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Evaluation of the Effect of Deep Compost Application in the Areas around Vineyard Tree Trunks on Selected Soil Chemical Properties and the Vegetative Growth of the Vine

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Abstract: In the context of sustainability, viticulture will address issues related to soil fertility in the coming period. Greater attention will therefore be paid to replacing traditional manure-based fertilisers, such as farmyard manure, with new types of fertiliser in the form of composts, digestate, etc. Experience to date suggests that good-quality composts are not only a source of nutrients that the vines take from the soil each year, but also a source of organic matter. The application of compost and its subsequent decomposition in the soil profile can have a positive effect on the growth of the roots and above-ground parts of the vine. However, optimising the effects and action of compost is linked to determining the necessary doses and methods of application. The aim of this three-year study was to provide an overview of the results aimed at evaluating the effects of the application of compost (CO) and compost enriched with the addition of lignohumate (CO+L20), at a rate of 30 t·ha^{-1}, in the areas around vineyard tree trunks on selected soil chemical properties and the vegetative growth of the vine (*Vitis vinifera* L.). The unfertilised variant (CWC) was used as a control. Each variant was established in three replicates that were 20 m long. Experimental measurements and evaluation were carried out in the period of 2018–2020 on two sites with different soil conditions (Lednice and Velké Bílovice) and two different grape varieties (Sauvignon Blanc and Pinot Gris). Meteorological data were continuously monitored during the period under review. Chemical properties of the soil samples of the three experimental variants were determined (e.g., content of organic carbon, humic acids, humic substances, humification rate, etc.). The evaluations that were carried out confirmed that the addition of organic matter in the form of composts to the soil in the CO and CO+L20 variants positively influenced the quality of organic matter. The organic carbon content increased by 56–139% in variants with deep compost application (CO, CO+L20) during the monitored period compared to the CWC, depending on the location. Similarly, the degree of humification increased by 70–84%, and the soil microbial biomass increased by 38–136% in the treated variants compared to the CWC. In addition to the dynamics of the changes in the chemical properties, the aim of the performed measurements was to evaluate the rate of the growth shoots, which was linked to the fertilizing effects of the applied compost in the experimental vineyard. At the site in Velké Bílovice, the total difference in the length of the shoots was higher in the CO by 2.6–4.6% and in the CO+L20 by 7.5–12.5% compared to the CWC. At the site in Lednice, the situation was similar, and the total difference in the length of the shoots was higher in the CO by 4.6–7.2% and in the CO+L20 by 5.3–13.2%. The results that were obtained may constitute an important basis for the management of organic fertilization

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on plots with different soil conditions and cultivated varieties in order to optimize the vegetative growth of the vine.

Keywords: viticulture; soil fertility; grapevine nutrition; compost; vegetative growth; annual shoots

1. Introduction

Environmental problems caused by the intensification of wine production have raised concerns about the application of conventional cultivation systems, which are gradually being replaced by more sustainable cultivation systems, such as integrated production and organic production [1]. The shift towards more environmentally friendly farming systems is being supported quite intensively in Europe by government subsidies to growers, in particular through the Common Agricultural Policy [2]. Changes in consumer preferences, which favour sustainable and healthy production, are also having a significant impact on the adoption of forward-looking farming systems [3]. The increasing use of sustainable practices in viticulture has, therefore, increasingly become a research interest, with a focus on soil quality, including soil biodiversity [4]. Other aspects with an impact on the environment, such as agricultural production, waste recycling [5], or the quality of produced grapes, are also being explored [6]. A progressive way to recycle waste is composting. In the context of waste management, today, composting is a commonly established recycling technology, which contributes significantly to reducing the production of a considerable amount of biodegradable waste that cannot be landfilled according to current legislation. From a waste management point of view, composting can be characterized as an integrated recycling system that effectively contributes to nutrient cycling and soil fertility, to a positive energy balance, and to reductions in greenhouse gas (GHG) emissions, e.g., in comparison with traditional recycling technologies [7].

In terms of impacts on soil quality, particular attention has been given to methods of applying organic matter (e.g., manure and compost) to increase soil organic matter (SOM) content, improve the physical properties of the soil [8], reduce soil compaction, and increase hydraulic conductivity, including reducing runoff and erosion [9], greening the soil surface (spontaneously or by seeding), and increasing water infiltration [10,11].

Calderón et al. [12] reported that common viticultural practices applied in agroecosystems are associated with a reduction in SOM, which causes disturbances in soil microbial biomass and activity. Ramos and Martínez-Casasnovas [13] described a decrease in vineyard production capacity of up to 50% due to soil degradation.

The remedy for this condition, leading to improved soil properties in vineyards, is the application of organic fertilizers or composts [14]. For example, Calleja-Cervantes et al. [15,16] and Bustamante et al. [17] have described an increase in soil organic carbon, available nutrient content, and soil microbial activity following the application of composted sheep manure or composts with variations in composition, re-considering soil properties in vineyards.

