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Original article

Effectiveness of biochar and compost on improving soil hydro-physical properties, crop yield and monetary returns in inceptisol subtropics

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ABSTRACT

Organic manures in combination with biochar might improve efficacy of biochar in improving soil functions related to hydro-physical properties and a field experiment was conducted over the course of two years with two levels of biochar @ 0 and 2tha^{-1} and four levels of compost (100% recommended dose of N through farm yard manure, 100% recommended dose of N through vermicompost, 50% recommended dose of N through farm yard manure, and vermicompost each, and unfertilized control). Each treatment was replicated three times in factorial randomized block design (RBD). The objective of this research was to determine the effects of biochar and compost on soil hydro-physical properties, water use efficiency, monetary returns and yield of knolkhol (*Brassica oleracea* var. *gongyloides* L.) under sub-tropics of North West India. Compared with no-biochar, application of biochar significantly increased knolkhol yield by 7.8% and soil properties (infiltration rate, aggregate stability, maximum water holding capacity and hydraulic conductivity). Similarly, integration of compost significantly enhanced the soil water retention, aggregate stability, hydraulic conductivity and crop yield and gave highest infiltration rate, water retention, hydraulic conductivity and crop yield under M3 (50 % N through farm yard manure, +50 % N through vermicompost) treatment. Furthermore, synergetic positive effect of biochar and compost were noted for soil infiltration rate (4–38%), water retention (0.9–13.7%), aggregate stability (6–10.7%) and yield (6–11.9%) over the sole application of compost. Combined use of farm yard manure, and vermicompost accompanied by biochar resulted in highest net returns and B:C ratio. Biochar in combination with farm yard manure, and vermicompost can enhance soil hydraulic properties resulting in increased crop yield and maximum monetary returns under subtropical conditions.

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1. Introduction

Biochar is a solid porous material that is rich in carbon content, has large surface area and cation exchange capacity (CEC), produced from pyrolysis process in oxygen limited environment (Hussain et al., 2017; Mansoor et al., 2020). Many studies have reported positive effects of biochar incorporation on crop performance and soil properties such as improved soilstructure, water retention, porosity, infiltration rate, bulk density and hydraulic conductivity (Laird et al., 2010; Herath et al., 2013; Abrol et al. 2016), which may lead to increase in crop yield (Basso et al., 2012; Carlsson et al., 2012; Herath et al., 2013; Mukherjee and Lal, 2013; Martinsen et al., 2015; Hansen et al. 2016; Blanco

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et al., 2017). Mensah and Frimpong (2018) reported that the biochar amendment would improve the soil health by increasing the pH, water retention capacity, CEC, apart from the microbial flora. Simarani et al. (2018) demonstrated improve soil labile C, organic carbon and microbial biomass C in short term application of rice husk and palm kernel biochar amended plots over control in tropical acidic soil.

Adding compost would alleviate the soil structural quality by significantly reducing the compaction and increasing water content (Tiwari et al., 1998; Carter et al., 2004; Evanyloet al., 2008). To avoid high cost and unsafe effect of inorganic fertilizers use of compost would be a traditional and better management option. Zhang et al. (2014) noted that the incorporation of organic manures would significantly improve the root growth by modifying the soil physical properties. Biochar is rich in carbon content but do not provide the sufficient nutrients for nutrient exhaustive crops. Adding biochar along with chemical fertilizers and compost resulted in improved soil water retention (Abel et al. 2013), aggregate stability (Sun and Lu, 2014), more efficient use of nutrients (Major et al., 2009; Novak et al., 2009), increase in microbial biomass and activities which would promote the plant growth (Adekiya et al., 2018; Mansoor et al., 2020; Sadegh-Zadeh et al., 2018) over the sole application (Ippolito et al., 2016; Hagemann et al., 2017). In addition to its impact on soil parameters and plant growth biochar with compost or lime decreases leaching of nutrients and would improve the efficiency of compost (Major et al., 2009; Novak et al., 2009). Studies of hydraulic properties of soil are vital for understanding the water flow and change in physicochemical properties influenced by different management practices (Zhang, 1997). Structure stability, hydraulic conductivity, bulk density and water retention has been widely used to investigate the soil physical health and hydraulic properties (Reynolds et al., 2009; Castellini et al., 2019). Partial research has been conducted to evaluate the effect of compost and biochar on the soil hydraulic properties (Kammann et al., 2016). Ataallah et al. (2019) noticed reduction in soil loss and increase in aggregate stability in short term birchwood biochar treated plots. Knolkhol (*Brassica oleracea* var. *gongyloides* L.) is one of the important fast growing, short duration cole crop, and has originated from the coastal countries of the Mediterranen region. In India, it is highly grown as a vegetable crop in Jammu and Kashmir State having a large area and production of about 70,000 metric tonnes. Now a days, it has become popular in most of the other states as the whole plant is edible owing to its high nutritional value as 100 gm of edible portion would contain 92.7gm moisture, protein (1.1 gm), minerals (0.7 gm), Energy (25 calories), carbohydrate, Ca, vitamin A (3.8 gm, 20 mg, 36 I.U, respectively) (Cosic et al., 2013).

