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Effects of fermented and supplemented chicken manure on the nutrient management aspects of an apple orchard

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SUMMARY

It is a huge challenge for farmers worldwide to successfully increase the organic matter content of their soils and improve their water balance at the same time. Therefore, the main aim of the study is to develop and test organic-based nutrient composite materials that can be successfully used by farmers to increase soil organic matter content, improve water management parameters and implement water-efficient technologies. The study was performed in the orchard of the Institute of Horticultural Science of the University of Debrecen in Hungary (Debrecen-Pallag). The experiment was set up in a ten-year-old apple (Malus domestica 'Pinova') orchard. In the trial, fermented poultry manure and superabsorbent polymers (SAP) were used at different doses to study their effects on soil properties and fruit quality. Applied composite materials increased the nitrate and organic nitrogen content of the soil. Treatments did not affect the sugar content of the fruits but significantly and positively affected the individual fruit weight and the titratable acidity of the fruits.

Keywords: *organic fertilisation; chicken manure; fruit nutrition, superabsorbent polymer*

INTRODUCTION

Today, European farmers face two major challenges. On the one hand, they have to increase the organic matter content of their soils, which is decreasing and deteriorating continuously in the last decades, and on the other hand, they have to solve the decreasing and increasingly hectic rainfall patterns.

Therefore, the main task in our research is to find and develop formulations that can address and solve these huge problems together.

In Europe, 75% of EU croplands having less than 2% organic carbon, and nearly half of European agricultural soils have suffered from poor organic matter content (Panagos et al., 2013) moreover soil organic carbon (SOC) content is still reducing in many areas (Yigini and Panagos, 2016). This problem can be solved by using agricultural by-products that meet the requirements of sustainable soil nutrient management.

Worldwide, the poultry industry is a large and rapidly growing agro-based industry. It produces millions of tons of hazardous waste (sometimes without handling and converting) per year and causes serious environmental problems if may not apply eco-friendly management technologies (Sharpley et al., 2007). The chicken manure (CM) has been used in agriculture conventionally due to its high nutrient content (Masarirambi et al., 2012). CM could increase the yield and recover or improve the soil's physical, biological and chemical properties (Haga, 1999; Cordovil et al., 2005; Ravindran et al., 2017).

It extends the amount and variety of microbiota, especially in sandy soil. This factor benefits the plant as it enlarges water and nutrient accessibility (Kaiser et al., 2009).

Furthermore, its application is in good correlation with Green Deal aims (shift to a more sustainable system of agricultural production that minimizes farming's environmental footprint and does more to protect and sustain nature).

Although, chicken manure is regarded as an excellent nutrient source, it alone does not provide an adequate nutrient supply (Amanullah et al., 2010). Therefore, it was important for us to complement its effects with materials that meet today's challenges of lacking water resources, drought events, hectic rainfall and nutrient leaching.

To achieve this, superabsorbent additive was used to improve the properties of fermented chicken manure.

In a large part of Europe, mostly in the arid and semiarid climate zones, water scarcity is one of the biggest major environmental problems due to the irregular amount of rainfall with spatial and temporal distribution, which has serious effects on the sustainability of agriculture.

In the last decades, there is an increasing interest in applying water superabsorbent hydrogels or polymers (SAPs) to solve water management agricultural problems (Buchholz and Graham, 1998; Abd EI-Rehirn et al., 2004; Malik et al., 2023).

By now superabsorbent polymers (SAPs) have been widely used in agriculture as soil moisture conditioner because of its multifunctional roles in water absorbency and water-retaining ability. These polymers are excellent materials for maintaining high water swelling and releasing capacity, mostly under water deficit conditions. Consequently, SAPs increase water and nutrient use efficiency, enhance deep water percolation, prevent nutrient leaching and check evaporation loss by improving plant development and crop yield not only in the arid and semiarid climates of the world (Bedi and Sohrab, 2004; Abobatta, 2018; Saini et al., 2020; Patra et al., 2022).

SAPs have three-dimensional networks. There are loosely held cross-linked hydrophilic macromolecules in their structures interconnected by covalent bonds or

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physical interactions with specially designed absorbency and biodegradability. SAPs can absorb and keep a large amount of moisture in their structure within a short period when they meet freely available water in the soil. So, one of the main advantages of SAPs using to release the stored moisture to the surrounding soil and rhizosphere zones because SAPs to form an amorphous gelatinous mass on hydration when applied in soil. According to this, SAPs are able to cyclic adsorption and desorption of water for a longer period. Hence, hydrogels considered an effective tool in conserving adequate amounts of water quickly in soil and providing water and dissolved nutrients slowly to the plants over an extended period when the surrounding soil near the crop root zone starts drying up (Yazdani et al., 2007; Sayyari and Ghanbari, 2012; Gaikwad et al., 2017).

