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Full Paper

The use of biochar as a soil amendment did not affect wine quality in a *Müller Thurgau* vineyard in South Tyrol (Italy)

Die Verwendung von Pflanzenkohle (Biochar) als Bodenverbesserungsmittel hatte keine Auswirkungen auf die Weinqualität in einem *Müller-Thurgau*-Weinberg in Südtirol (Italien)

L'uso del biochar come ammendante del suolo non ha influito sulla qualità del vino in un vigneto di *Müller Thurgau* in Alto Adige (Italia)

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ABSTRACT

The aim of this study was to identify the effects of biochar as a soil amendment on grape and wine quality. The study showed that the addition to soils of pure biochar and biochar enriched with compost did not negatively affect organoleptic properties of the wine. Furthermore, there were no significant differences between volatile organic compounds (VOCs) in wines made from biochar-treated grapevines and those of the untreated control. Pure biochar and biochar moderately enriched with compost as soil amendments did not permanently change nitrogen availability in the soil, nor did they alter the vegetative growth or productivity of the vines. Therefore, the use of biochar in viticulture can be recommended to correct the pH of the soil and for long-term carbon sequestration, as no negative side effects are to be expected and the quality of the grapes and wines is not affected.

KEYWORDS

Soil fertilizier, wine quality, soil management, sustainable strategies

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INTRODUCTION

Biochar is a carbon-rich product obtained from the pyrolysis of biomasses (wood, untreated waste from wood processing, organic residues from agricultural crops such as cereal glume and straw, organic waste from garden or food, algae, manure and others) under conditions of limited O2-supply and high temperatures. During this process, a part of the carbon contained in the raw material is transformed into stable structures, and therefore carbon remains fixed in the char for at least a century and sometimes longer [1]. Given that it has a very high internal surface area, biochar has a "sponge" effect: it can store nutrients and increase the retention of mineral nitrogen, subtracting it from leaching or gaseous dispersion, and making it available for plant consumption [2] [3] [4]. Used as a soil amendment, biochar can improve soil productivity, its physical and chemical properties, and increments its water content and fertility [5] [6] [7] [8] [9]. Several experiments have shown that in poorly fertile soils lacking in organic matter and in dry conditions, the addition of biochar can very clearly improve crop growth and productivity [10]. For these reasons, biochar is a very interesting product for agriculture: today its use is still one of the few - if not the only - affordable methods of atmospheric carbon sequestration, having therefore a mitigating effect on climate change. If practiced on a large scale, the effects would be highly significant.

The objective of South Tyrolean viticulture is to produce high-quality grapes and wines. To achieve this, it is important to have a certain water deficit during the growing phase, especially for the red varieties, but also for the white. However, since the 1990s, as a result of climate change, periods of severe drought have been increasingly frequent, which can cause quantitative and qualitative losses to production. Currently, through irrigation, it is possible to overcome these critical phases, but the experts predict even more pronounced climatic extremes in the future. Moreover, in South Tyrol, as a consequence of the disappearance of glaciers, the availability of water will probably be even more limited, and water deficits could increase with the rise of temperatures and extreme climatic conditions. The use of biochar could therefore be valuable in viticulture where significant water stress is expected to occur, soil fertility is already compromised, or where the desired yields are no longer being achieved. However, it is important to investigate the possible side effects of this practice, especially on wine quality.

Several studies [11] [12] [13] [14] [15] [16] [17] [18] [19] have reported positive effects from biochar application on various crops, mainly due to the characteristics already described. Schmidt et al. [20] found that applications of biochar and biochar enriched with compost do not influence the growth parameters of vineyards (Vitis vinifera cv. Pinot Noir, 25-35 years) on cal-

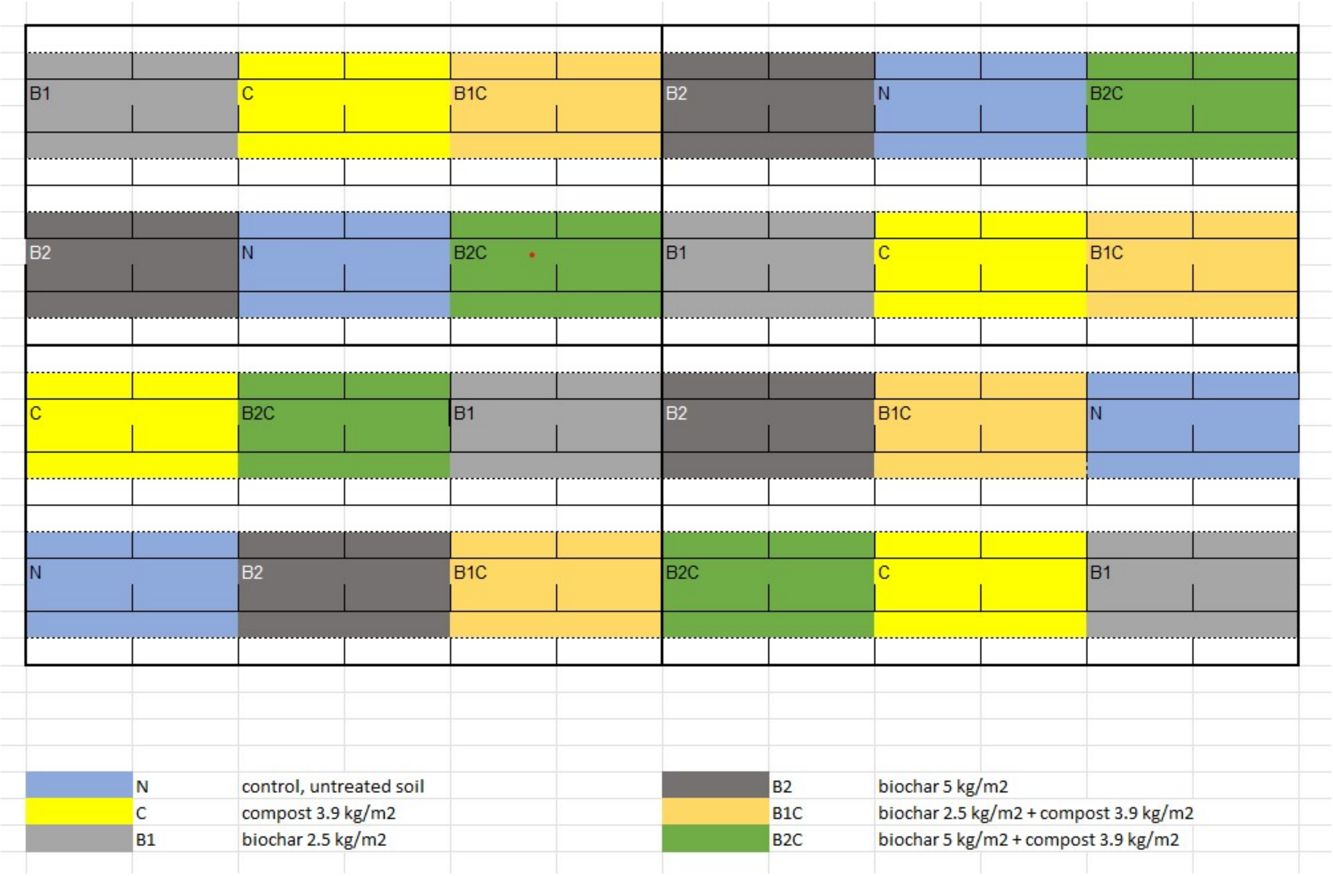

Fig. 1: Map of the field of study Moarhof: randomized block design with five treatments plus control.

careous soils in temperate climatic conditions, and they have no negative influence on the quality parameters of musts. Holweg [21] found higher content of yeast assimilable nitrogen (YAN) in musts from plots treated with biochar; sufficient YAN content in musts favours fermentation and provides precursors for the synthesis of aromatic compounds in wines. The results obtained in Tuscany by Genesio et al. [22] showed that the incorporation of biochar in the soil has led to significantly better yields in years with prolonged drought and no irrigation without altering the quality parameters of the grapes. The incorporation of biochar in sloping soils, moreover, can limit erosion, the formation of preferential water flows and the leaching of nutrients and/or agrochemicals [23]. However, the effects of biochar as a soil amendment on wine quality have not yet been investigated.

