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Improving the Nutrient Management of an Apple Orchard by Using Organic-Based Composites Derived from Agricultural Waste

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Abstract: Extreme weather and the declining organic matter content of soils cause serious sustainability problems in agriculture. Therefore, soil conditioner composites (chicken manure, bentonite and super absorbent polymer) were developed and tested in an integrated apple orchard characterized by poor nutrient and water management to study their effects on soil, leaf and fruit attributes. Composites with higher doses of additives increased soil organic carbon by 4–9 g/kg, and organic nitrogen by 1.8–2.8 g/kg compared to the control ($p < 0.05$). Similarly, soil nitrate content steadily increased from 8–10 mg/kg to 30–38 mg/kg by composites. Composites effectively elevated leaf N, K, Ca, and Mg while not affecting the leaf P ($p < 0.05$). Treatments significantly enhanced the yields by 14–63% on average compared to the control. Treatments with bentonite improved the fruit weight by 2% and 24% compared to the chicken manure. On average, composite treatments increased the titratable acidity of fruits by 26–43% compared to the control and 0.5–10% compared to the treatment containing solely chicken manure. Overall, the developed organic-based composites are able to cope with changing circumstances that could help mitigate the negative effects of climate change, especially in arid areas, thus contributing to sustainable nutrient management.

Keywords: apple; organic manure composites; nutrient management; agriculture sustainability

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1. Introduction

Preserving the environment is a key objective of agro-environmental management. In horticultural crops, where significant amounts of fertilizers and chemicals (e.g., pesticides) are used, the production must be conducted on an environmentally friendly, adequate agro-ecological basis concerning changes in the ecosystem/environment properties.

Apple is one of the most important fruits in the world, and its production has continuously increased in the last decade from 83 to 93 million tons. However, in the last two years, the world's fresh apple production has decreased by 4.3 million metric tons, according to the most recent USDA (2023) report [1]. The causes of the decline can be attributed to several factors: increasing weather anomalies, deteriorating soil water management, soil degradation, and declining SOM content. In Hungary, for example, apple production was 30% lower due to the severe drought in 2022 compared to 2021. Similar but smaller reductions were recorded in Poland, Germany and New Zealand as a result of climatic anomalies [2]. Therefore, it is crucial all across Europe to retain as much of the rainfall as possible in the soil and make it available to the trees. To mitigate the effects of weather anomalies and land use intensification, our plantations have to be in good condition, and their soils should provide adequate nutrients, organic matter and water content during the whole vegetation period, resulting in appropriate fruit production [3].

SOM and soil moisture (SM) are essential for the proper development of plants since they have a key role in the regulation of soil temperature, productivity, nutrient availability, and toxic substance elimination; meanwhile, they improve the structure of soil and prevent soil erosion [4]. Despite their crucial role, providing adequate organic matter and soil moisture content has become an increasing challenge for farmers worldwide due to the ecological consequences of land use intensification and other human impacts. In Europe, a significant portion of croplands (75%) have less than 2% of soil organic carbon content (SOC) [5]. Moreover, many regions continue to experience a decline in SOC levels [6]. Furthermore, water scarcity seriously affects agroecosystems and poses a significant environmental problem during the growing season due to the irregular rainfall distribution, which implies serious consequences for agricultural sustainability and ecosystem-environment interactions.

The amount of chicken manure (CM) has continuously increased in the last decades since the chicken industry is a fast-growing industry fuelled by overwhelming customer demand [7]. However, fresh and uncomposted CM contains bacteria that are harmful to the environment and humans. In spite of this, CM has the potential to generate value-added products because it has conventionally been utilized in agriculture due to its rich nutrient composition [8]. CM can enhance the yield and improve several physical, biological and chemical properties of the soil [9]. However, it is important to recognize that CM alone may not provide a sufficient nutrient supply [10]. Therefore, it was crucial to complement its effects with materials that address contemporary challenges such as water scarcity, declining SOM, droughts, erratic rainfall and nutrient leaching.

Superabsorbent polymers (SAPs) have gained extensive use in agriculture, especially in areas where agricultural practices can have a serious impact on soil fertility and water management [11]. These polymers enhance water and nutrient use efficiency, soil permeability, density, structure, evaporation, and water infiltration rates through the soil layers. They affect water percolation and nutrient leaching and reduce evaporation losses, ultimately promoting plant development and increasing the yield [11–13]. Additionally, SAPs reduce irrigation frequency and compaction tendency, prevent erosion and water run-off, and enhance soil aeration and microbial activity [14]. These polymers are considered effective in providing a slow and steady supply of water and dissolved nutrients. This effect is particularly important when the moisture content approaches the wilting point in the root zone after a long dry period, which is increasingly common in Europe [15]. The effect of potassium polyacrylate SAP on soil water content and physiological changes of Bermuda grass in a greenhouse was studied by Liu and Chan [16]. Moreover, the residual monomer of acrylamides is bio-degradable and does not accumulate in soils. SAPs themselves, for example, polyacrylamide, do not pose any environmental threat and thus can be used effectively as a soil conditioner [17,18].

To improve the mechanical strength, swelling ratio and rate of SAPs, different materials (kaolin, montmorillonite and attapulgite) are often used [19]. In addition to these clay minerals, bentonite is a widely applied natural soil amendment, where agricultural management adversely affects the ecosystem/environment properties. It can retain a significant amount of water and nutrients, reduce evaporation, and improve topsoil infiltration, soil aggregation, and structure. The application of bentonite improves the available soil water-holding capacity and reduces soil evapotranspiration, thereby enhancing plant growth and the photosynthesis process [20]. Furthermore, due to its large specific surface area and high cation exchange capacity (CEC), bentonite can serve as a fertilizer and nutrient carrier [21]. Bentonite significantly increases the concentration of SOC and total N and the retention of applied nutrient cations in the soil [22,23].