Many authors pointed out that SAPs have been successfully used in the horticulture to improve the water management of soil given increasing their water-holding capacity and/or nutrient retention of sandy soil to be comparable to silty clay or loam (Brave and Nnadi, 2011; Malik et al., 2023). The application of SAPs has an effect on soil permeability, density, structure, evaporation, and infiltration rates of water through the soil layers. These specific hydrogels reduce irrigation frequency and compaction tendency of heavy clayed soils. The usage of SAPs can stop erosion and water runoff, and increase soil aeration and microbial activity mostly when the soil tends to aggregate (Abd EI-Rehirn et al., 2004; Burke et al., 2010). The usage of SAPs has a great effect on the nutrient management of soils because they create a slow nutrient release system in the soil by favoring the uptake of some nutrient elements, holding them tightly, and delaying their dissolution (Ahmed and Fahmy, 2019).

The specific objective of this study was to investigate the effects of fermented chicken manure and superabsorbent polymer composites on the nutrient management of an integrated apple orchard. To explore these facts, a fertilisation experiment was set up in an integrated apple orchard.

MATERIALS AND METHODS

The study was performed at the orchard of Experimental Station area (Debrecen-Pallag) of Institute of Horticultural Science of University of Debrecen in Hungary. The studied apple (*Malus domestica* Borkh. cv.'Pinova') orchard was ten years old. Trees were grafted on M9 rootstock and spaced at 1 m in rows and 4 m between rows. Trees were trained to slender spindle with the height of 3.5 m (Csihon et al., 2021). The trees were occasionally irrigated in the examined period. The experimental conditions and basic planting data were described in a previous communication (Tóth et al., 2022).

Orchard soil type was brown forest soil with sandy texture. Soil is poor in macronutrients and contains relatively low humus content. The main parameters of the Pallag soil are presented in *Table 1*.

Table 1: **Main parameters of Pallag soil (May 2021)**

Basic soil parameters	Value
pH (KCl)	6.70
Plasticity index (KA)	< 25.00
Water soluble salts (m/m%)	< 0.02
Carbonate (m/m%)	< 0.100
Humus (m/m%)	1.03
P_2O_5 (mg kg^{-1}) (AL)	412.00
K_2O (mg kg^{-1}) (AL)	369.00
Nitrate (mg kg^{-1}) (KCl)	54.10
Na (mg kg^{-1}) (AL)	41.20
Mg (mg kg^{-1}) (KCl)	169.00
S (mg kg^{-1}) (KCl)	30.70
Mn (mg kg^{-1}) (EDTA)	195.00
Zn (mg kg^{-1}) (EDTA)	11.6
Cu (mg kg^{-1}) (EDTA)	7.79
Organic Nitrogen (m/m%)	0.127

The soil pH is a slightly acidic (pH=6.7) and the humus content is near 1%. Water soluble salts concentration and carbonate content are low similarly. Soil N supply is weak, but soil P and K contents are too high according to the regular and significant P and K fertilisation management. Soil Cu and Zn contents are high with excessive Mn content in the upper soil layer.

In the trial, own developed prototype soil conditioners were used, which were mixtures from fermented chicken manure (Bio-Fer product) and a synthetic SAP (Stockosorb (EVONIK Nutrition &Care GmbH). The constitutions of mixtures are shown in *Table 2*.

Table 2: **Applied treatments in the trial (Pallag, 2021)**

Treatments	Dose of treatments
K – Control	–
KNEX – Control with NEX	10kg NEX
S1 – NEX with SAP	10kg NEX + 0.5kg SAP
S2 – NEX with SAP	10kg NEX + 1.0kg SAP

Besides control (K), three treatments were applied: KNEX (contained only fermented chicken manure: Natur Extra), S1 (contained Natur Extra and SAP in lower dose) and S2 (contained Natur Extra and SAP in higher dose). The amount of chicken manure was same in the treatments.

All treatments consist of five trees. The experiment was set up in May 2021 after the flowering stage. Before using chicken manure was milled and then mixed with SAP. The mixture was put in the soil (at 20 cm depth) on both sides of the trees in the drip line. After set up, soil samples were collected monthly from every treatment separately till September. Soil samples were collected from 0 to 40 cm layer of the soil by using manual soil sampling equipment according to international and Hungarian soil sampling guidelines for fruit orchards (Jackson, 1958; MSZ-08 0202-77). Before soil analysis, soil samples were pretreated (dried, sieved (2 mm) and homogenized). All essential nutrients were measured from the soil samples in the

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Agrarian Instrument Centre according to Hungarian standards (MSZ 20135:1999).

