EXTENDED ABSTRACT

Closing the carbon loop: evaluating the potential of grapevine-derived biochar as a soil conditioner in warm climate vineyards

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INTRODUCTION

Significant increases in anthropogenic carbon dioxide (CO_2) emissions due to combustion of fossil fuels and intensive land management practices that release CO_2 into the atmosphere have resulted in higher air temperatures due to the greenhouse effect. Agriculture offers tremendous potential to mitigate the negative impacts of climate change and global warming due to the CO_2 sequestering ability of crops via photosynthesis, which ultimately build soil organic carbon (SOC) through root sequestration of carbon and decomposition of plant litter (Woolf et al. 2007). Another avenue to increase SOC is through the conversion of plant biomass, particularly woody biomass, into a recalcitrant carbon product known as biological charcoal (aka "biochar"). This conversion is typically done through pyrolysis, an anaerobic combustion, of lignocellulosic feedstock(s). Sequestering biochar into the soil can result in a negative carbon balance and reduce CO_2 emissions by 12-84 % compared to using it as a fuel source (Lehmann 2007). As the wine industry seeks to meet their environmental, social and governance (ESG) targets, the use of biochar in vineyards as a carbon insetting tool could be a powerful tool in the viticulturist's toolkit, particularly with the potential benefits offered by biochar for vineyards.

Several studies have reported on the use of biochar in vineyards located primarily in Europe, but also, to a lesser extent, in USA. In an early trial of biochar conducted in a Valais, Switzerland Pinot noir vineyard, top-soil application of biochar at 8 t ha^{-1}, with and without compost, impacted neither grapevine vegetative and reproductive performance nor fruit composition (Schmidt et al. 2014). Similarly, a long term (4-year) study in Italy found no impact of biochar on grape composition, however, there was a significant and consistent increase in yield, by as much as 66%, compared to controls (Genesio et al. 2015). Biochars made with vineyard prunings as feedstock, as done in the current trial, had a positive impact on several soil physical parameters including bulk density (decreased), aggregate stability (increased), and plant available water (PAW; increased, but only at high soil matric potentials > -30 kPa) (Burrell et al. 2016). Oddly, the same study evaluated biochars made at two pyrolysis temperatures – 400 °C and 525 °C – and did not find differences in any of the aforementioned soil parameters despite the 525 °C biochar having higher porosity. Nevertheless, the study highlights the potential of using biochar to increase soil moisture retention, which would be advantageous in low rainfall seasons. Due to its highly porous structure, biochar could also provide habitats and niches for soil microorganisms including bacteria, fungi and Archaea (Li et al. 2018). The effect of biochar on soil microbial processes have not been reported in vineyards; in other cropping systems, addition of biochar to soil increased microbial abundance, which was favoured by less lignocellulosic feedstocks (Gul et al. 2015).

RESEARCH OBJECTIVES

In an attempt to address several gaps in the abovementioned studies and specifically those related to viticulture, we established a biochar and compost trial in a new Cabernet sauvignon vineyard prior to planting the vines. The specific aims of the trial in relation to soil biochar and compost applications were to: (i) understand changes to soil physical and chemical properties, seasonal soil moisture patterns and moisture infiltration; (ii) determine changes to soil microbiome, particularly fungal and bacterial diversity; and, (iii) assess changes in vegetation patterns in the vineyard. This was the first systematic study of the use of biochar in Australian vineyards.

MATERIAL AND METHODS

Vineyard site

The field site for this trial was located at Temple Bruer Wines, Angas Plains, SA (-35.34 °S, 138.98 °E). Soils were derived from alluvial parent material, predominantly deep loams and are well-drained. Seasonal supplemental irrigation was approx. 1.5 ML ha^{-1}. Integrated pest management was done as per organic production guidelines.

Biochar and compost synthesis

Biochar was made on-site using an open kiln reactor (capacity: 1.58 m^3). The feedstock was a combination of grapevines (woody, dry), tree branches, and wood staves. Pyrolysis was conducted by maintaining a constant supply of feedstock into the kiln with a flame on the surface of the feedstock to reduce the oxygen concentration. The pyrolysis temperature in the centre of the kiln within the feedstock was approx. 650 °C. Compost was also made on-site using a combination of grape marc, chicken manure, wood chips, and *Arundo donax*.

Experimental design and treatments

In December 2019, the vineyard was trenched down to 60 cm with approx. 50 cm wide trenches. Soil amendments, including biochar and compost, were added at this depth and the trenches refilled with native soil before planting the vines in January 2020. The young vines were pruned to two canes with ~12 nodes/m and trained to a sprawling system.