Therefore, in our study, we focused on the interaction between agroecosystems and the environment (soil, water) through an example of recycling and using organic agricultural waste to solve serious agricultural and waste management problems. The research aimed to investigate the applicability of recycled agricultural waste in an apple orchard to solve pressing waste management and agro-ecological problems like declining soil organic matter (SOM), and inadequate soil water and nutrient management. Additionally, the specific objective of the study was to precisely examine the effects of organically based, own-developed soil conditioner composites on soil organic carbon (SOC), soil organic nitrogen (SON), and nitrate content. Furthermore, the impact of these composites on leaf macronutrient status and fruit quality attributes was assessed as well.

2. Materials and Methods

2.1. Study Site

The experiment was conducted in an apple (*Malus domestica* Borkh. 'Pinova') orchard and was grafted on M9 rootstock. The study site was located at Pallag (47°25′28″ N 21°38′31″ E), which is owned by the Institute of Horticultural Sciences at the University of Debrecen, Hungary. The trees were planted in 2011, with a row spacing of 4 m × 1 m and trained to a slender spindle with a height of 3.5 m. The orchard has a drip irrigation system, and plant protection practice refers to the principles of integrated pest management.

2.2. Climatic Conditions

Temperature and precipitation were recorded by a data acquisition system every 10 min using a local weather station. The monthly values were calculated from these records (Figure 1). In the studied years of 2021 and 2022, the average air temperature was +1.2 °C and −0.3 °C in January (coldest month in both years) and +24.4 °C and +23.3 °C in July and in August (warmest months). In these particular years, the annual precipitation was 444 mm and 500 mm, respectively. These annual precipitation data indicate that both years were extremely dry due to the severe drought. The total monthly precipitation varied mostly from 5 mm up to 80 mm. The rainfall during the main growing season (April to September) was 236 mm and 312 mm in 2021 and 2022, respectively. Figure 1 shows that in both years, there were long periods of drought with only a few mm of precipitation, which supports the application of the water conservation treatments.

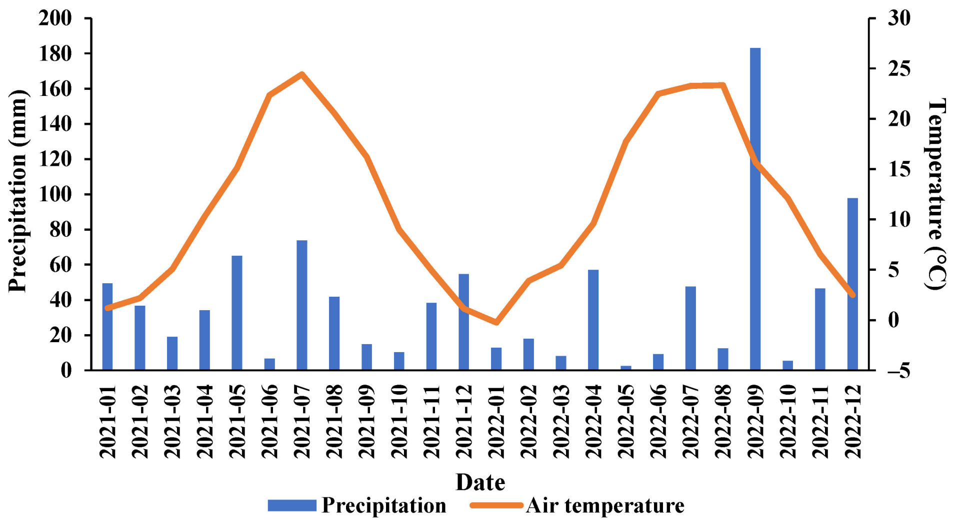

Figure 1. Meteorological data of the studied years (Pallag, 2021–2022).

2.3. Applied Composites and Doses

In the experiment, own-developed soil conditioner composites were used to improve SOM and soil water management. These composites consisted of mixtures of fermented chicken manure (Natur Extra (NEX)) as raw material, produced by Baromfi Coop Ltd (Nyírjákó, Hungary). alongside bentonite and synthetic SAP as additives. The main components of NEX are shown in Table 1.

Table 1. Main chemical characteristics of Bio-Fer Natur Extra product [24].

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

As a SAP, a cross-linked acrylamide and potassium polyacrylate copolymer, Stockosorb, was used (EVONIK Nutrition & Care GmbH, Essen, Germany). Furthermore, bentonite was used as a clay mineral, consisting predominantly of smectite minerals, usually montmorillonite (Axis Bentonit Ltd., Erdőkövesd, Hungary). In addition to the absolute control (K), seven treatments were set up and applied in the experiment, which can be divided into four groups. The ingredients of the composites are shown in Table 2.

Table 2. The ingredients of the composites used in the experiment (Pallag, 2021, 2022).

Treatments	Groups	Doses (kg/Tree)		
		NEX	Bentonite	SAP
K	Control	-	-	-
KNEX	NEX	2	-	-
B1	B	2	0.5	-
B2		2	1.0	-
S1	S	2	-	0.1
S2		2	-	0.2
BS1	BS	2	0.5	0.1
BS2		2	1.0	0.2

The dose of NEX was consistent in all treatments. The doses of additives were determined based on the recommendations of the manufacturers and a previous study [25]. Each treatment consisted of three repetitions of five trees per repetition. The experiments were set up in May 2021, and the fertilization was repeated the following May. NEX and additives (bentonite, SAPs) usually applied in the main root zone can maximize water and nutrient availability [26]. Therefore, fertilizers were applied to the soil at a depth of 20 cm on both sides of the trees along the drip line.