Fruit samples were picked at the end of September (at the ripening stage). All apples were collected from the trees to determine the fruit amount per tree. To measure outer parameters (e.g. fruit weight/apple) 100 apples were used. For inner parameters 1 kg sample was used. Apples were ground and homogenized before measuring the Brix and the titratable acidity (TA). In fruit juices TA was measured by titrating with 0.1 M NaOH to a fixed pH endpoint titration to 8.1 by Hanna Instruments' HI83352 Nutrient Analysis Photometer. The results were expressed as gram of malic acid per liter of juice (g MA/L).

Statistical analysis

For statistical analysis, the R Studio program was applied (version 4.1.3.). To examine the distribution of the data Shapiro–Wilk normality test was used. The type of test to be used for further analysis was selected according to the results of the normality test. To establish the statistical differences between the used treatments, a one-way analysis (Duncan-test) of variance was used at a $p < 0.05$ level of significance.

RESULTS AND DISCUSSION

Soil analysis

Results of soil analysis from May to September are shown in *Figure 1–3*.

Figure 1 shows the results of soil pH during the studied period. Soil pH varied between 5.36 and 7.41. Applied treatments did not affect the soil pH significantly in May, except for the S2 treatment, which resulted significantly lower pH than the other treatments. Soil pH was highly stable at control and KNEX treatment during the studied period. SAP treatments firstly significantly increased and later (after June) significantly decreased the soil pH compared to the control (*Figure 1*). Our results are in good correlation with earlier findings (Sarifuddin et al., 2021). Application of organic matter and SAP had effect on soil pH because these materials affect not only the hydrogel's H+ dissociation but the other cations', including functional groups' dissociation, and neutralizing the cation exchange sites so changing the pH of the soil.

Figure 1: **Effects of treatments on the soil pH during the examined period of the experiment**

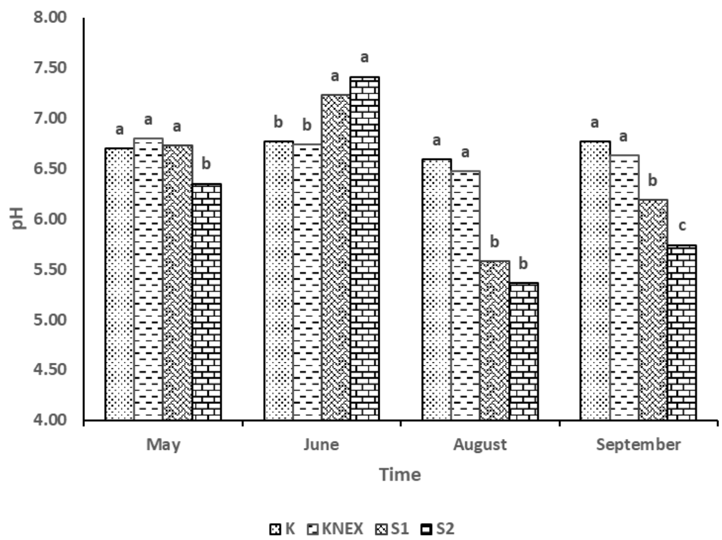

Figure 2 shows the effects of the applied treatments on the soil nitrate content in the studied period, from May to September. It was found that the nitrate content of the soil is not changed at the control during the investigated period. Fertilisers did not increase the soil nitrate content in the first half of the examined period. Later, from June the fertiliser treatments had a significantly increasing effect on nitrate content compared to the control. In August, soil nitrate content at KNEX, S1, and S2 treatments was significantly higher than in control and there was a significant difference between SAP treatments and KNEX. In September, soil nitrate content in all treatments significantly differ from each other. S2 treatment had the greatest effect, resulting in six times higher soil nitrate content than in the control (*Figure 2*). It may be explained by the more favorable conditions of soil (structure, moisture content, pH, EC) for nitrification. Several author pointed out that application of SAPs has created more favorable conditions for the transformation and uptake of nutrients and reduces the negative effects of alternating drying and wetting periods (Bai et al., 2010; Ji et al., 2022). Furthermore, the data show that the use of SAPs has a delay effect, i.e. the release of nutrients is delayed over time.