The experimental design was a randomised complete block with two (north-south) blocks consisting of seven treatments each. Each treatment was implemented within two panels of four vines each for a total of eight vines per treatment per block. The treatments were: (T1) Control; (T2) Compost and manure applied at 10% (w/v); (T3) 3% (w/v) biochar + compost; (T4) 5% biochar + compost; (T5) 10% biochar + compost; (T6) 20% biochar + compost; and (T7) 20% biochar without compost. In each biochar treatment except T7, compost was added to maintain a constant carbon:nitrogen (C/N) ratio to match the C/N of the native soil.

Soil measurements

Soil cores to 1 m depth were obtained in September 2021. Soil structure and compaction was assessed by measuring the resistance to penetration using a penetrometer (Model CP40II, Rimik, Towoomba, QLD) to a depth of 750 mm. Soil chemical analyses for 0-10 cm horizon was done by the Australian Precision Agricultural Laboratory (Hindmarsh, SA). Soil volumetric water content (VWC, %) was measured continuously (every hour) using multi-depth capacitance-based soil moisture sensors (EnviroPro, MEA, Magill, SA). Soil moisture infiltration rate was determined using hard alloy aluminium infiltrometer rings (height: 100 mm; diameter: 320 mm) driven into the ground 5-10 cm.

Soil microbiome was evaluated using next-generation sequencing on soil samples taken from the surface (0-10 cm) and biochar layers (~60 cm). The PowerSoil DNA Isolation Kit (MoBio Laboratories, Solana Beach, CA, USA) was used to extract DNA from 0.25 g of soil. Ribosomal RNA was amplified using one of two primer sets for bacterial or fungal community analysis: 27F-519R (16S, bacterial), and ITS1F-ITS2 (internal transcribed spacer, fungi). Soil samples were sequenced on an Illumina MiSeq platform. The bioinformatics analysis was conducted using Qiime2-2022.2, and involved demultiplexing, quality control, Amplicon Sequence Variant (ASV) calling, and taxonomic classification. Microbial diversity was determined using Qiime2. The DADA2 pipeline was used for both 16S and ITS data. Base pair reads were truncated (or trimmed) during denoising to 270. Quality filtering based on Phred scores (median of 35 for both amplicons) and the removal of chimeric sequences were also conducted during denoising with DADA2.

Statistical analysis

Statistical analysis was done using Graphpad Prism software. Means comparisons were done using either one-way or two-way ANOVA, with postdoc Tukey's HSD test used as needed. Differences were assessed based on an error rate of 5% ($P < 0.05$).

For the microbiome analysis, comparisons between treatments was conducted using R (version 4.2.0) in R-Studio (2022.02.02). Prior to significance testing, each treatment variable was tested for normality and homoscedasticity using the Wilkes-Shapiro test. A linear mixed model was fitted using the R package ASReml-R. All statistical analyses were conducted using R open source statistical software (version 4.2.0 in R-Studio version 2022.02.2) with additional agricultural data packages; "Biometrytraining" (Nielsen et al., 2020), "dplyr", "agricolae" and "ggplot2".

RESULTS

Soil physical and chemical properties

High penetration resistance, or more compacted soil, was observed in the upper horizons, which decreased with increasing soil depth. At the biochar layer, ca. 600 mm, the 10% and 20% biochar groups had some of the lowest penetration resistances, < 1.5 MPa (or 1500 kPa), while the lower biochar treatments, e.g. 3% and 5%, had higher values of around 3-4 MPa (data not shown). The Control group had values as high as 6 MPa at the same depth (600 mm) as did the groups with high levels of compost, both with and without (20%) biochar. The lower penetration resistance values in the high biochar treatment soils suggest that the soils were not compacted in this (lower) horizon. The higher penetration resistance of the other groups in this horizon suggests a degree of compaction, which can inhibit root growth and consequently soil absorption of nutrients and water and reduce soil aeration.

Soil moisture – seasonal patterns and infiltration

With the application of biochar at 20% (w/v), soil moisture levels peaked at 37% VWC and dropped to 15% VWC in a 24 h period. The slopes of the curves indicated that infiltration rates were somewhat lower and that perhaps there was greater retention of soil moisture at nearly every depth and particularly at 60 cm (green line in Fig. 1a) where the biochar was placed.

Soil moisture infiltration was determined in situ at the surface layer using infiltration rings in July 2022 (mid-winter) when soil moisture levels were relatively high. Infiltration rates increased with biochar amount up to 10% after which it decreased. The highest infiltration rates were measured for the 10% biochar (+ compost) treatment at approx. 4.5 mm s^{-1} compared to Control around 1.2 mm s^{-1} (Fig. 1b). With the highest levels of biochar (20%), regardless of compost, the infiltration rates were lower than with 10% biochar and similar to the 5% biochar levels.