2.4. Soil Characteristics

Before the experiments were set up, soil tests were carried out to determine the main parameters of the plantation soil (Table 3). Prior to the experiment setup, the main nutrients were analyzed from the soil samples to determine the initial soil nutrient status.

Later, during the experiment, soil samples were taken regularly from each treatment plot to monitor the effects of the treatments. Soil samples were collected from May to September in 2021 and 2022 at six-week intervals for each treatment separately (e.g., 2021_1 represents the first, 2021_2 represents the second soil sampling date, and so on). The first soil sample was taken before the annual fertilization.

Soil samples were taken with an auger from the 0 to 40 cm layer of the soil. Before the experiment, soil pH was measured by an electrochemical method (WTW pH 3110). SOC was measured by the Walkley–Black method (Perkin-Elmer Analyst 300). SON was determined using the Kjeldahl method (VELP DKL 20). Soil nitrate–nitrogen (NO_3-N) content was assessed by a spectrophotometric method (FOSS FIASTAR 5000). Soil phosphorus (P), potassium (K), and magnesium (Mg) were analyzed using the ICP-OES method (Thermo Fisher iCAP 7400). During the experiment, SOC, SON, and NO_3-N contents were measured (as described above) to study the effects of treatments on soil C-N conditions.

Table 3. Major parameters of Pallag soil (April 2021).

Soil Parameters	Value
pH $_{KCl}$	6.14 ± 0.1
Carbonate (wt.%)	<0.10 ± 0.02
SOC (g/kg)	11.50 ± 0.2
P_2O_5-P(mg/kg) (AL)	108.30 ± 18.3
K_2O-K(mg/kg) (AL)	263.90 ± 48.2
NO_3-N $_{KCl}$ (mgN/kg)	10.04 ± 0.1
Mg (mg/kg) (KCl)	180.00 ± 2.5
SON (g/kg)	0.96 ± 0.01
Soil texture	
sand (m/m%)	52.54 ± 0.2
silt (m/m%)	46.64 ± 0.2
clay (m/m%)	0.82 ± 0.2

Legend: AL (ammonium-lactate), KCl and EDTA are standardized Hungarian soil extractants MSZ 20135 [27].

The major parameters of the Pallag soil are summarized in Table 3. Orchard soil type was brown forest soil with mainly sandy-loam texture (Lamellic Arenosol). It had low levels of macro- and micronutrients and relatively low organic matter content.

The soil pH was slightly acidic (pH = 6.14). SOC content was low (11.5 mg/kg). Soil N supply was weak, as organic N and inorganic nitrate content were extremely low. The dominant N form was the organic form because the ratio of SON/NO_3-N was 95.62. The P and K content of the soil is highly correlated with the soil type. The whole plantation receives a uniform annual fertilization twice a year with 200 kg/ha dose each time (Yara Crop Care fertilizer—N:P:K = 11:11:21), and further N addition once a year with 100 kg/ha dose of Péti salt (CAN), which contains 27% N, 7% CaO and 5% MgO.

2.5. Characterization of Leaves and Fruits

For leaf analysis, ten normal-sized, healthy leaves were collected from each tree at the beginning of August. Leaf N was determined by the Kjeldahl method, while leaf P, K, Ca and Mg were measured by the ICP-OES method. Soil and leaf samples were measured in the accredited laboratory of the University of Debrecen (Centre for Agricultural Instruments).

Fruit samples were picked at the end of September (at the ripening stage). To establish the yield per tree, all fruits were removed from the trees. For the determination of fruit weight/apple, 20 apples were selected randomly. For the measurement of total soluble solids (TSS) and titratable acidity (TA), a 1 kg sample was used. TSS of the juices were determined by using an ATAGO PAL refractometer at 20 °C and expressed as Brix degrees (°Brix). TA was measured by titrating with 0.1 M NaOH to a fixed pH endpoint titration to 8.1 (Hanna Instruments' HI83352 Photometer). TA is expressed as grams of malic acid per liter of juice (g MA/L). All measurements were performed in triplicate.

2.6. Statistical Analysis

For statistical evaluation, the R studio agricolae package of R software was used [28]. The Shapiro–Wilk normality test was employed to assess the data distribution. Based on the results of the normality test, the appropriate type of statistical test was selected for further analysis. To determine the significant differences between the treatments, a one-way analysis of variance (ANOVA) with Duncan's post hoc test was conducted at a significance level of $p < 0.05$. The Spearman correlation matrix was generated by Statgraphics 18 software.

3. Results and Discussion

3.1. Soil Analysis

The effects of the treatments on the SOC content can be seen in Figure 2. Initially, the SOC content ranged between 10.2 g/kg and 11.1 g/kg. During the experiment, the differences in SOC content among the treatments were gradually increased, and by the end of 2021, a significant treatment effect was observed compared to the control. In 2022, after reapplication, these differences became more intensive, and all treatments significantly increased the SOC content compared to the control. KNEX, B2, S2 and BS2 treatments resulted in the largest increment in SOC content (≈4–9 g/kg) by the end of 2022. In these treatments, the SOC content remained consistent around 20 mg/kg during the second year of the experiment. Similarly, Kobierski et al. [29] and Zhang et al. [30] reported that fertilization with poultry manure resulted in a significant increase in the SOC content and carbon sequestration efficiency of manure [31]. Our results confirmed earlier findings that SAP and bentonite treatment improves SOC content [22,32].