The sub-tropical zone of Jammu is characterized as hot summer and dry winter having low inherent fertility and water holding capacity. Hence, the objective of this work was to asses and maximizes the favorable effect of biochar and compost on crop yield, soil properties, water use efficiency and monetary returns. Our hypothesis was that application of biochar in combination with compost would improve the soil hydraulic properties more than the compost and biochar alone under the sub-tropical conditions.

2. Materials and methods

2.1. Location, climate and soil

A field study was conducted for two years (2018 and 2019) at the Organic Farm Research Center (OFRC), SKUAST-Jammu (32°40′N Latitude and 78°48′E Longitude), Jammu & Kashmir, India. The location would represent the sub-tropical belt of Jammu which falls under the Agro-Climatic Zone 1 (Western Himalayan zone) of the Jammu region of Jammu & Kashmir. The average rainfall was1200 mm, the mean annual maximum and minimum temperatures were 45 °C and 2.8 °C, respectively. The experimental soil was sandy clay loam in texture; the available N, P, K, organic carbon was 196.7, 19.28, 175.62 kg ha^{-1}, 6.4 g kg^{-1}, respectively; the pH, EC, bulk density was 7.4, 0.24dsm^{-1}, 1.33gcm^{-3}, respectively (Table 1).

2.2. Experimental details

The experiment was set up in a factorial Randomized Block Design (RBD) with three replications consisted of eight treatment combinations of biochar (2tha^{-1}) and (ii) no biochar (0 t ha^{-1}) along with organic sources of fertilizer i.e., 100% recommended N through FYM, 100% recommended N through vermicompost; 50% recommended N through FYM + 50% recommended N through vermicompost and unfertilized control. The net plot size area was 3. 6 m × 2.6 m. Previousstudies have indicated a wide range (1 t ha^{-1} to 15 tha^{-1}) of biochar application in the soil. We had selected 2 t ha^{-1} of biochar, as it is expected to be economically viable, and also have a positive effect along with compost (Manolikaki and Diamadopoulos, 2017, 2019). The recommended dose of nitrogen for Knolkhol (80 Kg ha^{-1}) was applied through biochar, FYM and vermicompost based on mean nitrogen content of amendments (Table 2). The chemical properties of biochar and compost, which have been used in our study, are given in Table 2**.** FYM comprised of 0.36% of phosphorus, 1.15% of potassium and 0.5% of nitrogen; while vermicompost comprised of 1.83% phosphorus, 1.39% of potassium and 1.5% of nitrogen. The pH, EC of biochar (biochar: water ratio, 1:10) were 8.9 and 0.49 dsm^{-1}, respectively; total OC, phosphorus, potassium, nitrogen were 53.5%, 0.15%, 0.5%, and 0.09%, respectively; with bulk density of 0.28 g cm^{-3} (Table 2). The biochar, FYM and vermicompost were applied to the plots three weeks before transplanting of the Knolkhol.

2.3. Production and characterization of biochar

Biochar was produced from the rice husk due to its high availability in Jammu region of India. The rice husk was packed tightly in the low-cost cylindrical metal drum (200 L capacity) developed by (Venkatesh et al., 2018) and modified by CRIDA (Central Research Institute for Dryland Agriculture, Hyderabad). The conversion of rice husk to biochar was about 40–45%. The biochar was passed through a 2 mm sieve for making the soil application. The bulk density was measured by dividing the weight of the dry sample filled in 10 ml tube with the volume.