Soil microbiome

Measures of Pielou's evenness and Faith's phylogenetic diversity were used to compare microbiome data. Evenness is a measure of homogeneity of the populations within the sample. More evenness indicates that the populations of different species are relatively similar in abundance (samples that are dominated by few species are less 'even' than samples where all species are present in similar proportions). This is distinct from phylogenetic (alpha) diversity, which is a measure of how many different species are present within a sample. In Fig. 2, when looking at 16S plate, the 20% biochar and compost sample has significantly lower evenness than the control sample in the biochar layer. A similar trend is observed in evenness in ITS at the char layer, as well as for 16S and ITS at the surface layer where the control group had the highest measure of Pielou's evenness than all other samples, though not always significantly so. This is consistent with the theory that in soils of high heterogeneity, microbes will inhabit many niches, and few species will dominate.

CONCLUSION

Results from the trial suggest that biochar, particularly when supplemented with compost, enhances soil physical and biological properties that translate to increased undervine growth via increases in soil moisture retention and infiltration, and greater microbial diversity. The recommendation to growers would be to use biochar, together with compost, at rates of around 10% (w/v) to maintain soil C/N ratios relatively constant and such that the practice is economically viable.

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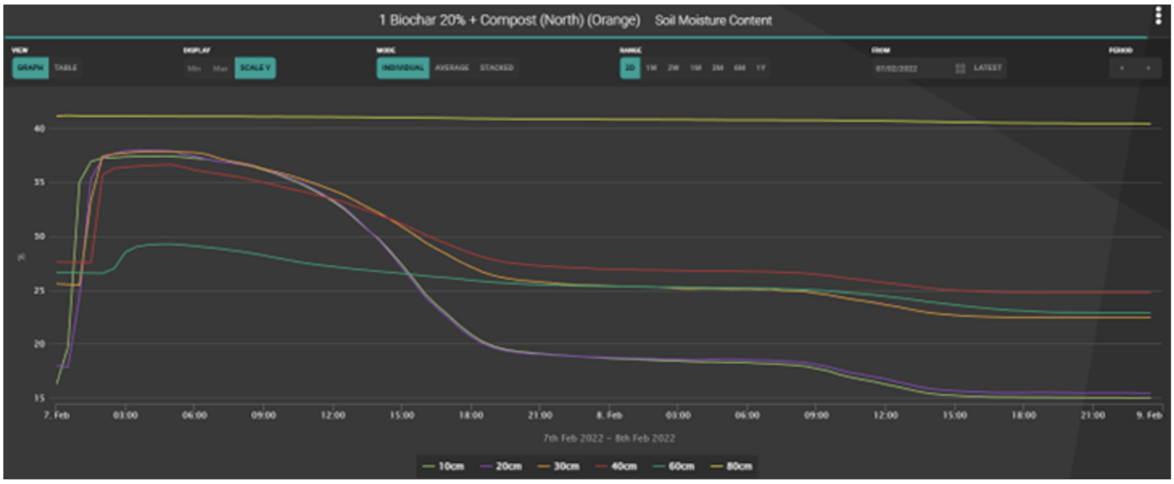
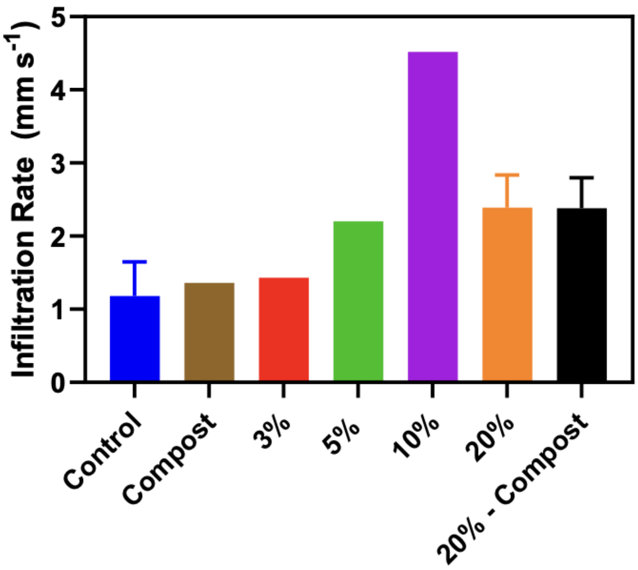
FIGURES



(a)



(b)

Figure 1. (a) Seasonal soil moisture patterns at multiple depths; (b) soil moisture infiltration rate.