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Figure 2: **Effects of treatments on the soil nitrate content during the examined period of the experiment**

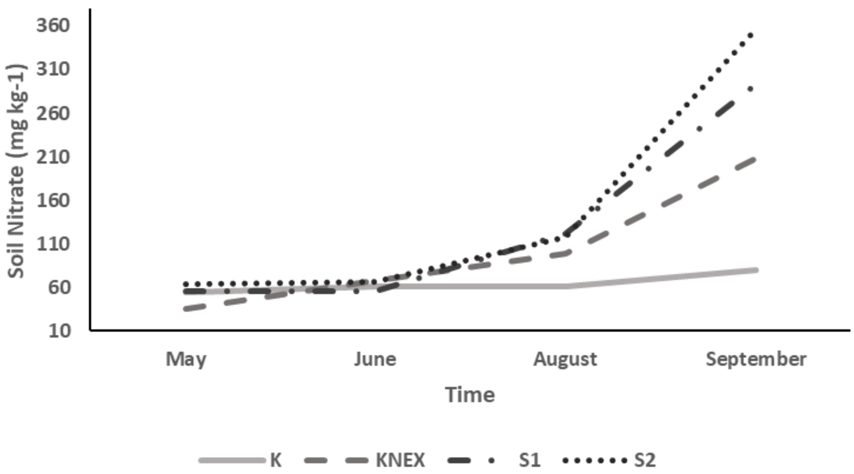
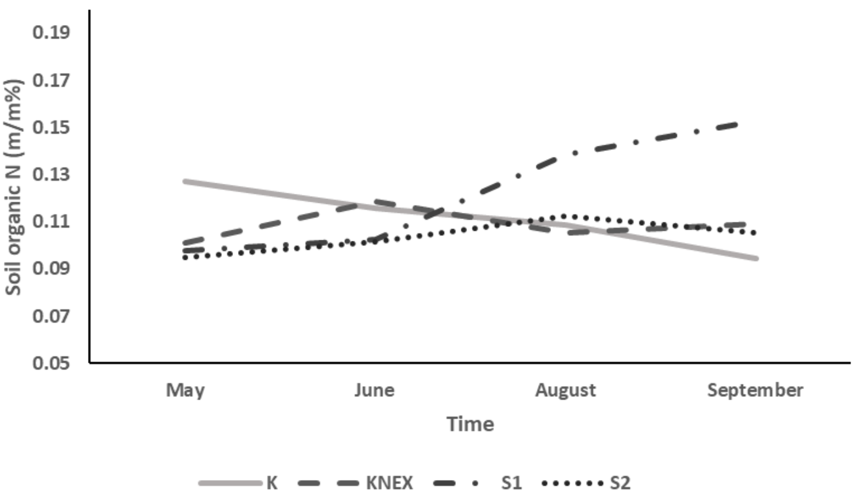


Figure 3 shows the effects of the applied treatments on the soil organic N (SON) content in the studied period, from May to September. The SON content was low (varied between 0.1 and 0.15%) according to the soil type. At the first sampling date, the SON content in the control was the highest and then it decreased continuously. In contrast, the other treatments slightly increased the value of SON during the examined period. Soil SON was significantly higher in K and KNEX treatments than in S1 and S2 treatments in June. Significant differences among K, KNEX and S2 treatments were not found in August but the S1 treatment caused significantly higher SON content. At the end of the studied period, the SON content in the control was significantly lower than in the other treatments. KNEX and S2 treatments resulted in quite a similar SON content but the S1 treatment caused significantly higher SON content compared to the other treatments (*Figure 3*). The explanation is similar to that for nitrate. More favorable soil conditions facilitate the transformation and uptake of nutrients.

Figure 3: **Effects of treatments on the soil organic N content during the examined period of the experiment**



Fruit analysis

In the experiment, the effect of the treatments on yield, individual fruit weight, fruit sugar and acidity content were investigated.

Fruit yields varied between 30.9 and 34.25 kg/tree according to the treatments (data not shown). No significant treatment effect on yields was observed during the experiment. However, fruit weight per piece (individual fruit weight) was significantly and positively affected by the treatments applied compared to the control (*Figure 4*). The highest value was observed at KNEX treatment, but SAP treatments also increased it compared to the control.

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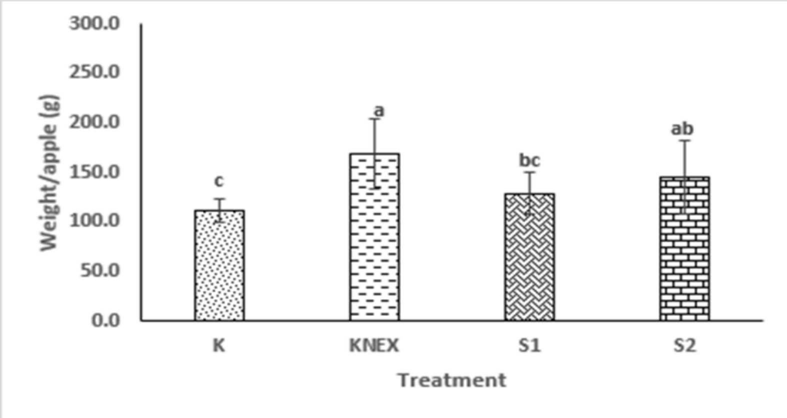
Figure 4: **Effects of treatments on individual fruit weight during the examined period of the experiment**



Similar to the fruit yields, the treatments had no significant effect on the total soluble solids content of the fruit. Brix values varied between 14.7 and 15.2 g/100g according to the treatments *(Figure 5*).