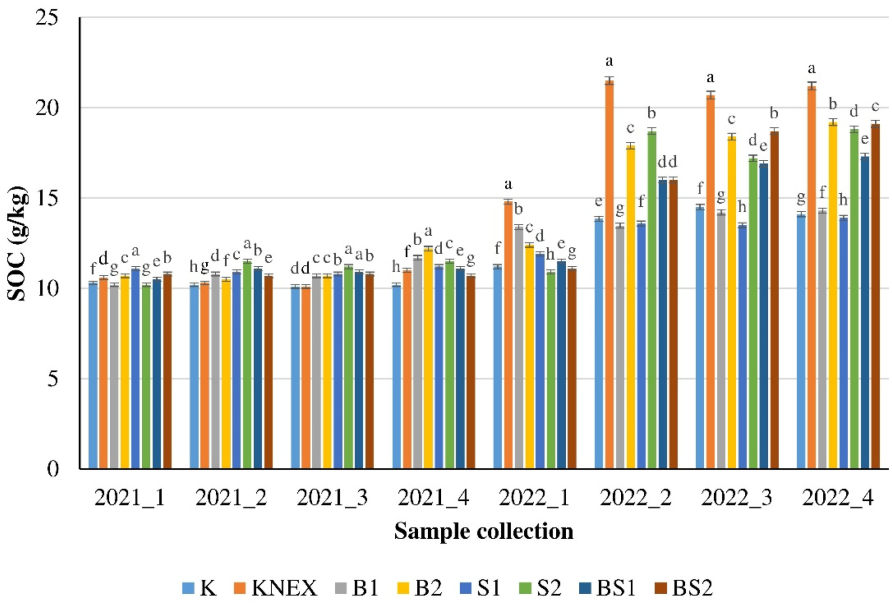

Figure 2. Effects of the treatments on the SOC content at different sampling dates. Different letters indicate significant differences between treatments ($p < 0.05$).

SON content varied between 0.95 g/kg and 2.82 g/kg in the studied years (Figure 3). Initially, the SON content (≈1 g/kg) showed a relatively homogeneous distribution among the treatments, with the highest value in the control. Later, these values became more and more divergent, and by the end of the second year, all treatments (except BS2 and KNEX) significantly increased SON content (≈1.8–2.8 g/kg) compared to the control ($p < 0.05$). In the control, SON content showed a continuous slight decrease (from 1.27 g/kg to 1.2 g/kg), indicating soil depletion without fertilization. The rate of increase varied between 0.3 and 3 times depending on the treatment, with the smallest increase observed in the KNEX treatment (from 1.0 g/kg to 1.5 g/kg). Our results confirmed earlier findings that organic fertilization effectively increases SON content; however, seasonal changes also affected its amount [33]. Composites except BS2 had a more significant effect on SON content compared to the KNEX treatment by the end of the second year. From the SOC and SON results, the SOC/SON ratios were calculated. It was found that the SOC/SON ratio remained stable throughout the experiment, with an average value of approx. 10 in all the treatments.

Initially, soil NO_3-N content was relatively low (≈10 mg/kg) (Figure 4). During the experiment, the KNEX and composite treatments gradually increased the nitrate content in the soil. By the end of the first year, soil NO_3-N content increased exponentially in the treated plots (Figure 4). This huge increment can be explained by the favorable soil conditions as the N mineralization rates generally increase as temperature and moisture increase (Figure 1).

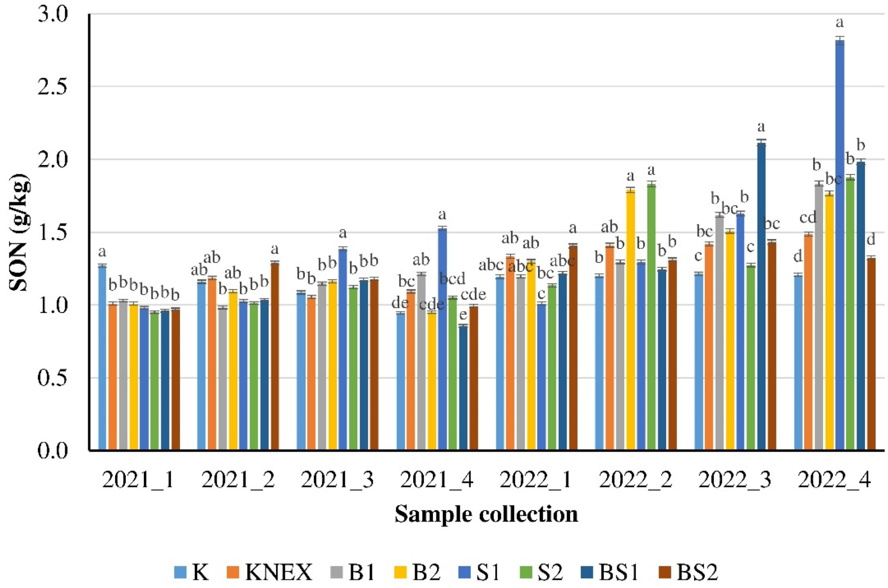

Figure 3. Effects of the treatments on the SON content at different sampling dates. Different letters indicate significant differences between treatments ($p < 0.05$).

