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Proceeding Paper

Enhancing Vegetative Growth of Quinoa and Soil Properties under Water Shortage through Targeted Organic Amendments †

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Abstract: The scarcity of water resources is considered a major threat and challenge for agriculture. Water limitations could strongly affect the growth and development of many crops including quinoa, a nutrition-rich, climate-resilient crop that is gaining attention globally. Organic amendment application has been reported as a suitable option to mitigate the detrimental impacts of water shortage on soil and plant growth. In this context, two experiments were conducted on *Chenopodium quinoa* "Titicaca"; in the first experiment, we investigated the effect of different organic amendments, namely woodchips biochar (Bw), vineyard pruning biochar (Bv), and vermicompost (V), applied (alone and mixed) at 2% soil dry weight, on soil properties and the plant biomass of quinoa subjected to a water stress period during vegetative development. Among organic amendments tested, Bw and Bw+V increased plant biomass on average by 15%, while Bv and Bv+V reduced the plant biomass by 62% compared to non-amended soil (C). A significant reduction in soil pH was observed with Bw (7.61), while BV increased pH (8.04) compared to C (7.76). The Bw and Bv also reduced soil bulk density (BD) (1.19 g/m^3 and 1.13 g/m^3, respectively) compared to C (1.28 g/m^3). As Bw performed better in the first experiment, the second experiment assessed only Bw at different doses, i.e., 0%, 2%, and 4% under water shortage by restoring only 50% evapotranspiration losses, when soil water content reached the 50% of available water content. Considering the Bw rates, the plants treated with Bw2% showed 34% and 19% more biomass and 36% and 66% more panicles than Bw0% and Bw4%, respectively. The Bw2% decreased the soil pH (7.79 versus 7.85) and electrical conductivity (286 versus 307 µS/cm) compared to Bw0%, which was not different from Bw4%. No differences were observed in BD between Bw0% and Bw2% (on average 1.28 g/m^3), while BD decreased in Bw4% (1.06 g/m^3). The findings of both experiments highlighted that the appropriate type and dose of biochar could improve soil properties and help quinoa plants to grow better under water-limited conditions.

Keywords: *Chenopodium quinoa*; Titicaca genotype; water shortage; organic amendments; biochar rates; vegetative development; soil properties

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1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a resilient seed crop belonging to the Amaranthaceae family; native to the Andean region, nowadays it is cultivated in many parts of the world. Its exceptional nutritional qualities and tolerance against various abiotic stresses are well documented [1,2]. However, wide differences are reported among the germplasm collections of the species currently available [3]. The Danish genotype Titicaca exhibited varying morphological and physiological responses, and notably revealed its sensitivity to drought [4]. As already known, drought significantly affects soil's physico-chemical properties, including soil fertility, soil aeration, decomposition of organic matter, and microbial activity [5]. Therefore, it is necessary to devise alternative methods for soil management that are environmentally friendly and sustainable, such as organic soil amendments (e.g., compost and biochar). Compost contains a large amount of labile organic matter, which stimulates soil biota, promotes plant growth by enhancing microbial activity and many soil properties [6], mitigating the negative consequences of water limitations [5]; the biochar addition improves soil's structure, porosity and water-holding capacity, plant water status, and photosynthetic efficiency [7]; in quinoa, biochar enhances vegetative development when facing early periods of severe water stress [8]. However, biochar's net benefits depend upon the feedstocks, pyrolysis conditions, dose, soil type, and crop [9]. The present study aims to investigate the effects of different organic amendments on selected soil properties and the growth of quinoa plants (Titicaca genotype), followed by testing the best performing amendment at different application doses, when the species is subjected to water limitations.

2. Material and Methods

2.1. Description of Treatments and Experimental Designs

Two experiments were carried out at the University of Basilicata, Potenza (PZ, 40°38′ N–15°48′ E, 819 m a.s.l.) in Southern Italy, during the spring–summer of 2022 on quinoa (*Chenopodium quinoa* Willd.), Titicaca genotype. Sandy loam textured soil (USDA classification) was used in the experiments. The biochar from woodchips (Bw) was purchased from Nera Biochar Company (Settimo Vittone, Italy), the biochar from vineyard prunings (Bv) was produced at the STAR*Facility Centre of Foggia University (South Italy), and the vermicompost from cattle manure (V) was purchased from a company located in Montescaglioso, Matera district (South Italy).