Rubio et al. [18] found that, after the application of different types of composts in vineyards under Spanish conditions, there is an initial decrease in soil pH and an increase in nitrate content, oxidisable carbon content, and carbon from microbial biomass. Tangolar et al. [19] presented the results of experiments with applications of different types of organic and inorganic material (inter-row application, with a dose of around 50 t·ha^{-1}) in Turkey. The obtained results demonstrate a positive effect of materials on soil properties, as well as on the yield and quality of grapes. Moreover, Wilson et al. [6] evaluated the effect of varying rates of compost applied in inter-row vineyards under northern California conditions on a wide range of aspects. These included monitoring the dynamics of changes in soil chemistry, grape yield, and its main quality parameters. In the vineyards, composted steer manure was applied at three rates (11.2, 22.4, and 33.6 t·ha^{-1}). The application of compost increased the measured properties of the soil and thus the yield of grapes and the quality of grapes.

Although a number of studies have shown the positive effect of applied compost on the physical and chemical properties of soil, the effect of compost on the vegetative growth of the vine is not entirely clear. The limited production of above-ground biomass, especially of shoots, can be a serious problem in grapevines. In the second half of the growing season, these annual plants turn into mature woody canes. These are subsequently cut back into fruit-bearing tillers during winter pruning [20]. The technological practices applied in vine cultivation are, therefore, directed towards the use of progressive work operations that allow for the supply and incorporation of compost into the soil in the required quantities, while respecting the low cost [21].

In addition to organic matter, biostimulants are an interesting alternative. They are a partial alternative to soil fertilization that improves nutrient absorption and prevents nutrient leaching into groundwater, but they can also contribute to suppressing vine diseases and improving grape quality [22]. At the level of the EU Member States, biostimulants can be characterized as substances or materials (not including nutrients and plant protection products) that can be targeted and applied to the surface of a treated plant, seed, or growth medium through specific formulations. The result of the application is to influence physiological processes occurring in the plant body. Successful application can lead to improved plant growth and development or to enhanced resistance to abiotic stresses [23].

The aim of this study was to provide an overview of the results aimed at evaluating the effects of the application of compost (CO) and compost enriched with the addition of lignohumate (CO+L20) at a rate of 30 t·ha^{-1}, in the areas around vineyard tree trunks on selected soil chemical properties and the vegetative growth of the vine (*Vitis vinifera* L.).

2. Materials and Methods

2.1. Characteristics of Experimental Sites

This three-year experiment was realised at two vineyard sites: Lednice (48°47′30″ N 16°47′56″ E) and Velké Bílovice (48°51′56″ N 16°52′55″ E), Moravia region, Czech Republic, starting in 2018 (Figure 1).

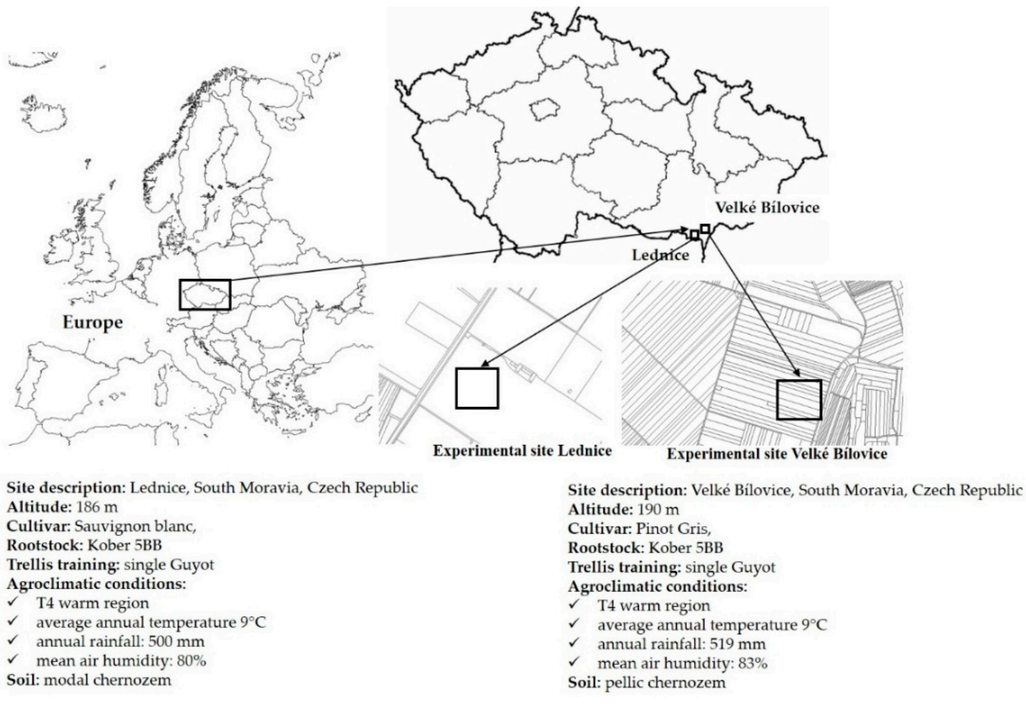

Figure 1. Main conditions of the experimental sites in Lednice and Velké Bílovice.

2.2. Measurement of Meteorological Data

Selected meteorological data were recorded on the experimetal sites by using meteorological stations (type: AMET, Moravský Žižkov, Czech Republic). Figure 2 shows the average monthly temperatures along with the monthly rainfall totals at the Lednice site, and Figure 3 shows those of the Velké Bílovice site, both for the period under study of 2018–2020.