The here presented research activities focus on the evaluation of the potential effects of biochar as a soil amendment on the quality of *Müller Thurgau* grapes and the wine produced from them.

MATERIAL AND METHODS

EXPERIMENTAL SITE AND EXPERIMENTAL SETUP

The experimental field is located on a hilly site, approx. 500 m a.s.l., near Merano (Bz, Italy, coordinates 46°40’2.7"N 11°11’43.5"E). The vineyard was established in 2007 with rows oriented south-north, a vertical shoot positioned (VSP) trellis system and a density of 5500 vines/ha. Vines are V. vinifera cv. *Müller Thurgau*, grafted on SO4 rootstocks. The soil has a permanent grass cover, treated with herbicide under the vines, and is classified as sandy loam, with a pH value of 6.3 and 2.5-3% organic matter in the topsoil (0-30 cm). The trial was laid out as a randomized 4-block design (Fig. 1): each replicate includes two rows and has 20 vines, giving a total of 80 vines per treatment. The amendments were then uniformly distributed in the alleyway between each replicate, with only a small space under the vines remaining untreated. Finally, the amendments were mechanically incorporated with the use of a spade plough and a disc harrow at an approximative depth of 30 cm (Fig. 2). The operation took place on the 21st of April, when the growth stage of vines, following the BBCH scale, was 53. The treatments included two different concentrations of biochar (respectively 2.5 and 5 kg/m2 of dry matter) taken individually and in combination with

Fig. 2: Distribution of soil amendments in the vineyard.

compost (3.9 kg/m2 of dry matter), and compost only (3,9 kg/m2), for a total of five treatments, plus a control. The general management of the experimental field, according to the usual practice, was uniform. Throughout the duration of the experiment no nitrogen fertilisation was given because of the good vegetative and productive performance of the vines and the adequate nitrogen provision as confirmed by leaf analyses. The Laimburg Research Centre's weather station used as reference for the meteorological data is located in Fragsburg, approx. 2500 m air-line distance from the experimental field.

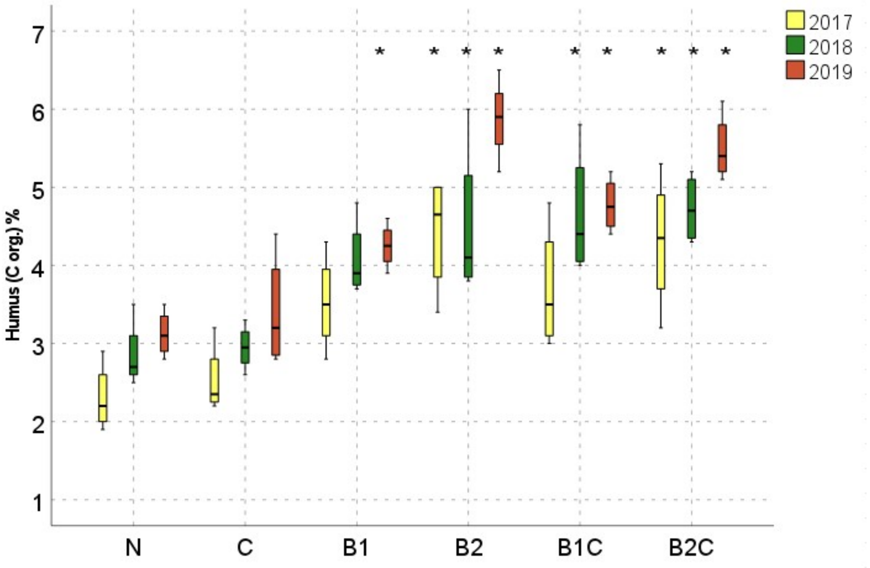

Fig. 3: Organic carbon (expressed as humus) in the soil (0-30 cm): asterisks indicate significant differences of treatments to the untreated control.

BIOCHAR AND COMPOST CHARACTERIZATION

The biochar applied comes from Marche region (Novolegno Company) and is a by-product of the gasification of Apennine coniferous wood. It is fine-grained and rather dusty (main characteristics reported in Table 1); the compost was supplied by the Egna/San Floriano (Bz) composting plant (main characteristics reported in Table 2).

FIELD ACTIVITIES

Field activities included: sampling soil and leaves for organic carbon (C-org), mineralized (N-min) and total nitrogen analysis; monitoring berries' ripeness; weight of harvested grapes and seasonal pruned wood. In order to evaluate the effects of soil amendments on the final product, single microvinifications were carried out yearly for every treatment applied, and sensory analyses were carried out on the wines that were produced.

Nitrogen and carbon analyses

Soil samples were collected at flowering, veraison and after harvest at two different depths (0-30 and 30-60) in the alleyway, then mixed and sieved to 2 mm.

Leaves were sampled twice each year in summer, after flowering and at veraison. For each replicate, 30 leaves attached to the first bunch were randomly collected: in the lab they were washed with distilled water, oven-dried at 65 ℃ for approximately 12 hours and then ground for analysis.

Organic C analyses on soil and nitrogen analyses on soil and destemmed leaves were conducted following the VDLUFA (Association of German Agricultural Analytic and Research Institutes) method: determination of nitrogen with Dumas protocol (DIN EN ISO 16634-¬1:2009), other elements by ICP-OES analyses (EPA 3052:1996 + EPA 6010D:2018).

Grapes analyses

In order to regularly monitor the ripening stages after veraison, 120 berries per replicate were randomly collected each week from a selection of bunches and taken to the lab. They were weighed, pressed, centrifuged and filtered with a 5 μm syringe disk filter from Sartorius Stedim Biotech GmbH (Goettingen, Germay) for FT-IR analysis based on RESOLUTION OIV/OENO 390/2010 (measured with FOSS®, WineScan™).

Determined Parameters:

- reducing sugars (g/l)
- total soluble solids (°Babo)
- pH
- total acidity (g/l)
- malic acid (g/l)
- tartaric acid (g/l)
- potassium (g/l)
- YAN - yeast assimilable nitrogen (mg/l)
- ammonia-nitrogen (mg/l)
- amino-nitrogen (mg/l)
- gluconic acid (g/l)

Evaluation of productivity and growth

In order to estimate productivity, before veraison the total amount of bunches per vine was counted. Every year, harvest occurred at the beginning of September, when total acidity values dropped below 7 g/l and sugar content was around 16-17 °Babo. Bunches were weighed separately per treatment and replicate.