2.1.1. Experiment 1

Pots were filled with 5 kg of soil or soil treated with different organic amendments, namely the two types of biochar, Bw and Bv, and vermicompost (V), alone or in mixed form (Bw+V and Bv+V) at a rate of 2% of soil dry weight (dw). Unamended soil was considered as a control (C). Then, soil was brought to field capacity (FC), previously determined together with the permanent wilting point (PWP) at −0.03 and −1.5 MPa, respectively, for each treatment. The soil available water content (AWC, % dw) was calculated as the difference between FC and PWP. Following, 10 seeds were sown in each pot and thinned to one plant per pot once the emergence was completed. The six experimental treatments were replicated three times, and the 18 experimental units were arranged according to a completely randomized design. From the emergence until the twelve-leaf stage, the plants were kept well irrigated by restoring 100% of evapotranspiration losses at the depletion of 40% of the AWC; then a period of water stress was applied until the soil reached the PWP. At the end of this period, the pots were re-watered to FC and kept well watered until the end of experiment (i.e., initiation of flowering when plants were cut and parameters were recorded).

2.1.2. Experiment 2

The pots were filled with 6 kg of soil treated with three different rates (w/w) of woodchip biochar: 0% (Bw0% as control), 2% (Bw2%), and 4% (Bw4%) of dry soil weight (dw). Each experimental treatment was replicated three times, and the nine experimental units were arranged according to a completely randomized design. From seedling emergence to the beginning of flowering, plants were irrigated by restoring 50% of evapotranspiration losses at the depletion of 50% of the AWC.

2.2. Soil and Plant Growth-Related Parameters

At the end of both experiments, soil-related parameters (i.e., pH, electrical conductivity (EC), and bulk density (BD)) were measured. Additionally, the total number of panicles (TNP, n°) and total plant fresh weight (TFW, g) were recorded. All the experimental data were processed by one-way analysis of variance (ANOVA) by using "Statistix 8.1" software. When significant differences among means were detected, the latter were compared by Tukey's honest significance difference post hoc test at the 5% probability level.

3. Results

3.1. Soil- and Plant Growth-Related Parameters of Experiment 1

The changes in soil-related parameters due to the application of different organic amendments at 2% rate are shown in Table 1. The pH variations ranged between 7.6 and 8.1. The woodchip biochar treatment (Bw) resulted in a significant decrease ($p < 0.001$) in soil pH (0.2 unit), while vineyard pruning biochar alone (Bv) and mixed with vermicompost (Bv+V) increased ($p < 0.001$) soil pH (0.3 unit) compared to the control (C). The electrical conductivity (EC) was not found to be significantly affected by treatments. Bulk density (BD) significantly ($p < 0.001$) declined in all treatments compared to C, with greater reduction in Bv+V (18%). The biochar produced from woody material has a larger surface area and lower ash content as compared to the biochar produced from crop residues or grasses [10]. In our case, the higher ash content in Bv (9.9%) is the driver for the higher pH than Bw (4.4%), which could reduce the availability of micronutrients, according to a previous study [11]. Moreover, the higher porosity of Bv [12] than Bw reduced bulk density and likely increased nutrient retention [12].

Table 1. The pH, electrical conductivity (EC, µS/cm), and bulk density (BD, g/m^3) of soil along with the total number of panicles (TNP) and total fresh weight (TFW, g) of quinoa plants grown under different organic amendments.

Experimental	Soil-Related Parameters			Plant Growth	
Factors	pH	EC	BD	TNP	TFW
C	7.8 B	268	1.28 A	13 B	31.4 B
Bw	7.6 C	297	1.19 B	18 A	34.6 A
Bv	8.0 A	279	1.13 BC	7 C	18.6 C
V	7.8 B	291	1.20 AB	15 AB	31.1 B
Bw+V	7.7 BC	274	1.14 BC	16 AB	37.1 A
Bv+V	8.1 A	302	1.05 C	12 BC	20.1 C
Significance	***	ns	***	***	***

Values are means (n = 3). In each column, means followed by different letters are significantly different ($p \leq 0.05$; Tukey's test). ***, F test significant at $p \leq 0.001$, respectively. C, control; Bw, woodchip biochar; Bv, vineyard pruning biochar; V, vermicompost.