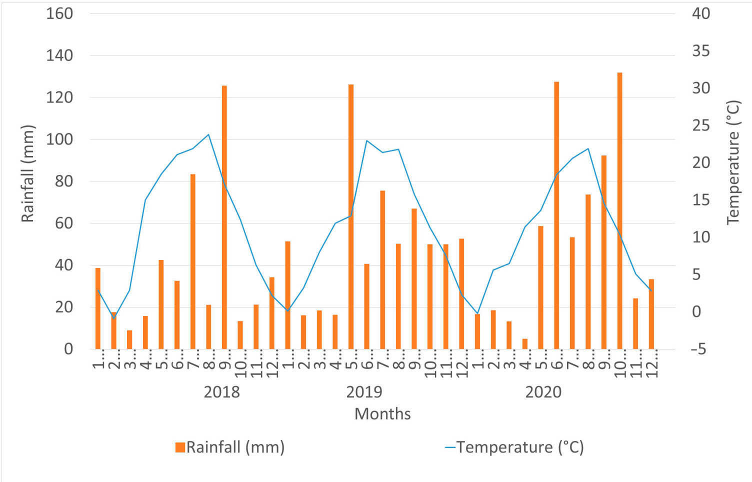

Figure 2. Meteorological data recorded from January 2018 to December 2020 at Lednice site.

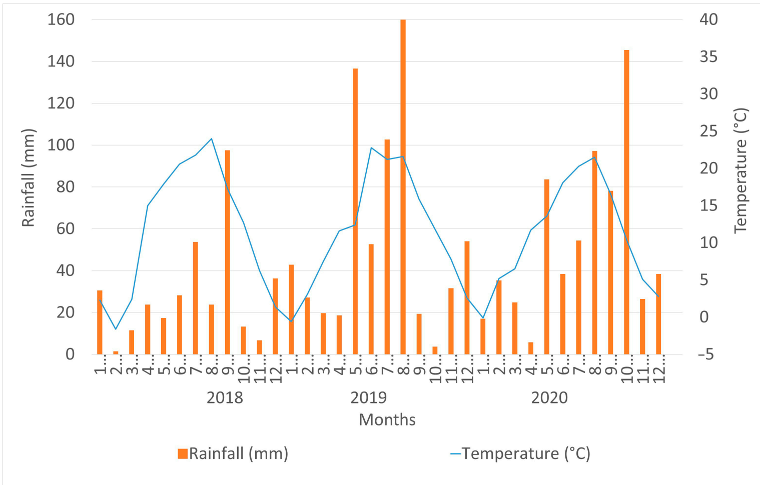

Figure 3. Meteorological data recorded from January 2018 to December 2020 at Velké Bílovice site.

2.3. Compost, Biostimulants, and Design of Experiment

The compost used for the field experiments was produced at the composting site of the Department of Horticultural Machinery in Lednice. The main input raw materials for the production of compost were horticultural waste in the form of grape pomace, vegetable and fruit waste, mown grass, wood chips, and straw in a ratio of 40:36:10:10:4. Strip-till technology was applied in the production of compost. The individual raw materials were first layered and then homogenised using a rotor compactor. The total time from the establishment of the stockpiles to the removal of the stabilised compost was 16 weeks. The output quality of the produced compost was evaluated according to the Czech state standard 46 5735 [24]. The following section presents the average values of the selected physical and chemical properties of the compost, which did not change significantly in individual years due to the uniform recipe and method of production. The chemical composition of the compost was, on average, 0.41 ± 0.05% N_t (total nitrogen), 185 ± 34 mg·kg^{-1} P, 705 ±

19 mg·kg^{-1} K, 323 ± 11 mg·kg^{-1} Mg, 79.3 ± 2.11% dry matter, 7.0 ± 0.04 pH_{exch}, and 1.93 ± 0.3% C_{org}.

Biostimulant Lignohumax 20 (L20) is an excipient available on the market consisting of an aqueous solution of synthetic lignosulfonates. These consist of a spectrum of humic and fulvic acids and their salts (manufacturer AMAGRO-Humic substance, Germany). Recent work has shown that the application of lignohumate supports higher photosystem activity and chlorophyll formation, increases the utilisation of nutrients contained in the soil, and has a positive effect on the root growth of cultivated shrubs. However, its effects on increasing yields and harvest quality are not clear. The recommended dosage indicated by the manufacturer corresponding to 0.40 L·ha^{-1} was used in these experiments.

The compost was applied each year during the autumn season. The compost was placed in pre-ploughed furrows, which were no deeper than 0.3 m. The furrows were run parallel to the treated vineyard rows at a distance of 0.2 m from the base of the caraway seeds. After application, the compost was covered with the surrounding soil using plate harrows. The dose of the applied compost was 30 t·ha^{-1}.

To verify the effects of the applied compost, the following treatments were established in the experimental vineyard: control without compost (CWC), compost alone (CO), and compost with the addition of the biostimulant Lignohumax 20 (CO+L20). The length of the experimental sections was 20 m, and each of the experimental variants was established in three repetitions to provide the necessary amount of input data with the subsequent possibility of their statistical evaluation.