During the winter pruning, the wood produced during the year, except for the fruit cane for the next year's production, was removed and weighed to quantify the seasonal growth of the vines. Ravaz Index (yield/pruning weight) was calculated only for 2017 and 2019, because pruning data for 2018 were missing.

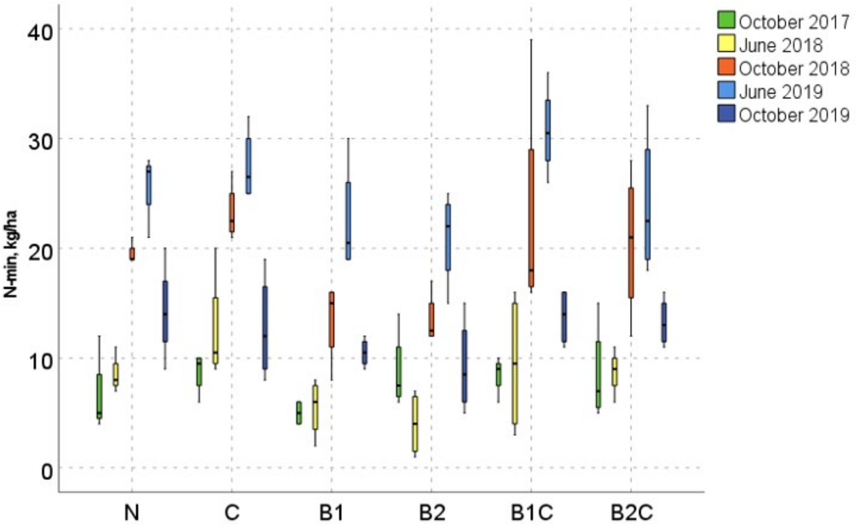

Fig. 4: Mineralized nitrogen content in the soil (0-30 cm): no significant difference between treatments was found.

MICROVINIFICATION

Two replicate samples of approximately 40 kg of grapes were taken at harvest for each treatment and taken to the Laimburg winery for separate vinification following the standard procedure.

The grapes were destemmed separately for each replicate with the destemming machine (CMA Lugana 1R, capacity 4-6 t/hr) and then pressed with a 70-litre pneumatic water-pressure press in two phases (10 min at 1 bar, 20 min at 2 bar). The resulting musts were weighed and transferred into 34-litre glass balloons with the addition of 30 mg/l potassium meta-bisulphite (E 224), then left in static settling overnight at 4 ℃. Thereafter, the lees were removed from the clear supernatant, which was heated up to 22 ℃. Then yeasts (VL2-Laffort, rehydrated S. cerevisiae var. cerevisiae, 20 g/hl) were inoculated; fermentation occurred at room temperature. After two weeks the wine was drawn off upon cessation of fermentation and/or upon attaining a residual sugar content of < 4.0 g/l. The coarse lees were removed during the subsequent racking without aeration, followed by another sulphitation. The wine was then stored in a fridge at a standard temperature of 4 ℃ for 15-20 days in order to favour the tartaric stabilisation of the wine.

WINE ANALYSES

After the tartaric stabilisation of the wines, another draw-off occurred at room temperature. Periodic FT-IR analyses according to RESOLUTION OIV/OENO 390/2010 (measured with FOSS®, WineScan™) were carried out, monitoring total acidity (g/l) as well as malic, tartaric and gluconic acid content, pH, yeast assimilable nitrogen (YAN, mg/l), alcohol content and residual sugar in the wine (g/l). After approx. seven months, once the SO2 content was stable, wines were filtered through a 4-layer cardboard filter, type SSF0, 0.7-0.9 µm from STRASSBURGER Filter GmbH + Co.KG. (Westhofen, Germany) and then through a sterile cartridge filter (Vinosart PS, 45µm from Sartorius Stedim Biotech GmbH, Goettingen, Germany), before being bottled.

Sensory tastings

In the following spring after each harvest, all wines were subjected to a sensory tasting analysis. A panel of 15 experts evaluated the main wine characteristics by blind tasting: intensity, complexity, typicity, body, harmony, state of maturity and overall impression. To check the reliability of judgements, four samples were duplicated to verify the homogeneity of the evaluations of each taster, and therefore the reliability in evaluating and characterizing the wines. Only the results from the tasters who had performed well, being able to judge the same wines in a similar manner, were taken into account for the assessment of the wine quality of every single treatment.

Volatile organic compounds (VOCs) analyses

The same wines used for the tasting were analysed for VOCs. Wines from the first two vintages (2017 and 2018) were analysed with GS-MS using an untargeted approach in a full-scan mode following the Welke method [24] with some modification.

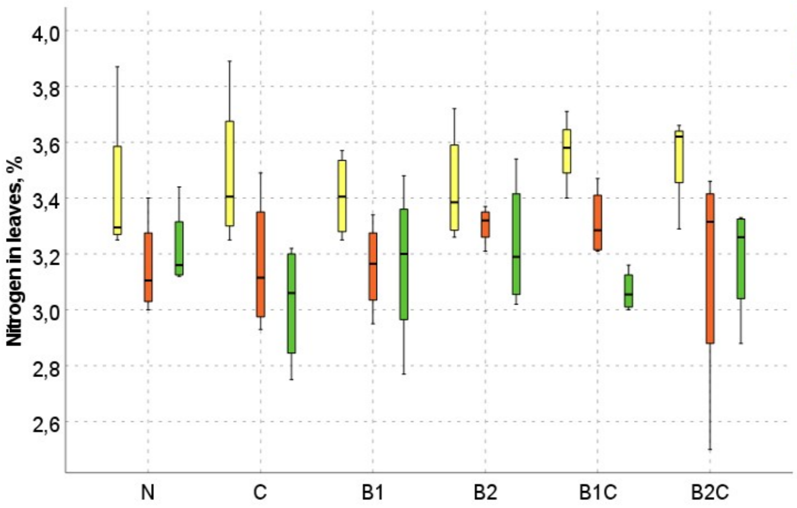

Fig. 5: Nitrogen content in leaves at flowering: no significant difference between treatments was found.

Briefly, 1 ml of wine was transferred into a 20 ml glass vial containing 0.3 g of NaCl; five µl of 2-octanol (123.75 mg/l) were added as an internal standard (IS). All samples were prepared in triplicate and analysed in full scan mode on a GC-MS instrument. A quality control (QC) was created by mixing all samples from each year and injected each 10 samples to monitor the progress and quality of the analysis. Samples were kept at 45 ℃ for 10 min in agitation and compounds in the headspace were absorbed for 45 min at 45 ℃. The headspace was sampled using 2 cm DVB/CAR/PDMS 50/30 m fibre from Supelco (Bellefonte, PA). A GC-MS-QP2010 SE gas chromatograph

mass spectrometer (Shimadzu) was used to separate the compounds with a capillary ZB-WAX column (Phenomenex, 30 m x 0.25 mm i.d. x 0.25 m). The compounds were desorbed in the GC inlet at 250 ℃ for 2 min in splitless mode. The GC oven temperature programme was 35 ℃ (5 min hold) to 250 ℃ (ramp of 3 ℃/min, 5 min hold). Helium was used as the carrier gas with a flow rate of 1 ml/min. The MS detector was operated in full scan mode (mass range 40-510 m/z) and the transfer line to the MS system was maintained at 250 ℃. Peak compound areas were compared with the IS area and expressed as area ratio (cp-area/IS-area). Peaks were integrated using a Shimadzu software programme (Lab Solution Insight): their identification was carried out comparing the spectra with the NIST14 database; retention indices were calculated using a C8-C20 mix alkane injected with the same instrumental conditions.