Table 1
Initial soil properties of the experimental soil.

Soil component	Value obtained
Soil pH (1:2.5)	7.4
Electrical conductivity (dS m^{-1})	0.24
Organic carbon (g kg^{-1})	6.4
Available Nitrogen (kg ha^{-1})	196.7
Available P_2O_5 (kg ha^{-1})	19.28
Available K_2O (kg ha^{-1})	175.62
Bulk density (g cm^{-3})	1.33
Sand (%)	57.32
Silt (%)	22
Clay (%)	20.68
Textural class	Sandy clay loam

Table 2
Characterization of biochar and organic amendments.

Components	Biochar	FYM	Vermicompost
pH (1:10)	8.9	–	–
EC (1:10)	0.49	–	–
Total carbon	53.5%	–	–
Phosphorus	0.15%	0.36%	1.83%
Potassium	0.5%	1.15%	1.39%
Nitrogen	0.09%	0.5%	1.5%
Bulk density	0.28 g cm^{-3}	–	–

2.4. Measurement of soil physical properties

The maximum water holding capacity of soil was determined by using Keen Rackzowski box method (Keen and Raczkowski, 1921); infiltration rate (IR) was measured by mini-disk infiltrometer and calculations were performed using the spreadsheet given (Decagon Devices, 2016); bulk density was determined from the undisturbed soil samples by the core method; aggregate stability by wet-sieving apparatus (Eijkelkamp); water use efficiency (kg/mm ha) calculated using the formula WUE = Y/ET, Where Y = crop yield (kg/ha) and ET = Evapotranspiration during the entire growth period (mm).

2.5. Soil and manure analysis

The soil pH and electrical conductivity were measured in the 1:2.5 soil: water ratios by using a pH meter and EC meter (Jackson, 1967). Soil texture (Bouyoucos hydrometer method), organic carbon (Walkley and Black, 1934), available nitrogen content was determined using the alkali potassium permanganate method (Subbiah and Asija, 1956), available phosphorus was determined by Olsen's method (Olson et al., 1954) total organic carbon and total N of the biochar and compost were determined using an Elementary Analyzer (multi N/C 2100S, Analytikjena).

2.6. Measurements of agronomic parameter

The plant height and knob diameter were measured at the harvest stage by using the five tagged plants of each plot. Yield was measured on the basis of plant total weight, while the yield per plot was measured as kg per plot and expressed as quintals per hectare.

2.7. Economic analysis

The total cost was calculated by considering the total expenditure involved in all kinds of operations as per the treatments per hectare basis and expressed as Rs ha^{-1}. The benefit: cost ratio was determined by dividing the net returns with the cost of cultivation for different treatments.

2.8. Statistical analysis

The statistical assessment of the performance treatments was made by the carrying out the Analysis of Variance (ANOVA) of data based on the Randomized Block Design as described by Gomez and Gomez (1984). Based on the Least Significant Difference (LSD) values, the treatment differences were compared at $p < 0.05$ level of significance. Pearson correlation and linear regression analysis between different parameters were derived and tested based on *t*-test to further explore the relationship between different measured parameters.

3. Results

3.1. Soil hydro-physical properties

3.1.1. Soil bulk density

The effect of biochar and compost on soil bulk density was non significant. However, addition of biochar and compost decreased the BD over the control (Table 3). Reduction in BD was highest in B1 and M3. By 1.5% and2.9 % compared with control.

3.1.2. Infiltration rate

Biochar and compost significantly ($P < 0.05$) increased the soil infiltration rate (Table 3). Significantly higher IR (1.2 times) was noted with the application of 2tha^{-1} biochar over no biochar. Among the compost treated plots, significantly higher IR was observed with FYM + VC(M3) by 2.1 times compared with the control. The IR increased in the order of M0 > M1 > M2 > M3. IRvaried from 0.153 cm to 0.487 cm with mean infiltration rate of 0.322 cm (Fig. 1). Interaction of biochar and compost was significant, and highest was noted in T4 (biochar × FYM + VC) treatment. An increase in IR of 1.11, 1.04, 1.88 times in B + FYM; B + VC; B + FYM + VC over FYM, VC and FYM + VC, respectively were observed. Similarly, the CI values have increased in all the treatments with respect to the square root of time over control (Fig. 2).