2.4. Assessment of Chemical Soil Properties

The vineyards were managed in a standard way respecting the soil sub-conditions of the selected sites and the mechanisation equipment of the vineyard operations. Soil samples were taken according to the Central Institute for Supervising and Testing in Agriculture Czech Republic standard. The sampling scheme was performed in the selected length crosswise in the row of vine bushes for 5 individual samples and with 3 repetitions. Broken samples were taken manually with soil drills. Samples were taken as mixed samples to determine the chemical properties of soil and soil biomass, always from two depths of the topsoil profile, at the beginning and at the end of vegetation.

The following chemical properties were determined for assessment: pH_{exch}., C_{org}, C_{mic}, C_{HA}, C_{FA}, N_t, C_{mic}/C_{org}, C_{HA}/C_{FA}, R_H, and C_{org}/N_t from a depth of 0–0.15 m and 0.15–0.30 m. The exchange pH value was analysed potentiometrically with a KCl leachate, and the content of overall nitrogen mineralisation was determined via a distillation method (Kjeldahl method) according to [25] (expressed as %). The overall content of organic carbon (C_{org}) was analysed via oxidimetric titration [26]. The carbon content in humic substances (C_{HS}) and carbon content in humic acids (C_{HA}) were determined after fractioning [27]. Humic substances (HS), to determine the level of humification, were extracted with a mixture of 0.1M sodium pyro-phosphate and 0.1M NaOH. The content of carbon fulvic acids (C_{FA}) was calculated with the equation $C_{FA} = C_{HS} - C_{HA}$, and the humification rate (R_H) was calculated with the equation $R_H = (C_{HA} + C_{FA})/C_{org}$. The degree of humification of R_H shows the quality of soil OM and depends on soil moisture and the quantity and quality of soil organic matter. To evaluate the quality of organic matter, or humus, the ratio C_{HA}/C_{FA} was determined [28]. The humus content of the soil is determined on the basis of the amount of oxidised carbon (C_{ox}). The C_{ox} content is multiplied by the recognition factor 1.724.

2.5. Measurement of the Length of Growth Shoots

The length measurements covered the main period of long-lived growth, which was between the beginning of May and the end of June. During the measurement, the length of the shoots growing from the base to the end of the trailing stem was recorded for the shrubs forming each experimental variant. The length measurements were made by attaching an extendable steel band (BMI, Nové Město, Czech Republic) in order to not damage the rhizomes. The measured length was recorded in cm in a measurement log for each of the yearlings. A total of 28 rhizomes were measured for each variant in three repetitions.

2.6. Statistical Analysis

A one-factor analysis of variance was used to evaluate the data characterising the chemical properties of the soil. Tukey's test at a significance level of $\alpha = 0.05$ was used as a post-testing method. The method of constructing confidence intervals constructed around the arithmetic mean was used to estimate the length of growth shoots. The above statistical evaluation methods were applied using the computer software 'Statistica 12.0' (StatSoft Inc., Tulsa, OK, USA, 2017).

3. Results and Discussion

Tables 1 and 2 show the parameters $pH_{exch.}$, C_{org}, C_{mic}, C_{HA}, C_{FA}, N_t, C_{mic}/C_{org}, C_{HA}/C_{FA}, R_H, and C_{org}/N_t in all monitored variants at the Lednice and Velké Bílovice site vineyard localities during the years 2018–2020. Both sites were evaluated separately due to different site conditions.

Table 1. Average values of monitored parameters at Lednice site.

Year	Var.	$pH_{exch.}$ (-)	C_{org} (%)	C_{mic} ($\mu g\ C \cdot g^{-1}$ *)	C_{HA} ($g \cdot 100\ g^{-1}$)	C_{FA} ($g \cdot 100\ g^{-1}$)	N_t (%)	C_{mic}/C_{org} (-)	C_{HA}/C_{FA} (-)	R_H (%)	C_{org}/N_t (-)
2018	CWC	6.9 ± 0.00 ^{ab}	1.16 ± 0.11 a	2.18 ± 0.26 ^{a}	0.20 ± 0.00 ^{a}	0.17 ± 0.02 a	0.18 ± 0.04 abc	1.87 ± 0.04 ab	1.17 ± 0.14 a	0.32 ± 0.05 a	6.70 ± 2.26 a
	CO	6.8 ± 0.14 ^{ab}	1.19 ± 0.05 a	2.63 ± 0.01 ^{a}	0.23 ± 0.02 ^{ab}	0.16 ± 0.00 a	0.23 ± 0.01 bc	2.22 ± 0.08 b	1.45 ± 0.15 a	0.32 ± 0.00 a	5.27 ± 0.07 a
	CO+L20	6.7 ± 0.35 ^{ab}	1.25 ± 0.16 a	2.23 ± 0.37 ^{a}	0.25 ± 0.03 ^{ab}	0.17 ± 0.01 a	0.23 ± 0.03 bc	1.79 ± 0.06 ab	1.48 ± 0.21 a	0.34 ± 0.03 a	5.41 ± 0.00 a
2019	CWC	6.7 ± 0.07 ^{ab}	1.13 ± 0.26 a	1.95 ± 0.21 ^{a}	0.22 ± 0.04 ^{a}	0.21 ± 0.08 a	0.12 ± 0.00 a	1.76 ± 0.22 ab	1.02 ± 0.22 a	0.41 ± 0.20 a	9.28 ± 2.33 a
	CO	6.7 ± 0.14 ^{ab}	1.18 ± 0.32 a	2.09 ± 0.17 ^{a}	0.33 ± 0.01 ^{ab}	0.24 ± 0.00 a	0.16 ± 0.04 abc	1.83 ± 0.35 ab	1.35 ± 0.01 a	0.50 ± 0.13 a	7.61 ± 0.42 a
	CO+L20	6.6 ± 0.07 ^{a}	1.01 ± 0.18 a	2.33 ± 0.11 ^{a}	0.37 ± 0.10 ^{b}	0.23 ± 0.05 a	0.15 ± 0.04 abc	2.33 ± 0.30 b	1.62 ± 0.11 a	0.61 ± 0.25 a	7.03 ± 0.78 a
2020	CWC	6.8 ± 0,00 ^{ab}	1.11 ± 0.06 a	1.93 ± 0.08 ^{a}	0.23 ± 0.01 ^{a}	0.19 ± 0.00 a	0.13 ± 0.01 a	1.74 ± 0.06 a	1.21 ± 0.02 a	0.39 ± 0.03 a	8.54 ± 0.11 a
	CO	6.7 ± 0,07 ^{a}	1.21 ± 0.02 a	2.45 ± 0.15 ^{a}	0.33 ± 0.02 ^{ab}	0.25 ± 0.01 ab	0.14 ± 0.01 a	2.02 ± 0.08 ab	1.32 ± 0.05 a	0.47 ± 0.13 a	8.64 ± 0.15 a
	CO+L20	6.7 ± 0,00 ^{a}	1.23 ± 0.06 a	2.35 ± 0.04 ^{a}	0.39 ± 0.03 ^{ab}	0.25 ± 0.01 ab	0.16 ± 0.03 a	1.91 ± 0.05 ab	1.56 ± 0.01 ab	0.53 ± 0.05 a	7.69 ± 0.09 a

