composite product showed particular effectiveness in soils with low nutrient status and mineralization potential, such as sandy textured soils.

Based on the linear regression model, the net mineralization rate (NMR) was calculated by subtracting the initial inorganic N quantity from the inorganic N quantity after the incubation period, as described by Maitlo et al. (2022).
In the chernozem soil, the calculated NMR values were 10.55, 11.04, 11.58, and 11.87 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 3.79, 3.68,

3.60, and 3.40 mg N/kg soil/day for the 40 C, 40 NEX, 60 C, and 60 NEX treatments, respectively.

NMR value was two and a half to four times higher for the chernozem soil than for the brown forest soil except for the 60NEX treatment. The NEX treatment generally had an increasing effect on NMR, except for the 60 NEX treatment in the chernozem soil. Our findings regarding NMR values were consistent with earlier research reported by Sistani et al. (2008). The positive effect of CM on NMR results demonstrates the existence of CM that can be utilized efficiently and effectively as a potential N source and accelerator for the management of nutrient-poor soils and plant growth as Abbasi and Khaliq (2016) also reported.

Soil organic N content was measured again at the end of the experiment. Its content was 2100 mg/kg in chernozem soil and 370 mg/kg in brown forest soil. This means that between 60 and 47% of the initial amount remains in the chernozem and brown forest soil respectively, after one month of incubation.

CONCLUSIONS

Effects of organic composite fertilizer, containing fermented chicken manure, bentonite, and super absorbent polymer on soil nitrogen mineralization were investigated at two different, but typical Hungarian soil types and two soil moisture contents in our short-term soil incubation experiment.

The usage of composite did not significantly affect the soil pH during the examined period, compared to the control. Therefore, the observed changes in nitrogen mineralization processes can be attributed to the product rather than changes in soil pH.

Higher nitrate contents were observed in the chernozem soil compared to the brown forest soil, consistent with the soil type and its higher nutrient content. The composite product had an increasing effect on soil nitrate content, although the effect was not significant in all cases.

Ammonium content in the soil decreased while nitrate content increased continuously throughout the experiment. This suggests a coordinated change between the oxidized and reduced forms of soil nitrogen, influenced by soil mineralization potential. The incubation experiment successfully monitored the delicate balance of soil nitrogen forms. The mineralized N was calculated by summing the nitrate and ammonium content, week by week. Furthermore, the potentially mineralizable N was estimated.

The chernozem soil type had a higher mineralization potential compared to brown forest soil, due to its higher nutrient and organic matter contents. Moreover, our results pointed out that soil moisture content did not significantly affect the mineralization process.

It was found that the weekly formation of mineral nitrogen can be described by a linear relationship for both soil types and water regimes. Based on the linear regression model, the net mineralization rate was calculated. The composite product showed efficacy in promoting mineralization processes, particularly in soils with low nutrient status and mineralization potential.

ACKNOWLEDGMENTS

This research was funded by GINOP-2.2.1-15-2017-00043 project.

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