A more characteristic treatment effect was observed than the titratable acidity of apples (*Figure 6*). It can be seen that all treatments significantly increased the titratable acidity of the fruits. The highest value was obtained for the KNEX treatment, while treatments S1 and S2 increased the titratable acidity but not as much as the KNEX treatment.

Figure 5: **Effects of treatments on total soluble solids content during the examined period of the experiment**

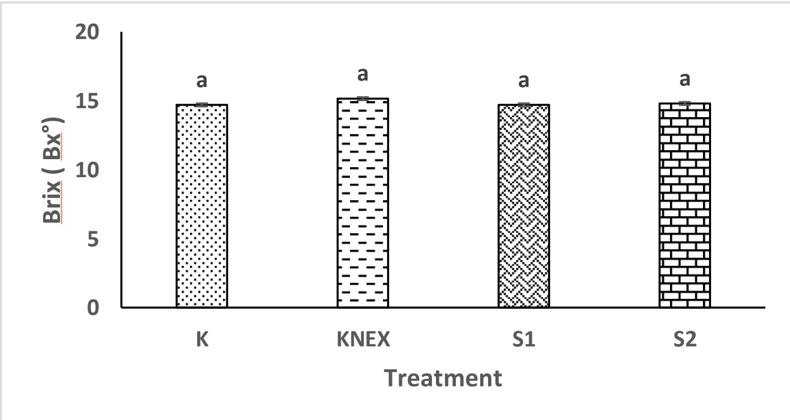
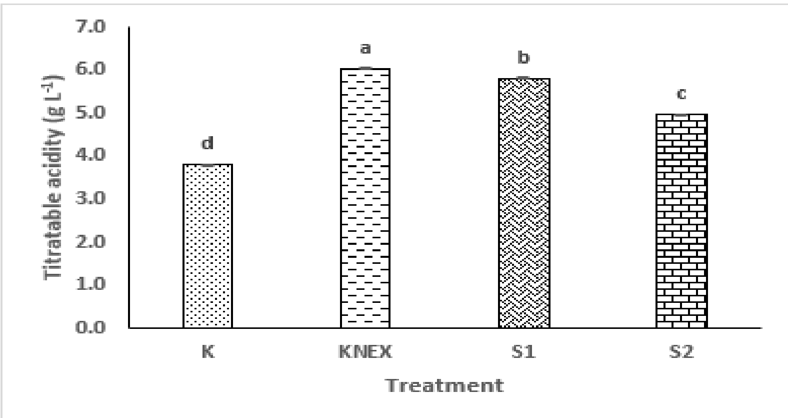


Figure 6: **Effects of treatments on titratable acidity during the examined period of the experiment**



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CONCLUSIONS

The following conclusions can be drawn from the soil analytical results. It was found that the soil pH was firstly increased and later decreased significantly by S1 and S2 treatments. Treatments with SAP amendments had a larger effect on soil pH than treatment receiving only chicken manure, because KNEX treatment did not resulted significant effect on soil pH compared to the control.

Soil nitrate content was significantly increased by the applied treatments after June. Enormous increment was observed from June to September. In September, soil nitrate content in all treatments significantly differ from each other. Treatments with SAP addition caused higher soil nitrate content than treatment receiving only chicken manure. These findings can be explained by the nutrient holding capacity of the SAP and the slow nutrient release effect of it.

Soil organic nitrogen content was continuously decreased at the control, but the applied treatments increased slightly its amount, mainly in the second part of the studied period.

Our results of fruit analysis pointed out that the treatments did not have a decisive effect on the yield of the fruit per tree, but had a significant and positive effect on the size and weight of individual apples. The treatments had no effect on Brix value but significant treatment effects on titratable acidity were observed in the experiment.

Overall, it can be concluded, that the applied treatments had a positive effect on the studied soil chemical parameters compared to the control, thus creating more favorable conditions for the supply of nutrients to the trees. This effect was also reflected in the individual weight and acidity of the fruit.

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