Note: Values are the average of three replicates and the coefficient of variation for each year, and different lower-case letters indicate statistically different values between the evaluated variants ($p < 0.05$). *, dry matter.

Table 2. Average values of monitored parameters at Velké Bílovice site.

Year	Var.	$pH_{exch.}$ (-)	C_{org} (%)	C_{mic} ($\mu g\ C \cdot g^{-1}$ *)	C_{HA} ($g \cdot 100\ g^{-1}$)	C_{FA} ($g \cdot 100\ g^{-1}$)	N_t (%)	C_{mic}/C_{org} (-)	C_{HA}/C_{FA} (-)	R_H (%)	C_{org}/N_t (-)
2018	CWC	7.4 ± 0.14 ^{a}	1.93 ± 0.06 ab	2.35 ± 0.30 ^{a}	0.20 ± 0.01 ^{ab}	0.16 ± 0.00 a	0.23 ± 0.06 a	1.05 ± 0.12 ab	1.28 ± 0.09 abc	0.19 ± 0.01 a	8.61 ± 1.85 a
	CO	7.3 ± 0.07 ^{abc}	2.06 ± 0.15 ab	2.19 ± 0.23 ^{a}	0.31 ± 0.01 ^{abc}	0.22 ± 0.02 a	0.24 ± 0.04 a	1.20 ± 0.16 ab	1.43 ± 0.06 ac	0.26 ± 0.00 ab	8.65 ± 0.91 a
	CO+L20	7.4 ± 0.07 ^{ac}	2.54 ± 0.21 b	2.68 ± 0.44 ^{a}	0.35 ± 0.01 ^{c}	0.21 ± 0.00 a	0.27 ± 0.01 a	1.13 ± 0.35 ab	1.67 ± 0.03 a	0.22 ± 0.01 a	9.56 ± 0.52 a
2019	CWC	7.1 ± 0.00 ^{bc}	1.78 ± 0.06 abc	1.94 ± 0.15 ^{a}	0.30 ± 0.04 ^{abc}	0.52 ± 0.01 ab	0.24 ± 0.01 a	0.98 ± 0.05 a	0.57 ± 0.05 b	0.46 ± 0.01 ^{c}	7.54 ± 0.55 a
	CO	7.2 ± 0.00 ^{abc}	1.77 ± 0.08 ab	2.05 ± 0.09 ^{a}	0.34 ± 0.07 ^{bc}	0.47 ± 011 ab	0.20 ± 0.03 a	1.16 ± 0.11 ab	0.74 ± 0.02 bc	0.46 ± 0.08 bc	9.55 ± 0.49 a
	CO+L20	7.0 ± 0.07 ^{b}	2.12 ± 0.08 bc	2.24 ± 0.19 ^{a}	0.51 ± 0.06 ^{d}	0.39 ± 0.03 a	0.22 ± 0.02 a	1.12 ± 0.04 ab	1.30 ± 0.25 abc	0.42 ± 0.00 bc	10.03 ± 0.62 ^{a}
2020	CWC	7.1 ± 0.00 ^{ab}	1.81 ± 0.15 a	1.90 ± 0.04 ^{a}	0.27 ± 0.00 ^{a}	0.39 ± 0.01 a	0.19 ± 0.03 a	1.05 ± 0.03 a	0.69 ± 0.02 a	0.39 ± 0.02 a	9.53 ± 0.37 a
	CO	7.1 ± 0.07 ^{ab}	1.84 ± 0.05 a	2.12 ± 0.11 ^{a}	0.32 ± 0.01 ^{a}	0.49 ± 0.00 ab	0.21 ± 0.00 a	1.15 ± 0.05 a	0.65 ± 0.03 a	0.47 ± 0.01 ab	8.76 ± 0.24 a
	CO+L20	7.0 ± 0.00 ^{a}	2.24 ± 0.05 b	2.35 ± 0.11 ^{a}	0.45 ± 0.02 ^{b}	0.44 ± 0.02 a	0.24 ± 0.01 a	1.05 ± 0.04 a	1.02 ± 0.05 ab	0.47 ± 0.00 ab	9.33 ± 0.11 a