STATISTICAL ANALYSES

Statistical analyses on field data were conducted using SPSS software: multiple comparisons were performed with ANOVA and Tukey's test for post-hoc analysis.

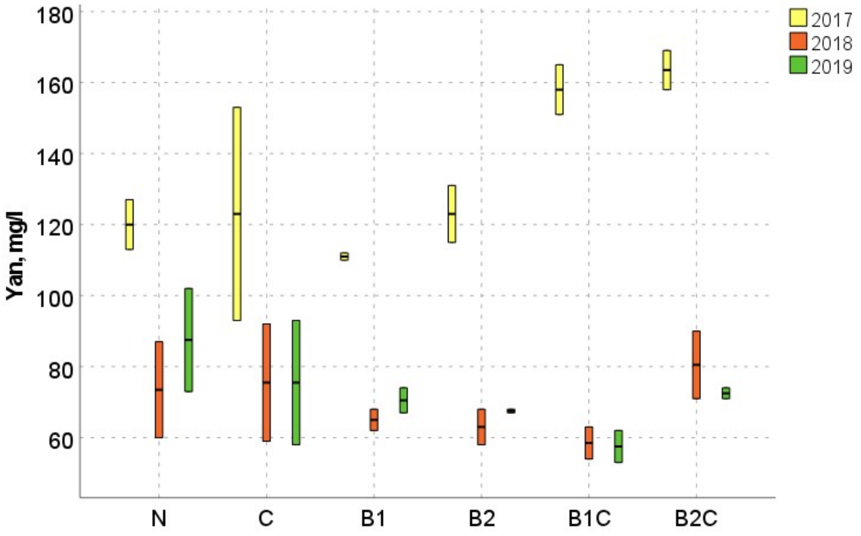

Fig. 6: Yeast Assimilable Nitrogen (YAN) content in musts. No significant difference between treatments was found.

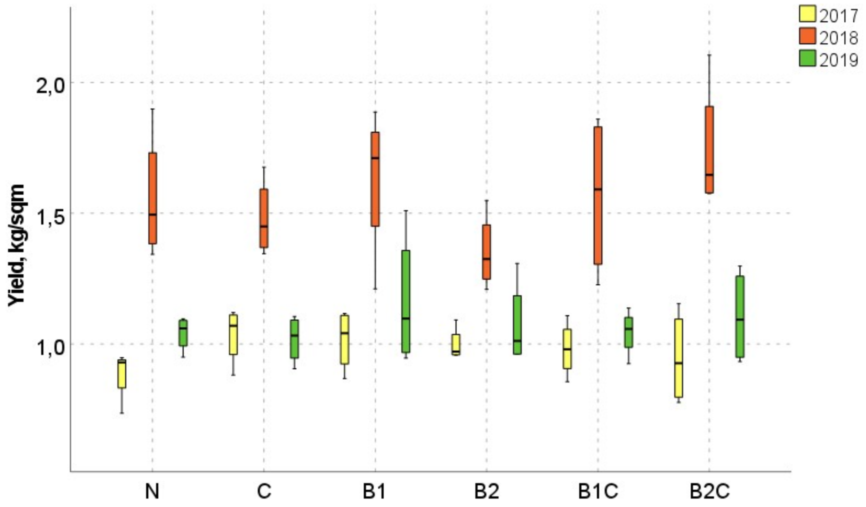

Fig. 7: Grape yield at harvest. No significant difference between treatments was found.

To explore the VOC results, a principal component analysis (PCA) was performed [25]. Prior to performing the PCA, all parameters were normalised to 0 mean and standard deviation of 1. The PCA was performed using R software [26] with packages lattice [27] and ggplot2 [28] for the visualisation.

RESULTS

WEATHER CONDITIONS

Climatic conditions during the whole study, in terms of both temperature and rainfall, showed no extreme values: in all three years there was no severe drought period, therefore it was not necessary to irrigate the field. On average, August and November were the wettest months of the years, and 2019 was the year with most total rainfall (1070 mm). On average, January and February were the driest months, while 2018 was the year with the least precipitation (849 mm). Data are shown in Table 3).

SOIL AND LEAF ANALYSES

Data showing the differences in organic carbon and N-min content of the soil between treatments are reported for each year in Figure 3 and Figure 4. Treatments with biochar showed significantly higher

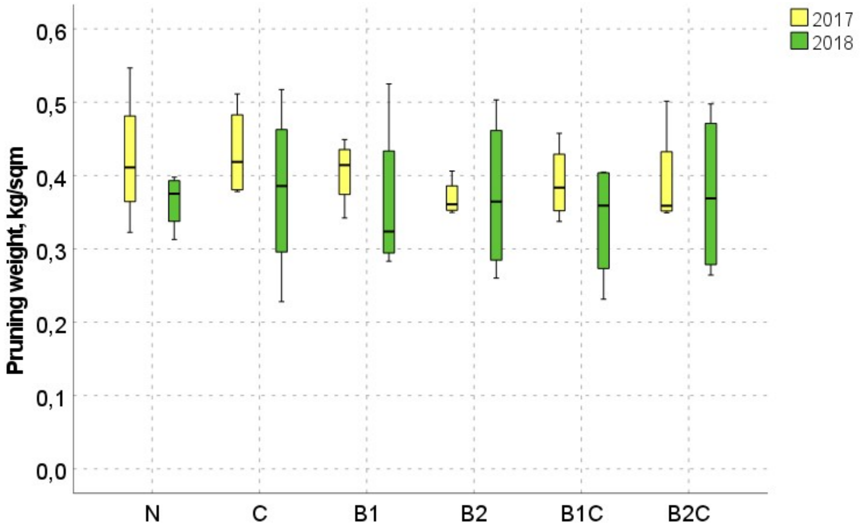

Fig. 8: Pruning weight of the one year old canes removed during winter pruning. No significant difference between treatments was found.

organic carbon content, especially at the higher biochar application rate. N-min values, in contrast, remained generally low throughout the trial and showed no differences between the treatments. The average amount of N was only considerably higher immediately after the incorporation of the soil amendments, due to tillage before and during the incorporation of amendments, which delivered some nitrogen (data not shown). In Figure 4 a slight tendency to lower N-min values in the biochar treatments can in part be seen, probably because of the very high C:N ratio of the biochar and the known effect of pure biochar to fix elements.

No significant differences between the treatments were found in the nitrogen content of the leaves (Figure 5), but values suggest that availability was generally adequate. Nitrogen contents were regularly higher at flowering than at veraison; this corresponds to the general natural development.