3.1.3. Maximum water holding capacity

The data presented in Table 3 revealed that biochar and compost significantly ($P < 0.05$) increased the maximum water holding capacity. Biochar addition was found to retain maximum soil water content (6.6 %) over no biochar. FYM + VC (M3) was superior with a significantly higher MWHC compared to FYM + B (M1) and VC + B (T2) which were at par with each other, and were significantly higher than the control. The interaction of B and compost at B × FYM + VC gave significantly higher MWHC, followed by B × VC, and B X FYM combinations (Fig. 3) and ranged from 40.86% to 52.86.

3.1.4. Aggregate stability and mean weight diameter

The data presented in Table 3 revealed that biochar and compost significantly ($P < 0.05$) increased aggregate stability and MWD. The AS and MWD were found to be significantly higher by 8.1% and 10% respectively, under the biochar amended plots compared to no biochar treatments. Significantly lower AS and MWD were observed under the control treatment relative to other treatments. Among the compost treatments, AS and MWD were found to be significantly higher under FYM + VC (M3) treatment, followed by M2 and M1 but these were significantly better compared to no compost application (M0). Based on Fig. 4, A significant interaction was observed in biochar and compost treatments and the highest MWD was observed in M3B1.

3.1.5. Hydraulic conductivity and water use efficiency

The data presented in Table 3 showed that application of compost affected the HC significantly. Maximum HC was observed under the FYM + VC (M3) treated plots, followed by M2 and M1 which were at par, but were significantly higher over the control treatment. The interaction of soil amendments (biochar and compost) on hydraulic conductivity (HC) was found significant and application of FYM + VC with biochar gave significantly higher HC compared to the remaining treatment combinations (Fig. 5). The water use efficiency (WUE) was found to range from 60.31 kg/ha mm to 199.5 kg/ha mm. Addition of biochar improved water use efficiency (WUE) by about 25.9% compared to no biochar (Fig. 6). Similarly application of compost has increased the WUE over control. Maximum WUE was attained when FYM and VC were

Table 3
Effect of biochar and compost application on soil properties.

Treatments	Bulk density (g cm^{-3})	Infiltration rate (cmh^{-1})	Maximum water holding capacity (%)	Aggregate stability (%)	MWD (mm)	Hydraulic conductivity (mmh^{-1})
Biochar						
B0	1.33	0.29b	43.35b	53.8b	1.19b	3.04
B1	1.31	0.35a	46.18a	58.21a	1.31a	3.29
CD	NS	0.03	1.73	1.82	0.02	NS
Compost						
M0	1.34a	0.20c	41.61c	44.16c	1.15d	1.82c
M1	1.33ab	0.32b	44.0b	57.68b	1.20c	3.35b
M2	1.32b	0.35b	43.78b	59.88b	1.29b	3.53ab
M3	1.30c	0.42a	49.68a	63.39a	1.35a	3.95a
LSD($p < 0.05$)	0.01	0.04	2.44	2.86	0.04	0.54
Interaction	NS	*	*	NS	*	*