Note: Values are the average of three replicates and the coefficient of variation for each year, and different lower-case letters indicate statistically different values between the evaluated variants ($p < 0.05$). *, dry matter.

At the Lednice site, the exchanged pH values generally remained at a neutral level (6.6–6.9) in all variants throughout the duration of the experiment (2018–2020) and gradually decreased in variants with CO and CO+L20 preparation. The C_{org} content ranged from 1.01 to 1.25% and increased in variants with applied organic matter by 8% on average in 2018, by 4% in 2019, and by 11% in 2020 in comparison with the control variant (CWC).

The C_{mic} ranged from 1.93% to 2.63% and also increased in variants with applied organic matter compared to the control variant (CWC). Over the 3 years, on average, CO increased it by 18.2%, and CO+L20 increased it by 14.4%. The highest C_{mic} contents were found in all variants in 2018. The C_{HA} values increased with the application of CO and CO+L20. The C_{HA} ranged from 0.20 to 0.39%, and C_{FA} ranged from 0.16 to 0.25% in all variants. The highest C_{HA} values were recorded during the experiment in 2020 for CO+L20 and increased by 56% from the beginning of the experiment. The C_{FA} content was at the same level each year during experiment, except the year 2020, when there was an increase in C_{FA} by an average of 47% in all experimental variants. The quality of organic matter decreased with the depth of topsoil. The calculated humification degree (R_H) increased with the application of CO+L20, and the highest values were determined in 2019, ranging from 0.32 to 0.61%. The content of N_t in 2018 and 2020 ranged from 0.12 to 0.23%. Increases were measured only in 2018 and ranged from 0.18 to 0.23%. The quality of organic matter (OM) was also found to be higher in variants with compost. There was an increase in the quality of OM, expressed as a ratio of C_{HA}/C_{FA}, with the highest increase in 2019 by 1.35 in the CO variant and by 1.62 in the CO+L20 variant. On average, R_H values ranged from 0.32% (year 2018) to 0.61% (year 2019), with the highest value of 0.61 with CO+L20 (Table 1). Standard deviations show a significant difference between the control variant without compost (CWC) and variants with compost (CO, CO+L20). The content of soil water was directly correlated with R_H and increases together with increasing R_H.

At the Velké Bílovice site, the exchanged pH values gradually decreased from alkaline (7.4) to neutral (7.0) during the experiment (2018–2020). The C_{org} content ranged from 1.77 to 2.54%. Soil microbial biomass ranged from 1.90 to 2.68%, and both the C_{mic} and C_{org} parameters increased in variants with applied organic matter, especially with CO+L20 preparation. The highest C_{mic} content (2.68%) was found with CO+L20 in 2018. The C_{HA} content increased particularly with the application of CO+L20 and ranged from 0.20 to 0.51%, and C_{FA} ranged from 0.16 to 0.52% in all variants. The highest C_{HA} values were recorded during the experiment in 2019 for CO+L20. A decrease in C_{HA} and an increase in C_{FA} were recorded for all variants in 2019. The highest C_{HA} content was detected for CO+L20 (0.51%) in 2019. The lowest content was found in variant CWC (0.20%) without compost. The highest susceptibility to the acidification and degradation of soil indicated the highest C_{FA} content, which was found for CO (0.52%) in 2019. The calculated humification degree (R_H) increased particularly with the application of compost (CO and CO+L20), and the highest values were determined in 2019 and 2020, ranging from 0.39 to 0.47%. The N_t parameter ranged from 0.19 to 0.24% in all variants (Table 2).