MUST ANALYSES

Must analyses conducted during pre-fermentation on total sugars, acidity and pH did not show any difference between treatments in any vintage (Tab. 4). As there were no differences in soil and leaf nitrogen content, it is not surprising that the must's YAN (yeast assimilable nitrogen) values also showed no variation between treatments. In general, YAN values were at their highest in 2017, while in 2018 and 2019 they were under the threshold of an adequate provision for white wine vinification (Fig. 6).

PRODUCTIVITY AND GROWTH

There were no significant differences in the yield of single treatments in all three years (Fig. 7), but there were differnces in the yield among years. In 2017, light frost damage in April slightly reduced the number of shoots. 2018 in South Tyrol was generally a year with high production, so the yield was higher than expected also in this experiment. The desired yield of approx. 1 kg grapes per square metre was achieved in 2019.

No significant differences between treatments were found in pruning weight (Fig. 8) or in the Ravaz Index.

Sensory analyses

After about six months of aging, the wines were considered ready for tasting. In all three vintages no significant differences in wine quality were found between treatments (Fig. 9). It was noticeable, however, that in 2017 the wines from the untreated plots (N) were slightly preferred, especially in terms of complexity, body and overall impression. The 2018 wines derived from biochar treatments at lower dosage were slightly preferred, while the 2019 wines from the char and compost treatments gave a marginally more typical and overall better impression, although they were not significantly different. It should be noted that no clear preference was expressed for one of the treatments in all the years of vinification, and if we consider individual years, the wines from different treatments were slightly preferred in each case. In other words, there was no consistent trend over the years.

Wines aromatic profile

The analyses of organoleptic properties carried out using the HS-SPME-GC-MS method resulted in the identification of 28 different volatile organic compounds (VOCs), as shown in Table 5). Among the identified compounds, acids, esters, alcohols and some terpenes were found. To visualise the datasets, a principal component analysis (PCA) was performed for each of the two years (2017 and 2018) with a biplot visualisation (Figure 10 and Figure 11). Both figures report the first and second component, which explains 59.6% and 59.23% of the total variance in 2017 and 2018, respectively. Looking at the two PCAs, there is no clear difference between treatments. Volatile organic compounds are reported in the plots, with the arrow pointing to the longest length signifying a greater influence of this compound for the samples projected in the same direction.

DISCUSSION

According to current knowledge, water supply and nitrogen availability are the most potent factors affecting vine growth and fruit composition. Most of the differences in grape composition and perceived wine quality may be attributable to differences in soil moisture [29] [30]. Nitrogen supply, if abundant, promotes vegetative growth, which may be associated with reduced sugar and polyphenol accumulation, whereas moderate nitrogen availability is thought to maximise the fla-

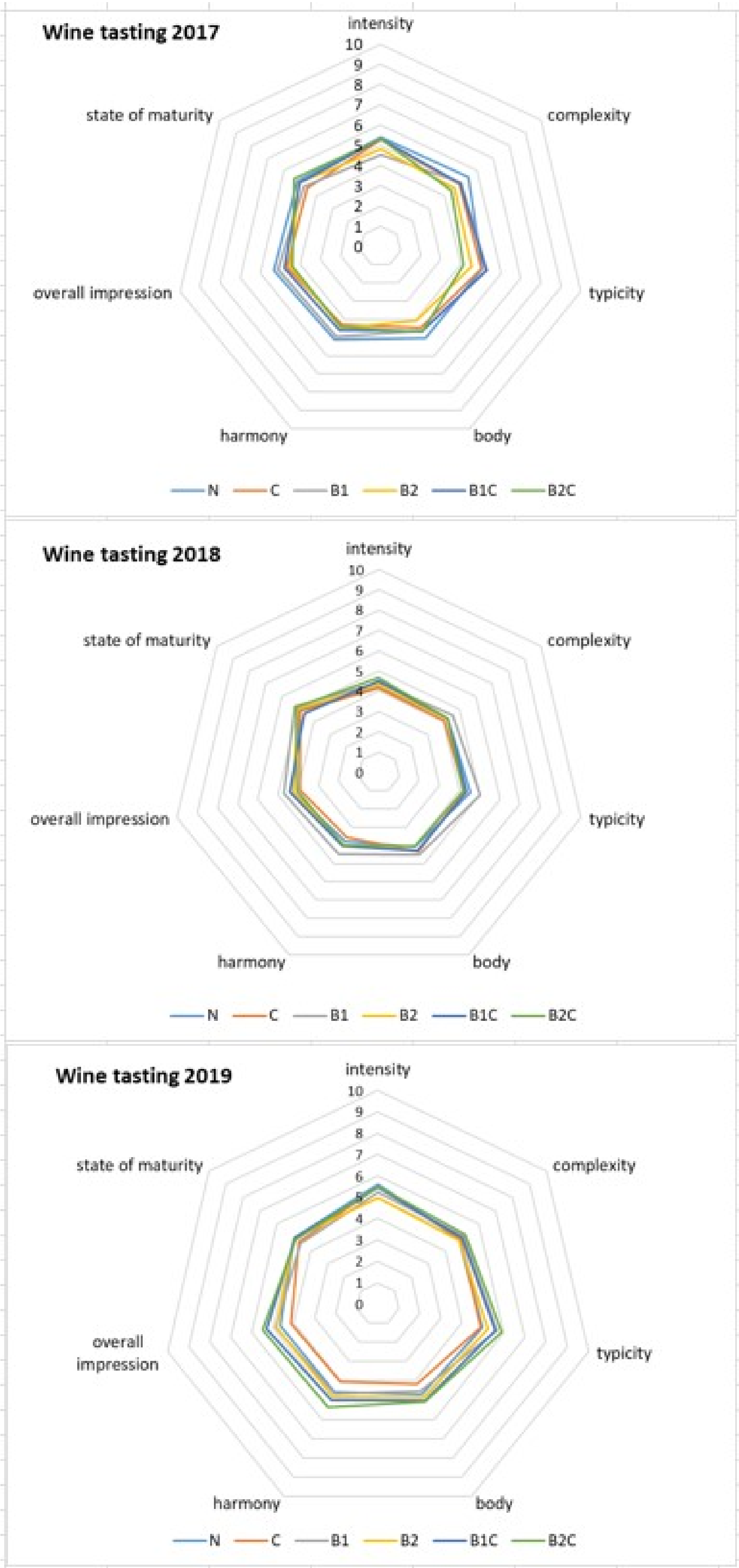

Fig. 9: Sensorial evaluation of 2017, 2018 and 2019 wines.N = untreated control; C = compost 3.9 kg/m2; B1 = biochar 2.5kg/m2; B2 = biochar 5 kg/m2; B1C = B1 + compost; B2C = B2 + compost.

vour and aroma potential of white grapes [31] [32]. Biochar as a soil amendment has an impact on the availability of water and nutrients to grapevines and could therefore potentially alter the quality of the wine. In this experiment, under conditions of sufficient water supply, it became evident that, in soils with rather limited nitrogen availability, the use of pure biochar or biochar and compost with a moderate nitrogen content, does not influence nitrogen availability for the grapevines, nor influence their vegetative growth, productivity or the quality of grapes and wines. The results also confirm what was found by Ye et al. [33] who reported as a result of their meta-analysis, that the addition of biochar only does not lead to a significant increase in yield, unless enriched with nitrogen. Rather, biochar has a “sponge effect” that allows water and nitrogen to accumulate but does not significantly affect vegetative growth and crop yield by itself. In our field trial no fertilisation with nitrogen was undertaken, since the vegetative growth, productivity and quality of grapes and wines were satisfactory. Also, the nitrogen content of the leaves revealed an adequate supply of nitrogen to the vines. However, the available nitrogen level in the soil (N-min) was rather low in the control and remained similarly low in all the amended plots. The biochar used in the experiment was wood derived, with moderate nitrogen content and a very high C:N ratio of 145.