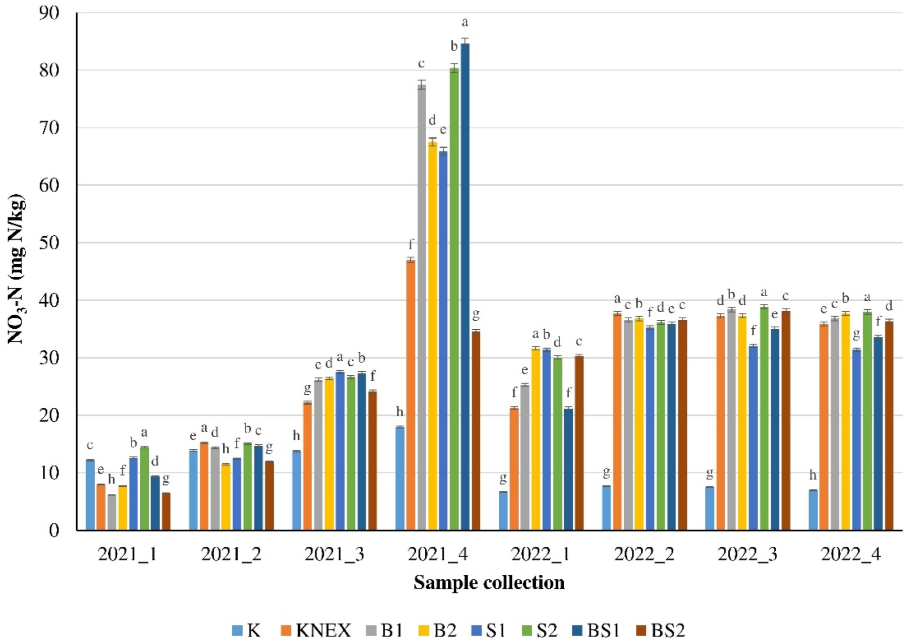

Figure 4. Effects of the treatments on the NO_3-N content of soil at different sampling dates. Different letters indicate significant differences between treatments ($p < 0.05$).

By the end of the second year, soil NO_3-N content steadily increased from 8–10 mg/kg to 30–38 mg/kg in all the treatments, except in the control, which remained 8 mg/kg. The most effective treatment combinations were B1, B2, S2 and BS2. These indicated that the used composites effectively mobilized nitrogen and enhanced the availability of soil nutrients for plants. According to Canali et al. [34] and Yagüe et al. [35], organic fertilization induces changes in soil nitrogen mineralization and promotes the amounts of inorganic forms. However, our results also highlighted the importance of maintaining an appropriate C/N ratio in low organic carbon soils to ensure the effectiveness of nitrogen mobilization without a further reduction in the C/N ratio.

From the SON and the NO_3-N results, the soil organic/inorganic nitrogen ratio significantly changed in the treatments in the studied period (Figure 5). The SON/NO_3-N ratio increased from 104 to 173 in the control treatment and decreased significantly in KNEX and composite treatments (except S1). The rate of decrease was highly dependent on the compounds of the applied composite. The decreasing SON/nitrate ratio indicated mineralization processes in the soil, which were intensified by the treatments. The decreasing SON/nitrate ratio resulted in more favorable nitrogen uptake conditions, which are confirmed by the leaf analytical data (Table 4).

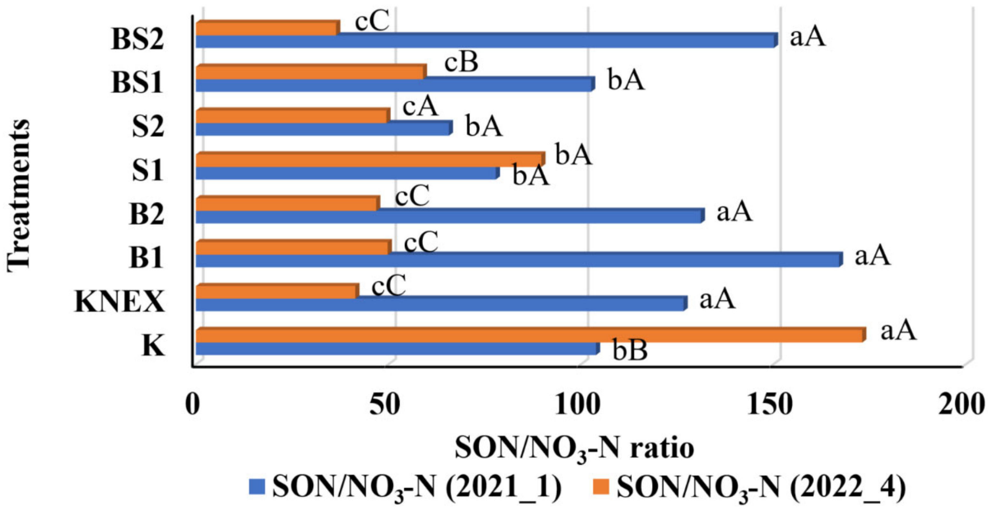

Figure 5. Effects of the treatments on the SON/NO_3-N ratio of soil at the start and end of the studied period. Small letters indicate the differences between the various treatments in a specific year, and capital letters indicate the differences between the same treatment in two years.

Table 4. Effects of the treatments on leaf macronutrient contents.