The application of CO+L20 had a long-term effect on soil pH decreasing. Acidification is caused by fulvic acids (FA) that remain in the soil solution. The solubility of fulvic acids (FA) in water is under all pH conditions [27], and the prevailing content of fulvic acids in CO+L20 explain the slight acidification of soil pH. The influence of quinone groups present in fulvic acids such as carboxylic, phenolic, and hydroxyl groups contribute to the lowering of soil pH [28]. However, the application of CO and CO+L20 had a greater effect on reductions in soil pH in the Lednice experimental locality compared to the Velké Bílovice locality, where the pH was, on average, around 7. Soil pH levels near 7 are optimal for overall nutrient availability, crop tolerance, and soil microorganism activity [29]. Soil C_{org} was increased in variants with CO+L20. A higher content of organic matter in the soil corresponds with higher doses of applied fertilizers and corresponds with the increased resistance of humic acids to their microbial degradation [30], which was confirmed by a continuous increase in C_{HA} in the CO and CO+L20 variants and also in the relationship of humus quality and C_{mic}. The C_{org} content was also related with C_{mic}. As the C_{mic} to C_{org} fractions become higher, so does the amount of carbon present in the available form, and so does the amount of microorganisms that can live on the substrate [31]. According to the microbial quotient in the work of Anderson and Domsch [32], we also found a conclusive relationship between C_{mic} and C_{org} in our experiment in the vineyards (Tables 1 and 2). Changes in the C_{mic}/C_{org} ratio indicate the supply of organic matter to the soil, characterising the efficiency of its conversion to microbial C, its loss from the soil, or the stabilisation of organic C by mineral fractions [33,34]. The amount of soil organic matter can influence the ease and effectiveness with which microorganisms bind to the surface of colloids and soil particles [31,35]. The reduction in C_{org} in variants with applied organic material can be explained by the consumption of organic carbon for microbial processes [36], which resulted in an increase in C_{mic}. Soil microbial biomass levels were generally lower in upper soil layers than those in the lower soil layers. Microbial activity (C_{mic}) usually increased continuously during the monitored years, mainly due to the addition of CO+L20 together with C_{HA}, and thus the humification degree also increased. Humic acids can stimulate the growth of soil bacteria strains acting as a regulator of cell metabolism [37]. Despite the dominant content of fulvic acids in the CO+L20 preparation, C_{FA} decreased over the years in variants with its application, likely due to the decomposition and increased activity of microorganisms.

The resulting values of the lengths of increments in growth shoots each year at both experimental sites are shown in Figures 4 and 5.

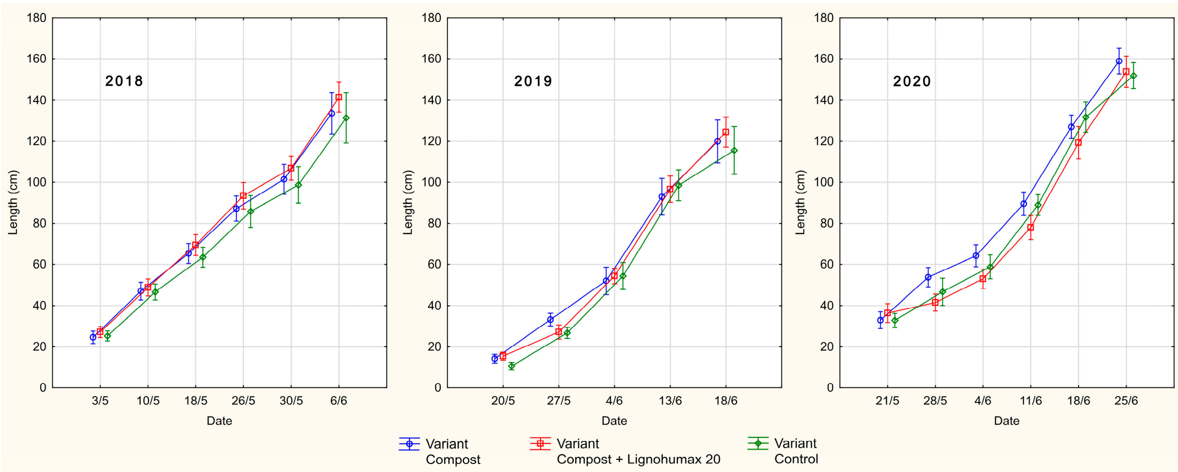

Figure 4. Average lengths of the shoots at the Lednice site (2018–2020).

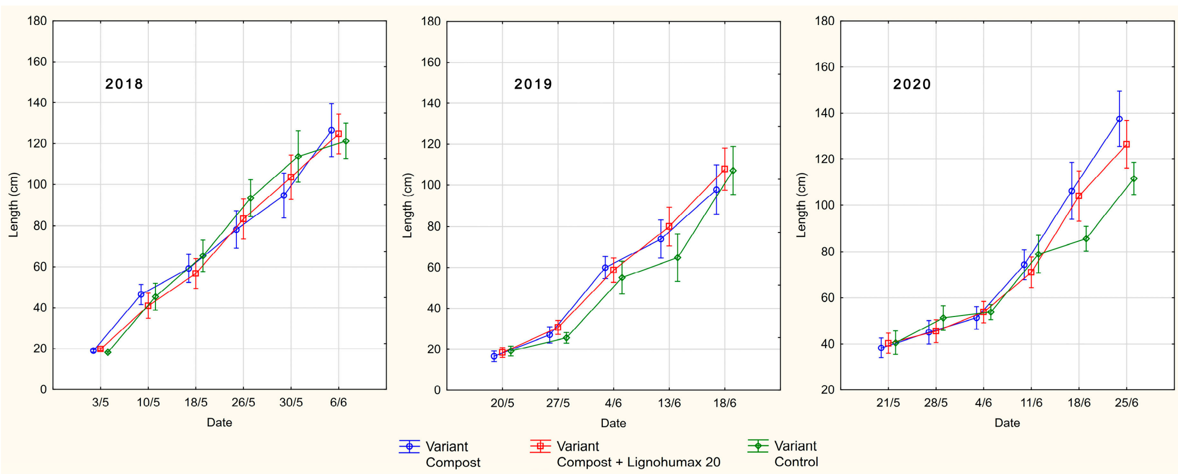

Figure 5. Average lengths of the shoots at the Velké Bílovice site (2018–2020).