At this level, the nitrogen availability is strongly reduced and so it is not surprising that neither vegetative growth nor yield were significantly affected. This means that in vineyards where there is no need to increase growth and productivity, biochar can be safely provided, but additional nitrogen fertilisation should be handled carefully. Conversely, the results achieved indicate that a supply of pure biochar is

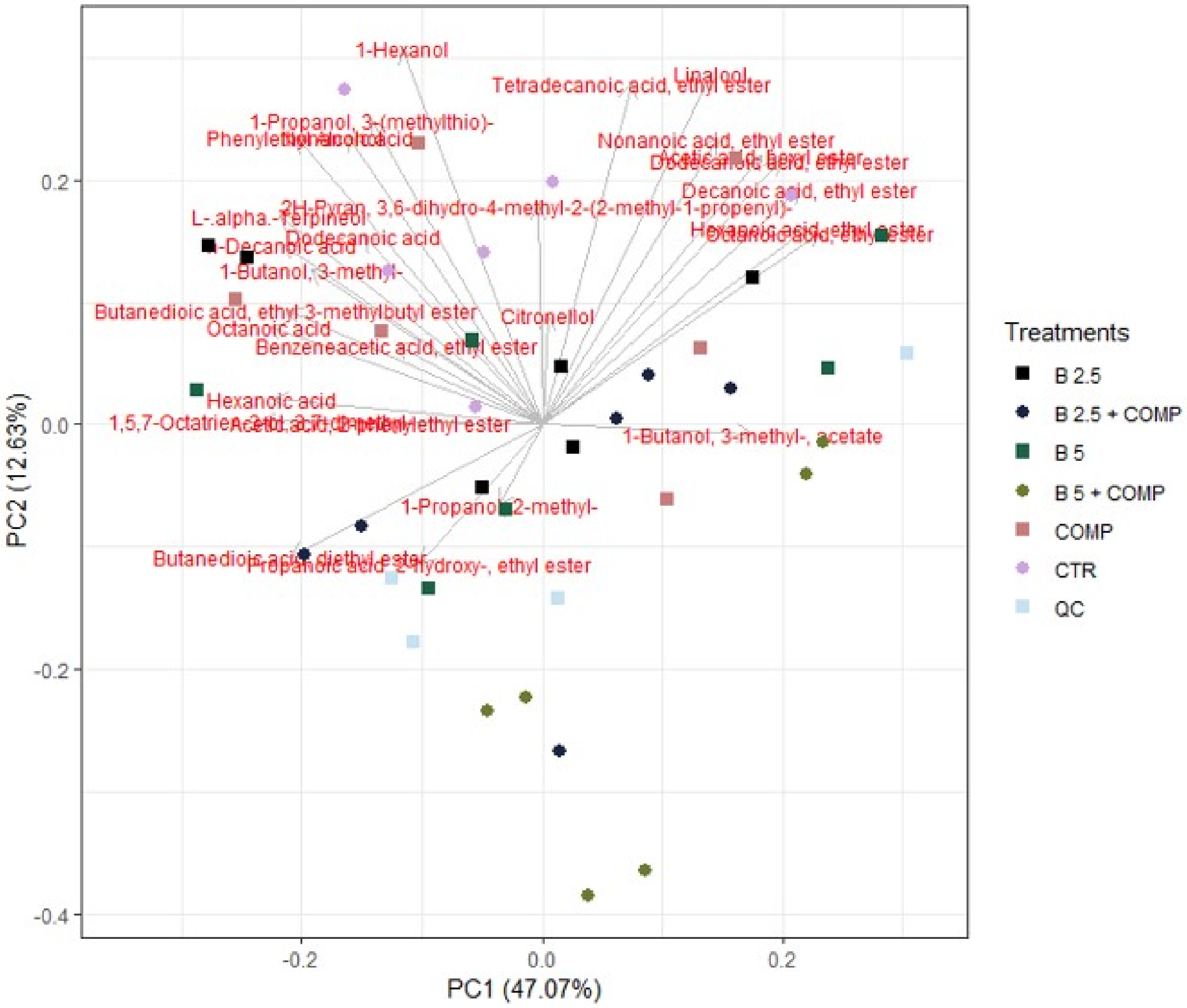

Fig. 10: Principal Component Analysis of 2017 wine samples.Legend of treatments: B 2.5 = biochar 2.5 kg/m2; B 2.5 + COMP = biochar 2.5 kg/m2 + compost; B 5 = biochar 5 k g/m2; B 5 + COMP = biochar 5 kg/m2 + compost; COMP = compost 3.9 kg/m2; CTR = control; QC = quality control.

not sufficient where there is a need to increase vegetative growth and yields, in which case it must be enriched with additional nitrogen.

The obtained results also show that the amount of nitrogen in the leaves did not increase in biochar-amended plots, nor in the respective musts. In fact, there was no difference in YAN content between biochar-amended and the control plots, contrary to what was observed in experiments in Germany [21]. In this experiment, the analysis of berries and musts did not show significant variations between treatments during the ripening phase. The total acidity, pH, total soluble solids and yeast assimilable nitrogen content of the different treatments remained almost unaltered; in contrast, the YAN and total acidity values were more variable in the single years of the study, with the YAN values being clearly higher during the first year. This is probably due to a generally higher N min content in the soil following the tillage that took place before and during to the incorporation of the amendments.

Sensory evaluation of the resulting wines did not reveal any significant difference between treatments. However, in 2017 the control wines were slightly more appreciated than the others; in 2018 this occurred with the B1 treatment, and in 2019 with the biochar and compost treatments. So, there was no perceptible consistent trend in the results of the wine assessment from the three vinification years.

The aroma profiles of the two years' wines did not show a clustering based on the biochar treatment as shown in the PCAs. The biplot shows the projection of the identified compounds influencing the first and second component but none of these are responsible for a clear differentiation of the wine aromas due to the application of biochar as a soil amendment.