Treatment	N (wt.%)		P (wt.%)		K (wt.%)		Ca (wt.%)		Mg (wt.%)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
K	2.49 ^{b}	2.49 ^{c}	0.25 ^{a}	0.21 ^{a}	1.60 ^{a}	1.37 ^{c}	2.27 ^{a}	2.54 ^{a}	0.52 ^{a}	0.47 ^{ab}
KNEX	2.51 ^{b}	2.47 ^{d}	0.25 ^{a}	0.21 ^{a}	1.26 ^{b}	1.74 ^{a}	2.18 ^{ab}	2.64 ^{a}	0.48 ^{b}	0.5 ^{a}
B1	2.60 ^{a}	2.37 ^{e}	0.25 ^{a}	0.21 ^{a}	1.09 ^{c}	1.30 ^{c}	2.13 ^{b}	2.22 ^{c}	0.54 ^{a}	0.53 ^{a}
B2	2.48 ^{b}	2.44 ^{d}	0.26 ^{a}	0.21 ^{a}	1.33 ^{b}	1.30 ^{c}	2.03 ^{c}	1.99 ^{e}	0.52 ^{a}	0.52 ^{a}
S1	2.58 ^{a}	2.72 ^{a}	0.24 ^{a}	0.21 ^{a}	1.12 ^{c}	1.45 ^{b}	1.96 ^{d}	2.13 ^{d}	0.48 ^{b}	0.45 ^{b}
S2	2.49 ^{b}	2.57 ^{b}	0.23 ^{a}	0.20 ^{a}	1.03 ^{c}	1.28 ^{c}	2.08 ^{c}	2.11 ^{d}	0.50 ^{ab}	0.48 ^{a}
BS1	2.47 ^{b}	2.50 ^{c}	0.27 ^{a}	0.20 ^{a}	1.15 ^{c}	1.65 ^{a}	2.26 ^{a}	2.26 ^{c}	0.58 ^{a}	0.42 ^{b}
BS2	2.37 ^{d}	2.66 ^{a}	0.26 ^{a}	0.21 ^{a}	1.59 ^{a}	1.51 ^{b}	2.07 ^{c}	2.17 ^{d}	0.53 ^{a}	0.50 ^{a}

Different letters indicate significant differences between treatments within the studied year ($p < 0.05$).

The Spearman rank correlations among SOC, SON and NO_3-N are shown in Figure 6. These plots show the estimated Spearman rank correlation coefficients. Color is used to denote the magnitude of the correlations, which range from −1 to +1, and measure the strength of the association between the variables. In contrast to the more common Pearson correlations, the Spearman coefficients are computed from the ranks of the data values rather than from the values themselves. Consequently, they are less sensitive to outliers than the Pearson coefficients.

Significant correlations were found between SOC and SON parameters at the 95.0% confidence level ($p < 0.05$) in KNEX, B1 and BS1 treatments. These treatments contain fermented chicken manure in the dose of 2 kg/tree in KNEX treatment, with the addition of bentonite (0.5 kg/tree) in B1 as well as SAP (0.1 kg/tree) in BS1. Weaker but still significant correlations ($p < 0.10$) were revealed between SOC and SON in the treatments of K, B2, and BS2. A double dose of bentonite was applied in the B2 treatment, while BS2 treatment included a double dose of bentonite alongside 0.2 kg/tree of SAP dose. The correlation matrix indicated a weak positive correlation (0.48) between the investigated parameters in the case of S1 treatment. The results showed a significant correlation at the 95.0% confidence level ($p < 0.05$) in K treatment between NO_3-N and SOC parameters with the value of −0.75. Besides the K treatment, another significant correlation was obtained at the same confidence level between NO_3-N and SON in the B1 treatment (0.79). At the 90.0% confidence level ($p < 0.10$), several statistically significant correlations were indicated, mainly between NO_3-N and SOC in the B1, B2 and BS2 treatments.

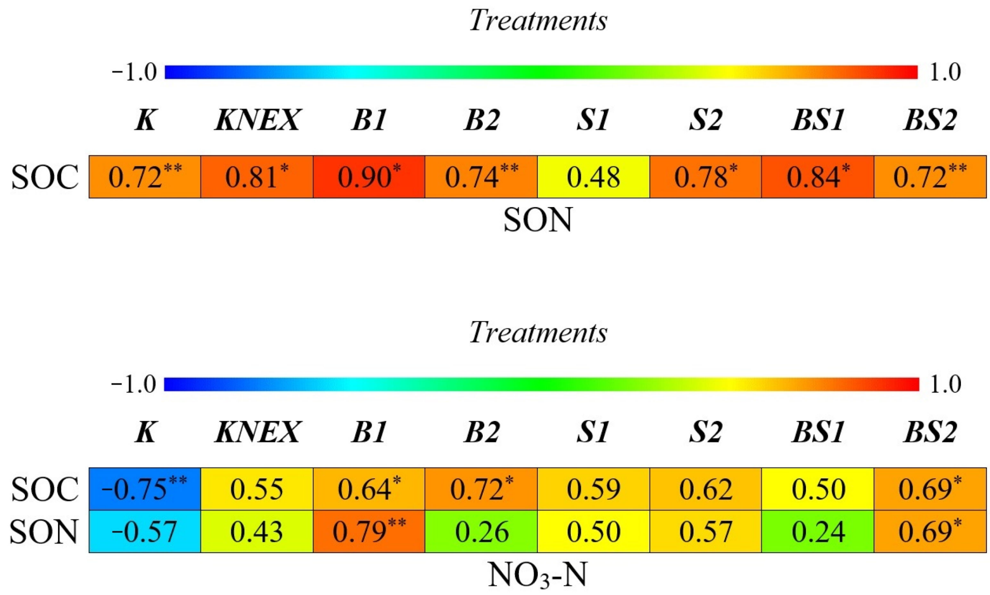

Figure 6. Spearman rank correlations among SOC, SON and NO_3-N. * Statistically significant correlations at the 95.0% confidence level ($p < 0.05$). ** Statistically significant correlations at the 90.0% confidence level ($p < 0.10$).