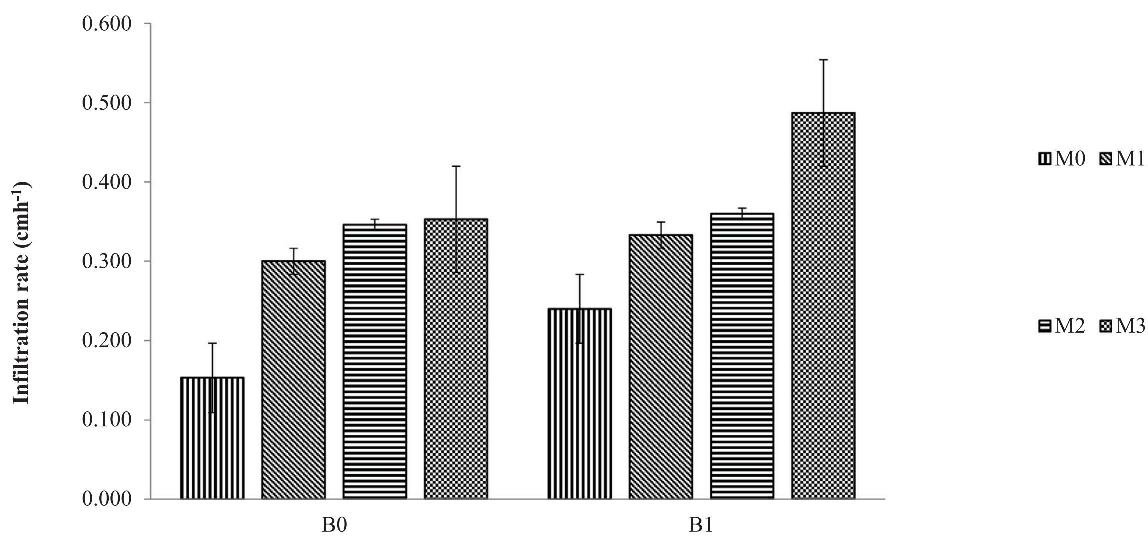

Fig 1. Interaction of biochar and compost on infiltration rate. B0 = 0 tha^{-1}, B1 = 2 tha^{-1} biochar; M0 = control; M1 = FYM; M2 = VC; M3 = FYM + VC.

applied together. The interaction effects indicated that the combination of FYM + VC with biochar has produced the highest WUE, which was 24.6% higher than the WUE observed under without biochar treatment (FYM + VC).

3.1.6. Plant height, knob diameter and yield

The results showed that plant height, knob diameter and yield of knolkhol were significantly influenced by application of different amendments (Table 4). The plant height ranged from 36.03 cm to 49.90 cm with mean plant height of 42.88 cm. The knob diameter ranged from 4.23 cm to 9.73 cm with mean knob diameter of 6.27 cm. The knolkhol yield ranged from 120.3 q/ha to 216.4 q/ha with mean yield of 177.1 q/ha. Among different compost amended treatments, FYM + VC application was beneficial and has significantly improved the plant height, knob diameter and yield, followed by VC and FYM treated plots. Significantly lower yield was attained with control. Compared to application of the compost alone, addition of biochar has improved the grain yield by 1.48, 1.52, 1.63 times respectively under FYM, VC and FYM + VC treatments, respectively. The magnitude of increase in the grain yield was higher in FYM + VC with and without biochar over control which was significantly higher when compared to the yield obtained with the FYM and VC treatments. Maximum grain yield of 216.4 q/ha was attained by the combination of B × FYM + VC combination, while minimum was attained under B × FYM application (Fig. 7). The results indicated that compost integrated with biochar had a significant effect on the plant height, knob weight and yield of knolkhol compared to the sole application of these amendments. Thus, the crop performance was found to decrease in the order of M3 > M2 > M1 > M0.

3.1.7. Monetary returns

Application of biochar and compost increased both the net returns and benefit-cost ratio over the control treatment (Fig. 8 and Fig. 9). The net returns has ranged from Rs.24523/ha to Rs.108732/ha with mean net returns of Rs.74295/ha. The benefit-cost ratio has ranged from 0.90 to 1.70 with mean benefit-cost ratio of 1.31. The biochar addition gave 1.4 times higher net returns compared to without biochar treatment. Addition of compost gave net returns of Rs.108732/ha and benefit-cost ratio of 1.70 with application of FYM + VC, followed by the application of FYM and VC. The biochar in conjuction with the compost have provided maximum net returns over the compost application alone. The mixed application of B + FYM + VC (T4) gave 1.4 times more net returns over application of FYM + VC without biochar. The findings have obviously indicated that the biochar application with FYM and VC was highly beneficial in terms of the improved soil hydro-physical properties, WUE, monetary returns and yield of knolkhol.

3.1.8. Relationship between different parameters

Estimates of correlation were derived between different pairs of parameters and were tested for their significance based on *t*-test (Table 5). Based on the correlation analysis, it is observed that(i)