The applied biochar had a high pH value and high contents of some mineral elements, such as calcium, potassium and magnesium. Their long-term effects on soil pH, nutrient provision to the vines and on

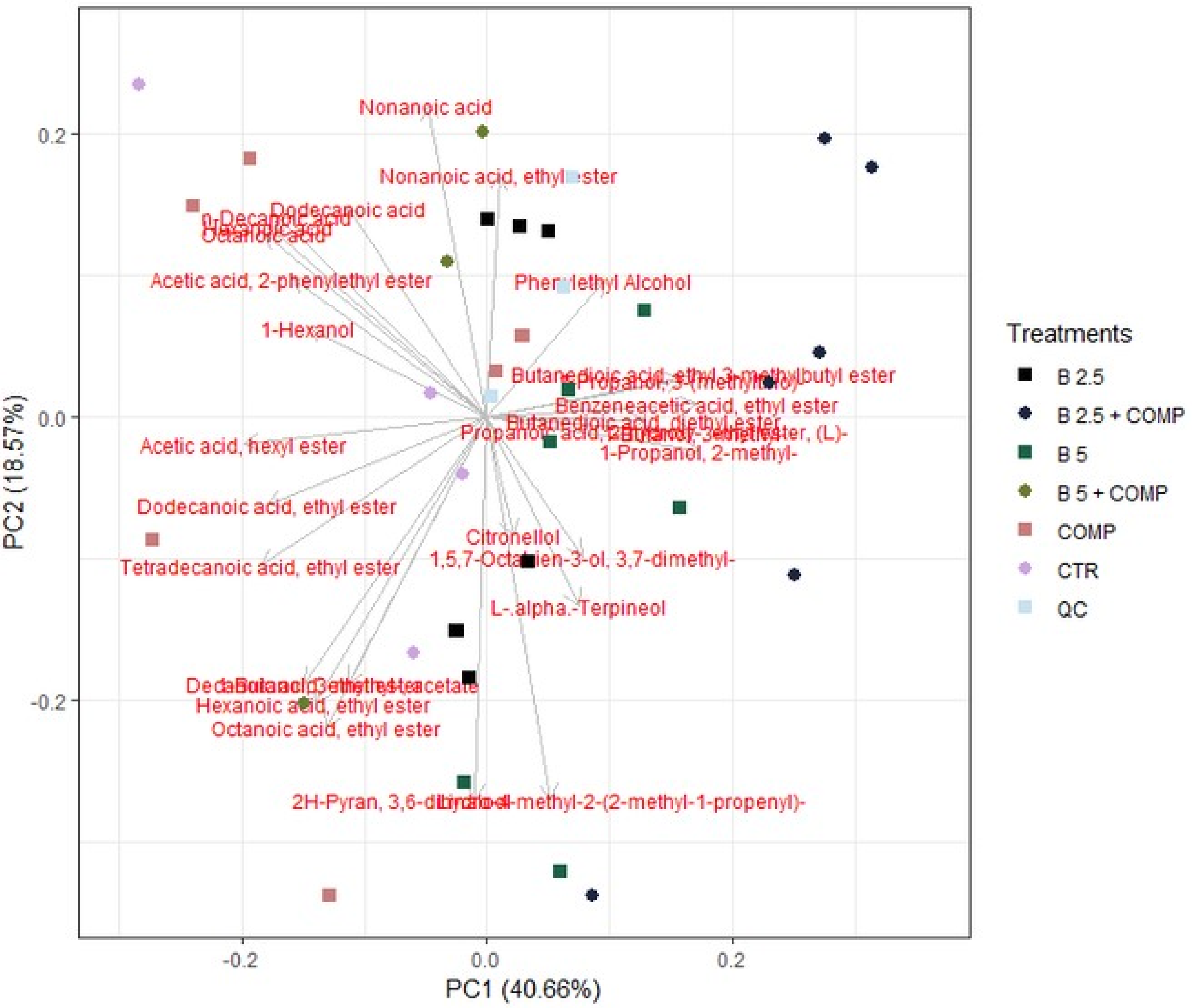

Fig. 11: Principal Component Analysis of 2018 wine samples.Legend of treatments: B 2.5 = biochar 2.5 kg/m2; B 2.5 + COMP = biochar 2.5 kg/m2 + compost; B 5 = biochar 5 k g/m2; B 5 + COMP = biochar 5 kg/m2 + compost; COMP = compost 3.9 kg/m2; CTR = control; QC = quality control.

must composition will be shown and discussed in a separate pubblication. The results obtained suggest that in viticulture both the use of pure biochar and a moderately compost-enriched biochar can be recommended: neither altered vegetative growth or the productivity of the vines, nor did they influence the quality of the wines. These results are probably due to a rather low availability of nitrogen in the soil in the experimental vineyard. It is possible that with greater N-availability the outcomes may be different.

CONCLUSIONS

The most important aspect of the use of biochar in this *Müller Thurgau* experimental vineyard is the almost complete lack of difference in the final product. The wines resulting from this experiment did not show significant variations, neither from the chemical point of view, including the volatile organic compounds, nor in terms of sensory aspects at the tastings.

These results were obtained under conditions of limited nitrogen availability in the soil. The N-min values of the different treatments showed no significant differences and were stable at a rather low level. The limited amount of nitrogen added with the biochar or biochar + compost treatments did not alter the nitrogen availability in the soil. It is possible that with higher nitrogen additions the results may be different.

In conclusion, the results obtained suggest that biochar per se can be used in viticulture without fear of undesirable side effects on wine taste and quality.

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ZUSAMMENFASSUNG

Reine Biokohle oder auch mäßig mit Kompost angereicherte Biokohle als Bodenzusatz veränderte weder die Stickstoffverfügbarkeit im Boden dauerhaft, noch das vegetative Wachstum oder die Produktivität der Reben. Daher kann die Verwendung von Biokohle im Weinbau empfohlen werden, um den pH-Wert des Bodens zu korrigieren, seine Wasseraufnahme und -speicherung zu erhöhen und langfristig Kohlenstoff zu binden, ohne dass sich dies nachteilig auf das Wachstum oder die Produktivität auswirkt und die Qualität des entstehenden Weins somit erhalten bleibt.

RIASSUNTO

Il biochar puro o anche moderatamente arricchito con compost come ammendante non ha modificato in modo permanente la disponibilità di azoto nel suolo, né ha alterato la crescita vegetativa o la produttività delle viti. Pertanto, l'uso del biochar in viticoltura può essere raccomandato per correggere il pH del suolo, aumentarne l'assorbimento e la ritenzione idrica e per il sequestro di carbonio a lungo termine, senza effetti deleteri sulla crescita o sulla produttività, mantenendo così la qualità del vino ottenuto.

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ANHANG: TABELLEN

Tab. 1: Main characteristics of the applied biochar.

	Extraction	Value	Unit	Method
pH	in $CaCl_2$	09. Jun		DIN EN 15933:2012
N		0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with elemental analyser
NO_3-N	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with AutoAnalyser
NH_4-N	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with AutoAnalyser
P_2O_5	in acids	0.3	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
P_2O_5	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
K_2O	in acids	03. Mai	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
K_2O	in water	03. Mai	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
CaO	in acids	04. Feb	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
CaO	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
MgO	in acids	0.8	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
MgO	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
B	in acids	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
B	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Fe	in acids	0.06	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Fe	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Mn	in acids	0.04	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Mn	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Cu	in acids	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Cu	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Zn	in acids	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Zn	in water	< 0.1	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Na_2O	in acids	0.12	% m/m	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Na_2O	in water	0.12	< 0.1	Reg. CEE n. 2003 del 13.10.2003, determination with ICP-OES
Fe	in aqua regia	0.63	g/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
Al	in aqua regia	0.54	g/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
Mn	in aqua regia	358.34	mg/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
Cu	in aqua regia	19.38	mg/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
Zn	in aqua regia	68.58	mg/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
Cr	in aqua regia	Jun 57	mg/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
Ni	in aqua regia	06. Dez	mg/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
Pb	in aqua regia	Mai 65	mg/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
Co	in aqua regia	0.75	mg/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
Hg	in aqua regia	0.029	mg/kg FM	EPA 7473:2007
Cd	in aqua regia	1.112	mg/kg FM	Mineralization in microwave with aqua regia, determination with ICP-OES
As	in aqua regia	< 0.1	mg/kg FM	Mineralization in microwave with aqua regia, determination with ICP-MS
Dry matter		33.4	%	VDLUFA Methodenbuch I A 2.1.1
Humidity		66.6	%	VDLUFA Methodenbuch I A 2.1.1
Ashes		13.4	% FM	VDLUFA Methodenbuch I A 15.2
Organic matter		20	% FM	VDLUFA Methodenbuch I A 2.1.1
Salts (KCl)	in water	3106	mg/100g	VDLUFA Methodenbuch I A 10.1.1
C:N ratio	calculated	145		

Tab. 2: Main characteristics of the applied compost.