Overall, the graphs generated from the data collected at both sites show less prolonged growth of the shoots, especially in CWC. On the other hand, the intensity of long-lived growth was higher in the fertilised variants using CO and CO+L20. At the site of Velké Bílovice, the total difference in the length of the shoots was higher with CO by 2.6–4.6% and with CO+L20 by 7.5–12.5% compared to the CWC. At the Lednice site, the situation was similar, and the total difference in the length of the shoots was higher with CO by 4.6–7.2% and with CO+L20 by 5.3–13.2%. The exception was at the Velké Bílovice site in 2020, when the length of annual shoots was, with CO+L20, 3% shorter compared to the CWC. This condition could have been caused by unpredictable factors. At the Lednice site, the length of annual shoots was lower with CO and CO+L20 by 3.1–5.0% compared to CWC. The reason could be a short time interval in the first year of deep compost application, which did not have a sufficient effect on the growth of shoots. In addition to deep compost application, the growth of shoots was also related to temperature conditions. Figures 1 and 2 show a relatively rapid increase in temperatures with values above 10 °C in 2018, which, in combination with smaller amounts of precipitation at the beginning of the growing season, caused intensive growth of shoots. In 2019 and 2020, there was a slower increase in temperatures at the beginning of the vegetation, which also affected the slower growth of the shoots. When comparing the absolute lengths of annual shoots, it is clear that, in 2018, a length of around 1.20–1.40 m was reached around June 6, and in 2019 and 2020, the same length was reached with a delay of 10–12 days. Pavloušek [38] described the correlations between daily temperatures, which, from a physiological point of view, are reflected in the higher production of plant hormones. The greatest emphasis is placed on auxins, which, already in small concentrations, affect the long-lived growth of plant cells and thus influence the growth rate of vine tillers. Another reason given for the faster growth of vines was higher temperatures, which cause the soil profile in which the root system is located to warm up. Consequently, the transport of nutrients from the roots to the above-ground parts of the shrubs is faster. Experiments to verify the effects of applied compost on the growth of vine bushes were carried out by Gaiotti et al. [14] in a fertile vineyard in the conditions of north-eastern Italy. For the purpose of the evaluation, they used two types of composts with different compositions, variations in the method of application, and incorporation. The experiments were carried out in a fertile vineyard with Cabernet Sauvignon. The undeniable advantage of their experiments was the time interval, which covered a period of five years. The results clearly show the positive effect of the applied compost on the vegetative growth of the above-ground parts of the shrubs. The leaflets of the fertilized variants were 10–45% longer than those of the shrubs that were not fertilized with compost. The optimisation of the relationships between vineyard fertilization, growth, and fruiting was carried out by Nardi et al. [39]. The results of their experiments place great emphasis on ensuring the correct nutrient supply to the soil in an optimal ratio that respects the nutritional requirements of the bushes with respect to the yield of grapes of adequate quality. Disruption of these relationships can lead to enhanced vegetative growth, the deterioration of the health of the bushes, and a reduction in the quality of production. Moreover, Arrobas et al. [40], carried out a set of experiments related to the fertilization of vineyards using compost. The experiments verified the effect of compost made with biodegradable municipal waste. When applied at a rate of 20 $t \cdot ha^{-1}$ over a three-year time-frame, it increased the yield of grapes produced by almost 30%.

4. Conclusions

The obtained results provide a set of information concerning the changes in soil chemical properties and the intensity of the growth of shoots for vine bushes depending on the chosen fertilization method using CO and CO+L20 over a three-year period. The application of CO and CO+L20 achieved a positive effect on the quality of organic matter (OM), which was higher in the fertilized variants. The effect of applied compost on the degree of humification (R_H) and on soil microbial biomass (C_{mic}) was also positive. In particular, the application of CO+L20 had the effect of partially lowering soil pH. The measured and evaluated results prove the high efficiency of the tested method of application of CO and CO+L20 into pre-ploughed furrows with a depth of 0.3 m, led at a distance of 0.2 m from the base of the cotyledons, for the growth of grapevine plants. The use of composts for the leading application of synthetic fertilizers fulfils the standards of agronomic management, which monitor the physiology and phenological rhythms of cultivated plants. Lower susceptibility of plants to be attacked by pathogens and an increase in the stability of the entire agroecosystem can be achieved. The use of compost to optimise soil conditions and the nutritional status of shrubs can have a positive effect on a number of aspects. In particular, it can achieve the necessary yield of grapes of the appropriate quality but can also significantly reduce a wide range of factors that negatively affect the health of bushes and grapes. The chosen type of organic fertilizers (CO and CO+L20) and the method of their application and incorporation into the soil contribute to the expansion of knowledge in the field of promising methods for vine nutrition in the context of sustainable farming. In addition to the positive effects on soil chemistry, this method of application also has a positive impact on optimising the vegetative growth of the vines. Further developments in this area should be directed towards the further development of the promising technologies enabling fast and efficient applications. Attention should also be focused on the evaluation of composts of different origin, composition, and application rates, respecting the nature of the stand and habitat. Only a comprehensive overview of this information can contribute to the further development of vineyard production in the future.

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