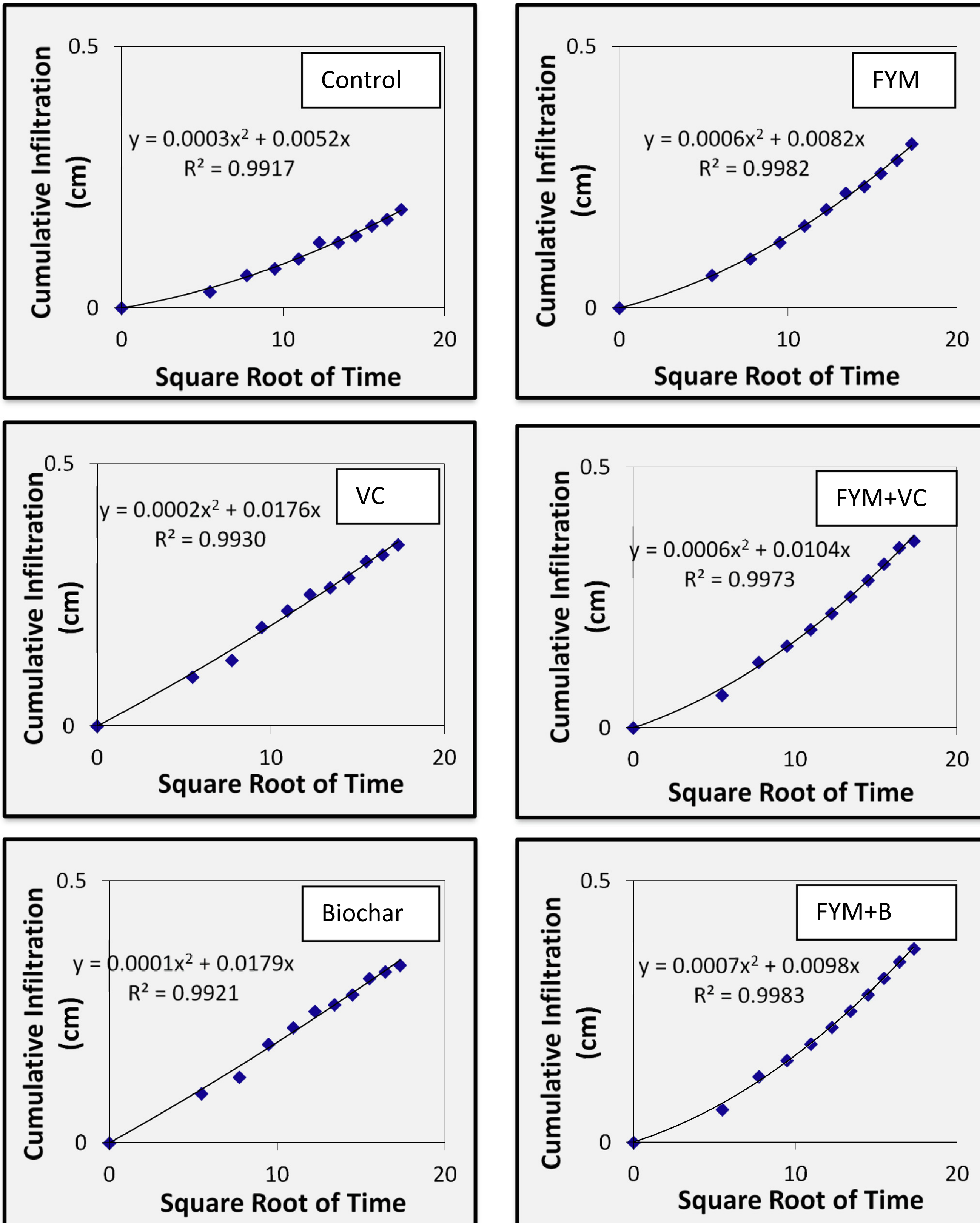

Fig 2. Effect of biochar and manures on the soil cumulative infiltration under different treatments.

aggregate stability had a significant correlation of 0.956** with infiltration rate, 0.862* with mean weight diameter, 0.985** with hydraulic conductivity, 0.964** with water use efficiency, 0.893* with knob diameter, 0.977** with plant height, 0.987** with yield, 0.959** with net returns and 0.834* with benefit-cost ratio; (ii) bulk density had a significant correlation of −0.822* with infiltra-