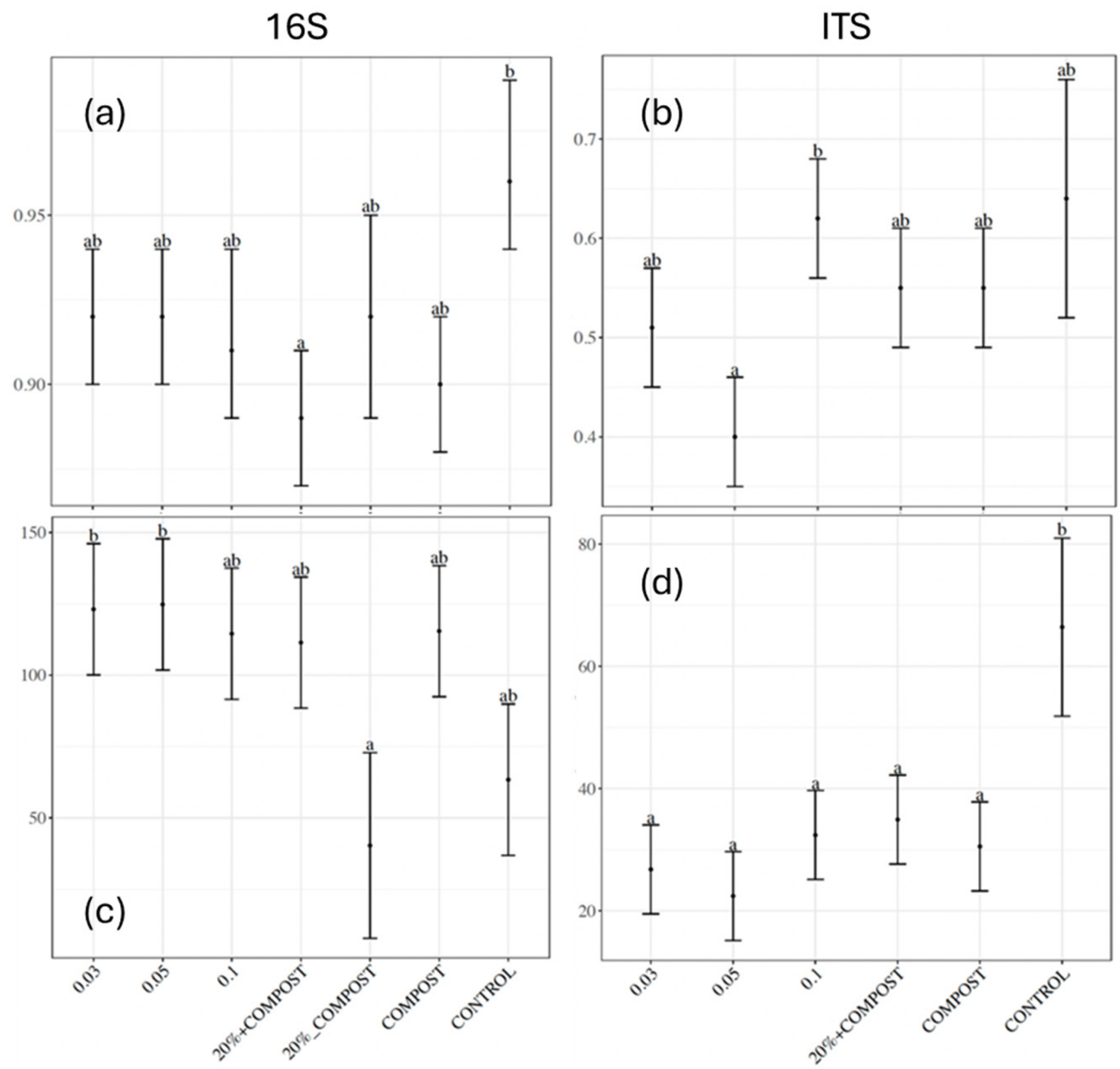


Figure 2. Evenness (a, b) and Faith's phylogenetic diversity (c, d) of 16S (a, c) and ITS (b, d) samples from the surface (0-10 cm). Treatments are 0.03 (3% biochar, balance compost), 0.05 (5% biochar, balance compost), 0.1 (10% compost, balance compost), 20%+COMPOST (20% biochar, balance compost), 20%-COMPOST (20% biochar, NO compost), COMPOST (100% compost), CONTROL (no biochar, no compost).