3.2. Leaf Analysis

The results of the leaf analysis are shown in Table 4. Leaf N content was significantly increased in B1 and S1 treatments in 2021 and in S1, S2 and BS2 treatments in 2022 compared to the control and KNEX treatments. However, BS2 in 2021 and B treatments in 2022 decreased leaf N significantly. There was no significant effect observed from the treatments on leaf P content. However, leaf P was higher in 2021 compared to 2022 in all treatments due to the extreme drought conditions in 2022. In 2021, leaf K was the highest in the control, but in 2022, several treatments (KNEX, S1, BS1, and BS2) showed increased K levels compared to the control. Treatments containing SAP resulted in increased leaf K, similar to leaf N, despite the drought in 2022, possibly due to the application of the K-salt of SAP. Ali et al. [36] also observed enhanced leaf nutrient contents with the addition of SAPs to the soil in grapevines. Similar to leaf K, leaf Ca was the highest in the control in 2021. Only the KNEX treatment increased leaf Ca, but not significantly, compared to the control, while composite treatments led to lower leaf Ca content in 2022. Composites, except for BS1 treatment, caused lower Ca content in leaves than in the control. It may be explained by the effects of additives on cation exchange capacity that resulted in slow-release fertilizer effects [37]. Similarly, leaf Mg content slightly decreased in all treatments except KNEX from 2021 to 2022. In 2021, KNEX and S1 treatments resulted in significantly lower Mg content in leaves than the control, while in 2022, the effects of treatments were not significant.

3.3. Fruit Analysis

The individual fruit weight was significantly higher ($p < 0.05$) in all fertilizer treatments compared to the non-treated trees in 2021 and 2022, except for the BS2 treatment in 2022 (Figure 7). B2 treatment resulted in the highest apple weight in both years. The fruit weight in all treatments showed a slight increase in 2022 compared to 2021, except for the BS2 treatment. Among the composite treatments, B1 and B2 in 2021 and B1, B2, S1, S2 and BS1 in 2022 increased the fruit weight compared to the KNEX treatment. Additionally, Keivanfar et al. [38] reported that SAP usage increased the fruit yield in the second year of their treatment. Based on the average values over the two investigated years, only the B1 and B2 treatments showed a significant increase in fruit weight compared to the KNEX treatment, with an increase of 2% and 24%, respectively.

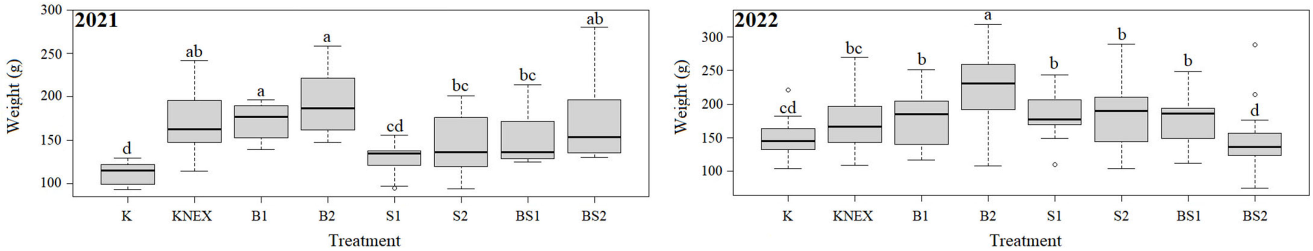

Figure 7. Effects of the treatments on the apple weight (2021 and 2022). Different letters indicate significant differences between treatments within the studied year ($p < 0.05$).

The yield per tree is shown in Table 5. All treatments significantly increased the two-year average yields compared to the control, except the B1 treatment. The rate of increase varied between 14 and 63%, on average, over the examined years, depending on the compounds of the applied composite. The BS2 treatment resulted in the highest yield in both years. Cen et al. [39] also indicated that organic management in apple orchards is useful and effectively increases apple yield. However, the yields were significantly affected by the different weather conditions as well. In some cases, the difference in yields between years was greater than the effect of treatments.

Table 5. Effects of the treatments on apple yield (kg/tree).

Treatments	Yield (kg/Tree)		
	2021	**2022**	**Average (2021–2022)**
K	17.80 ^{c}	28.70 ^{c}	23.25 ^{d}
KNEX	30.90 ^{ab}	33.10 ^{b}	32.00 ^{b}
B1	21.20 ^{bc}	20.70 ^{d}	20.95 ^{d}
B2	26.60 ^{b}	26.80 ^{c}	26.70 ^{c}
S1	32.10 ^{a}	25.30 ^{c}	28.70 ^{b}
S2	33.30 ^{a}	26.40 ^{c}	29.85 ^{b}
BS1	21.70 ^{bc}	31.40 ^{b}	26.55 ^{c}
BS2	34.30 ^{a}	41.50 ^{a}	37.90 ^{a}

Different letters indicate significant differences between treatments within the studied year ($p < 0.05$).

To study the effectiveness of composite products on fruit quality, TSS and TA values were measured. The Brix values varied between 14.5° and 15.5° in 2021 and between 13.1° and 15.8° in 2022, depending on the treatment (Figure 8). Our results correspond with those reported by Serpen [40].