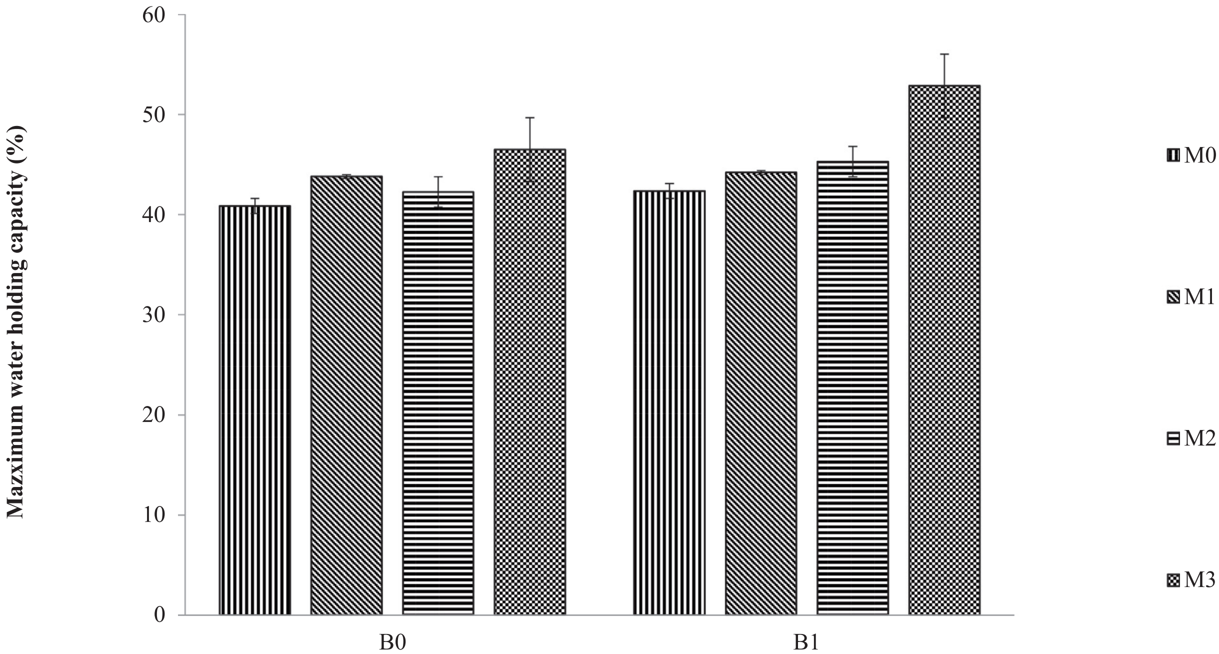

Fig 3. Interaction of biochar and compost on maximum water holding capacity.

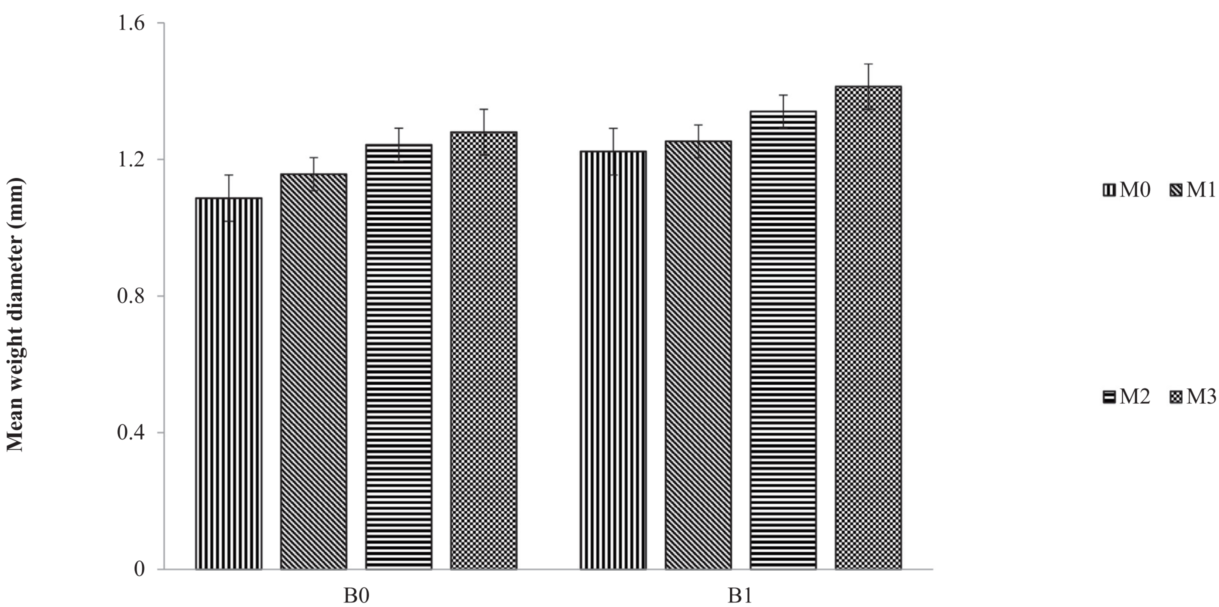

Fig 4. Interaction of biochar and compost on mean weight diameter.