	Value	Unit	Method
pH	8.2		DIN-EN 15933:2012 in $CaCl_2$
Dry matter	78.9	%	VDLUFA Methodenbuch A 2.1.1
Humidity	21.1	%	VDLUFA Methodenbuch A 2.1.1
Humidity	936	g/l	VDLUFA Methodenbuch A 13.2.
Salts (KCl)	5	g/l	VDLUFA Methodenbuch A 13.4.1
N	297.5	mg/l	VDLUFA Methodenbuch A 13.1.1
NO_3-N	94.4	mg/l	VDLUFA Methodenbuch A 13.1.1
NH_4-N	203.1	mg/l	VDLUFA Methodenbuch A 13.1.1
P_2O_5	139	mg/l	VDLUFA Methodenbuch A 13.1.1
K_2O	3764	mg/l	VDLUFA Methodenbuch A 13.1.1
Mg	394	mg/l	VDLUFA Methodenbuch A 13.1.1
Na	190	mg/l	VDLUFA Methodenbuch A 13.1.1
B	3.01	mg/l	VDLUFA Methodenbuch A 13.1.1
Fe	150	mg/l	VDLUFA Methodenbuch A 13.1.1
Mn	44.7	mg/l	VDLUFA Methodenbuch A 13.1.1
Cu	7.5	mg/l	VDLUFA Methodenbuch A 13.1.1
Zn	17.5	mg/l	VDLUFA Methodenbuch A 13.1.1
Ashes	62.5	% FM	VDLUFA Methodenbuch A 15.2
Organic matter	16.5	% FM	Calculation
N	0.7	% FM	DIN-EN-ISO 16634-1:2009 (Dumas)
Fe	22.9	g/kg DM	Mineralization in microwave, determination with ICP-OES
Al	15.4	g/kg DM	Mineralization in microwave, determination with ICP-OES
Mn	448	mg/kg DM	Mineralization in microwave, determination with ICP-OES
Cu	67	mg/kg DM	Mineralization in microwave, determination with ICP-OES
Zn	146	mg/kg DM	Mineralization in microwave, determination with ICP-OES
Cr	54	mg/kg DM	Mineralization in microwave, determination with ICP-OES
Ni	28	mg/kg DM	Mineralization in microwave, determination with ICP-OES
Pb	19	mg/kg DM	Mineralization in microwave, determination with ICP-OES
Co	9.3	mg/kg DM	Mineralization in microwave, determination with ICP-OES
Hg	0.046	mg/kg DM	Mineralization in microwave, determination with ICP-OES
Cd	0.34	mg/kg DM	Mineralization in microwave, determination with ICP-OES
C:N ratio	13.0		

Tab. 3: Monthly rainfall (mm) at the Fragsburg climate station (700 m a.s.l.).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2017	0.2	45.6	24.0	48.2	51.0	147.0	85.8	203.8	107.2	19.6	63.8	82.4
2018	58.0	6.4	85.2	61.8	85.0	60.4	81.6	175.4	35.4	125.0	57.8	16.6
2019	11.6	33.2	32.0	128.0	126.6	43.4	88.2	67.2	86.4	71.4	303.8	78.0

Tab. 4: Principal characteristics of musts at harvest of the years 2017, 2018 and 2019 (means ± standard error).

Treatment	TSS - °Babo		
	2017	2018	2019
N	16.30 ± 0.07	16.76 ± 0.50	16.81 ± 0.09
C	16.14 ± 0.09	16.66 ± 0.10	16.76 ± 0.19
B1	16.05 ± 0.21	17.10 ± 0.09	16.49 ± 0.07
B2	16.07 ± 0.12	17.01 ± 0.38	16.46 ± 0.12
B1C	16.43 ± 0.07	16.27 ± 0.10	16.44 ± 0.37
B2C	16.32 ± 0.03	15.98 ± 0.04	16.35 ± 0.08

Treatment	pH		
	2017	2018	2019
N	3.32 ± 0.00	3.31 ± 0.01	3.33 ± 0.03
C	3.30 ± 0.02	3.30 ± 0.01	3.32 ± 0.01
B1	3.30 ± 0.01	3.33 ± 0.01	3.32 ± 0.01
B2	3.30 ± 0.00	3.35 ± 0.03	3.34 ± 0.01
B1C	3.36 ± 0.03	3.29 ± 0.00	3.33 ± 0.00
B2C	3.36 ± 0.02	3.31 ± 0.02	3.35 ± 0.01

Total acidity (g/l)			
	2017	2018	2019
	5.67 ± 0.05	4.68 ± 0.05	6.07 ± 0.14
	5.97 ± 0.13	4.73 ± 0.08	6.21 ± 0.19
	5.98 ± 0.05	4.50 ± 0.03	6.00 ± 0.01
	6.16 ± 0.01	4.48 ± 0.01	6.11 ± 0.08
	6.20 ± 0.19	4.68 ± 0.11	5.71 ± 0.30
	6.38 ± 0.21	4.88 ± 0.06	5.78 ± 0.13

Tab. 5: List of the volatile organic compounds (VOCs) identified in the wine samples.

1-Propanol, 2-methyl-	L-.alpha.-Terpineol
1-Butanol, 3-methyl-, acetate	1-Propanol, 3-(methylthio)-
1-Butanol, 3-methyl-	Citronellol
Hexanoic acid, ethyl ester	Benzeneacetic acid, ethyl ester
Acetic acid, hexyl ester	Acetic acid, 2-phenylethyl ester
Propanoic acid, 2-hydroxy-, ethyl ester	Dodecanoic acid, ethyl ester
1-Hexanol	Hexanoic acid
Octanoic acid, ethyl ester	Butanedioic acid, ethyl 3-methylbutyl ester
2H-Pyran, 3,6-dihydro-4-methyl-2-(2-methyl-1-propenyl)-	Phenylethyl Alcohol
Nonanoic acid, ethyl ester	Tetradecanoic acid, ethyl ester
Linalool	Octanoic acid
1,5,7-Octatrien-3-ol, 3,7-dimethyl-	Nonanoic acid
Decanoic acid, ethyl ester	n-Decanoic acid
Butanedioic acid, diethyl ester	Dodecanoic acid