KNEX, B1 and BS2 treatments significantly increased the TSS content of fruits in 2021 compared to the control. In 2022, the B1 and BS1 treatments had a significant positive effect on TSS, while KNEX and S1 caused significantly lower TSS values in fruits. The highest value (15.8°) was measured at the BS1 treatment in 2022. These results support previous studies that indicated a significant improvement in TSS and TA content with the application of SAP [38,41,42]. Furthermore, Kai and Adhikari [43] demonstrated that organic fertilization can lead to higher sugar content in fruits compared to chemical fertilization. Differences in Brix values between the two years can be attributed to the variations in climatic conditions. Based on the average values obtained from the two investigated years, the B1 treatment showed a 6.6% increase in TSS, while the BS1 and BS2 treatments resulted in a 5.9% and 5% increase, respectively, compared to the KNEX treatment.

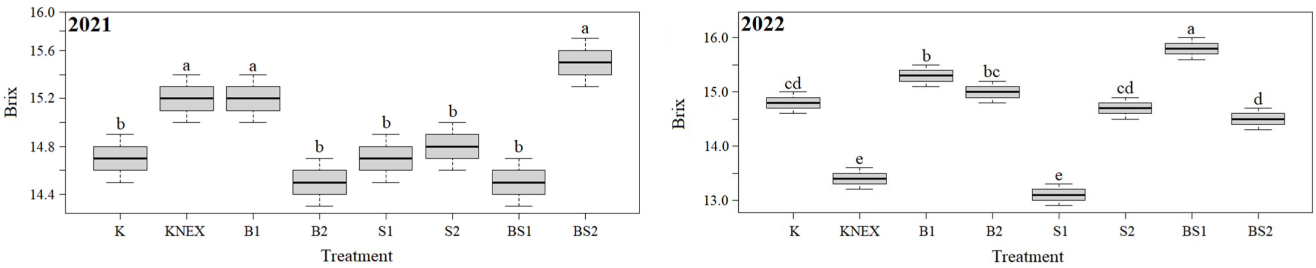

Figure 8. Effects of the treatments on the TSS content (2021 and 2022). Different letters indicate significant differences between treatments within the studied year ($p < 0.05$).

TA values ranged from 3.8 mg/L to 6.92 mg/L in 2021 and 5.12 mg/L to 6.80 mg/L in 2022 (Figure 9). The control samples consistently had the lowest TA values in both years. All treatment combinations significantly increased the titratable acidity of the apples compared to the control ($p < 0.05$). The highest values were obtained in the BS2 treatment in 2021 and the B2 and BS1 treatments in 2022. These findings are consistent with previous studies by Keivanfar et al., Zoghdan and Abo El-Enien, and Solanki et al. [38,41,42].

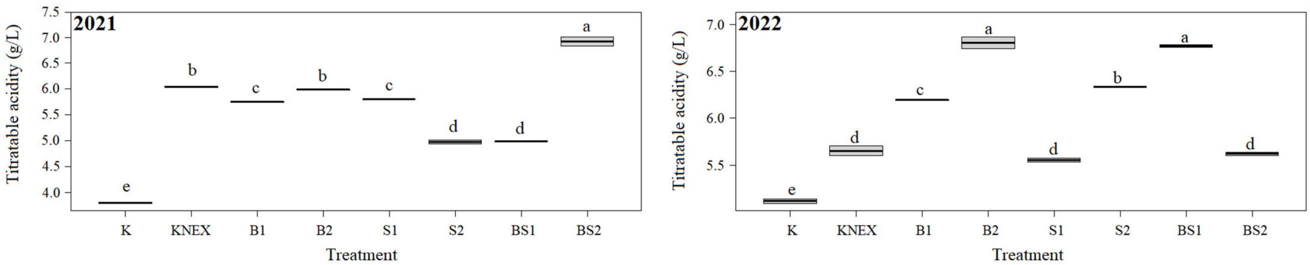

Figure 9. Effects of the treatments on the TA content (2021 and 2022). Different letters indicate significant differences between treatments within the studied year ($p < 0.05$).

However, there were occasionally significant differences between the years due to the different weather, mostly precipitation conditions. On average, over the two years, treatments increased TA by 26–43% compared to the control and 0.5–10% compared to the KNEX treatment, except for the S1 treatment. B1, BS1, and BS2 treatments showed the greatest increase in TA values compared to both the control and KNEX treatments, based on the average values.

4. Conclusions

The results of this study proved that the developed soil conditioner composites had positive effects on the soil nutrient status and leaf macronutrients and different fruit parameters like individual fruit weight, total soluble solids, and titratable acidity in an apple orchard. Based on the results, all treatments except S1 significantly increased the SOC content compared to the control by the end of the second year. Moreover, it was found that almost all applied composites have an increasing effect on SON content compared to the control and KNEX treatments. All treatments increased the nitrate content of the soil compared to the control by the end of the first year, and this effect remained stable in the following year.

Furthermore, in leaf nutrient contents, yield, and some quality parameters, higher differences were found between years than among treatments. This can be explained by the different weather conditions of the studied years. Some of the applied composites increased TSS content, and all of them significantly increased the TA content of apples.

Based on the soil, leaf and fruit analytical results, it can be concluded that most of the treatments had a positive effect on the values of the studied parameters compared to the control. Overall, the treatments with higher doses (e.g., BS2) proved to be the most effective, but it is important to consider that further studies are needed to analyze the effects of the composites more precisely.

Summarizing the results, applied composites influenced the nutritional status of the soil and resulted in better nutrient uptake as well as fruit attributes in an orchard that can be characterized by poor water and nutrient management. Therefore, developed composites can be used generally to promote farming in fruit orchards planted on sandy soils. Based on our results, the higher dose composite treatment (BS2) is recommended, with a 3.2 kg/tree per year dose.

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