The significant effect of the organic amendments tested on plant growth under a period of water stress is presented in Table 1. The Bw and Bw+V treated plants produced more ($p < 0.001$) panicles (on average 17) compared to Bv and Bv+V (on average 9.5). Likewise, the Bw and Bw+V treatments yielded higher ($p < 0.001$) biomass (on average 35.9 g), while the Bv and Bv+V yielded lower biomass (on average 19.3 g). Using biochar boosted the nutritional availability and source–sink relationship under drought, increasing panicle length and grain yield also in rapeseed [13], and in quinoa, as reported by Kammann et al. [14] under similar biochar application conditions. Probably, the higher porosity of Bv [12] than Bw, although reducing the bulk density, increased nutrient retention, especially N [15], lowering their availability for plant growth.

3.2. Soil- and Plant Growth-Related Parameters of Experiment 2

Applying different woodchip biochar rates significantly affected the soil properties under water shortage conditions (Table 2). More specifically, the addition of 2% biochar

(Bw2%) decreased ($p < 0.001$) pH (7.79) more than the 4% rate (Bw4%) (7.82) as compared to the non-amended soil (Bw0%) (7.9). The EC was also reduced ($p < 0.05$) in Bw2% treated soil (286 µS/cm), while it increased in Bw4% (313 µS/cm) compared to Bw0% (307 µS/cm). Both Bw4% and Bw2% treatments reduced bulk density (BD) by 20% and 8%, respectively, compared to Bw0%. Several studies have previously reported changes (increase or decrease) in pH level resulting from the application of different biochar rates [16]. Consistent with our study, a decrease in soil pH after biochar addition was observed by Qiang et al. [17]. Soil pH variation after biochar application influences the microbial activity and enzyme production in addition to carbon and nutrient availability [18]. The higher biochar application rate may increase soil salinity and EC, subsequently leading to undesirable impacts on plant growth [19]. Moreover, biochar addition, by lowering soil bulk density, increases the total soil porosity, thereby positively impacting root development [20].

Table 2. The pH, electrical conductivity (EC, µS/cm), and bulk density (BD, g/m^3) of soil along with total number of panicles (TNP) and total fresh weight (TFW, g) of quinoa plants grown under different rates of woodchips biochar.

Experimental	Soil-Related Parameters			Plant Growth	
Factors	**pH**	**EC**	**BD**	**TNP**	**TFW**
Bw0%	7.85 A	307 A	1.32 A	11 B	14.6 B
Bw2%	7.79 B	286 B	1.23 A	15 A	19.7 A
Bw4%	7.82 A	313 A	1.06 B	9 B	16.5 B
Significance	***	*	**	*	*

Values are means (n = 3). In each column, means followed by different letters are significantly different ($p \leq 0.05$; Tukey's test). *, **, and ***, F test significant at $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively. Bw0%, no biochar; Bw2%, 2% biochar; Bw4%, 4% biochar.

Significant variations of plant growth were observed among the different biochar rates under water shortage conditions (Table 2). In particular, the Bw2%-treated plants showed more ($p < 0.05$) panicles (15) compared to plants receiving Bw0% and Bw4% treatments (on average 10). Similarly, the Bw2% plants produced higher ($p < 0.05$) biomass (19.5 g) than Bw0% and Bw4% (on average 15.6 g). The significant enhancement of biomass and yield was reported in quinoa under water limited conditions by Kammann et al. [14]. However, some non-significant or negative impacts of biochar have also been reported [21,22], leading to the need to further consider appropriate biochar type and dose for desired responses. In the present study, Bw4% negatively affected plant growth, as reported by several studies due to detrimental effects including reduced soil nutrient availability under altered pH [15,23]. The higher biochar rate increased negative charges on the soil surface, leading to intensified electrostatic interactions with cations [24], as also reported by Rees et al. [15] under woody biochar application, resulting in detrimental effects on plant growth and yield due to reduced nutrient availability [25].

4. Conclusions

Among the organic amendments tested, woodchip biochar application, alone or mixed with vermicompost, was shown to be the better option to mitigate short-term water stress conditions arising during the vegetative growing cycle of quinoa, Titicaca genotype. Considering the different woodchip biochar rates, 2% application was determined to result in a greater growth response of Titicaca under water limitations compared to 4% biochar, probably due to more favorable soil conditions. Both experiments pointed out that the proper type and dose of biochar could help quinoa plants to grow better and cope with water-limited conditions. Further investigations should be extended to the evaluation of different quinoa genotypes in order to better understand the specific response to biochar application in controlled and open field conditions.

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