tion rate, −0.904* with mean weight diameter, −0.888* with maximum water holding capacity, −0.868* with knob diameter, −0.880* with plant height; (iii) infiltration rate had a significant correlation of 0.915* with mean weight diameter, 0.876* with maximum water holding capacity, 0.935** with hydraulic conductivity, 0.897* with water use efficiency, 0.938** with knob diameter, 0.974** with plant height, 0.940** with yield, 0.906* with net returns and 0.853* with benefit-cost ratio; (iv) mean weight diameter had a significant correlation of 0.843* with maximum water holding capacity, 0.921** with knob diameter, 0.905* with plant height, 0.821* with net returns and 0.855* with benefit-cost ratio; (v) maximum water holding capacity had a significant correlation of 0.922** with knob diameter, 0.889* with plant height and 0.837* with benefit-cost ratio; (vi) hydraulic conductivity had a significant correlation of 0.956** with water use efficiency, 0.838* with knob diameter, 0.950** with plant height, 0.997** with yield and 0.935** with net returns; (vii) water use efficiency had a significant correlation of 0.926** with plant height, 0.974** with yield, 0.992** with net returns and 0.863* with benefit-cost ratio; (viii) knob diameter had a significant correlation of 0.922** with plant height and 0.833* with yield; (ix) plant height had a significant correlation of 0.953** with yield, 0.941** with net returns and 0.884* with benefit-cost ratio; and (x) yield had a significant correlation of 0.956** with net returns, while net returns had a significant correlation of 0.914* with benefit-cost ratio.

4. Discussion

The present study showed an improvement in soil hydro-physical properties and water use efficiency upon the addition of

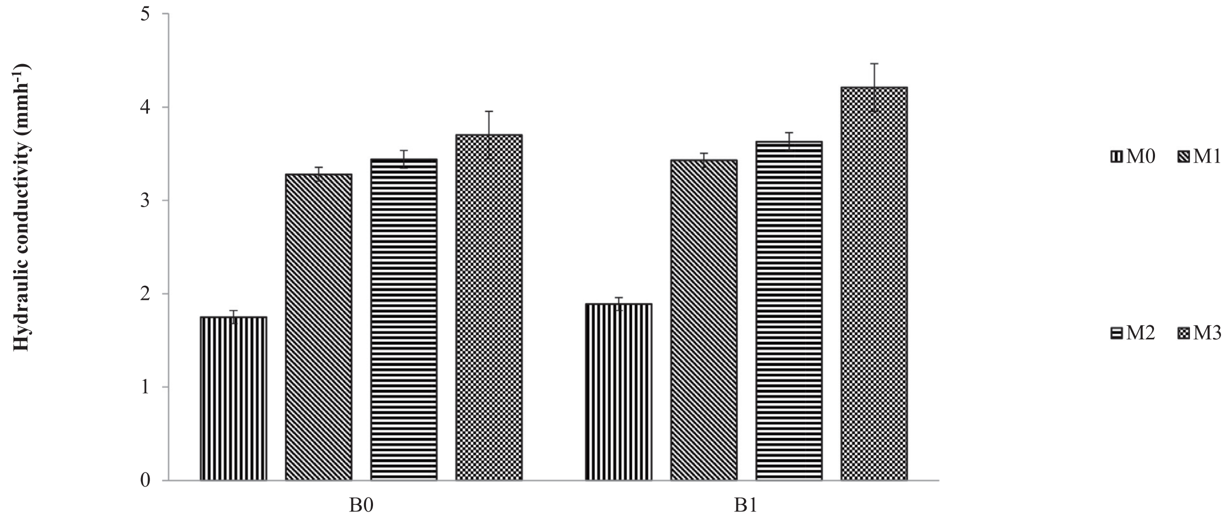

Fig 5. Interaction of biochar and compost on hydraulic conductivity.

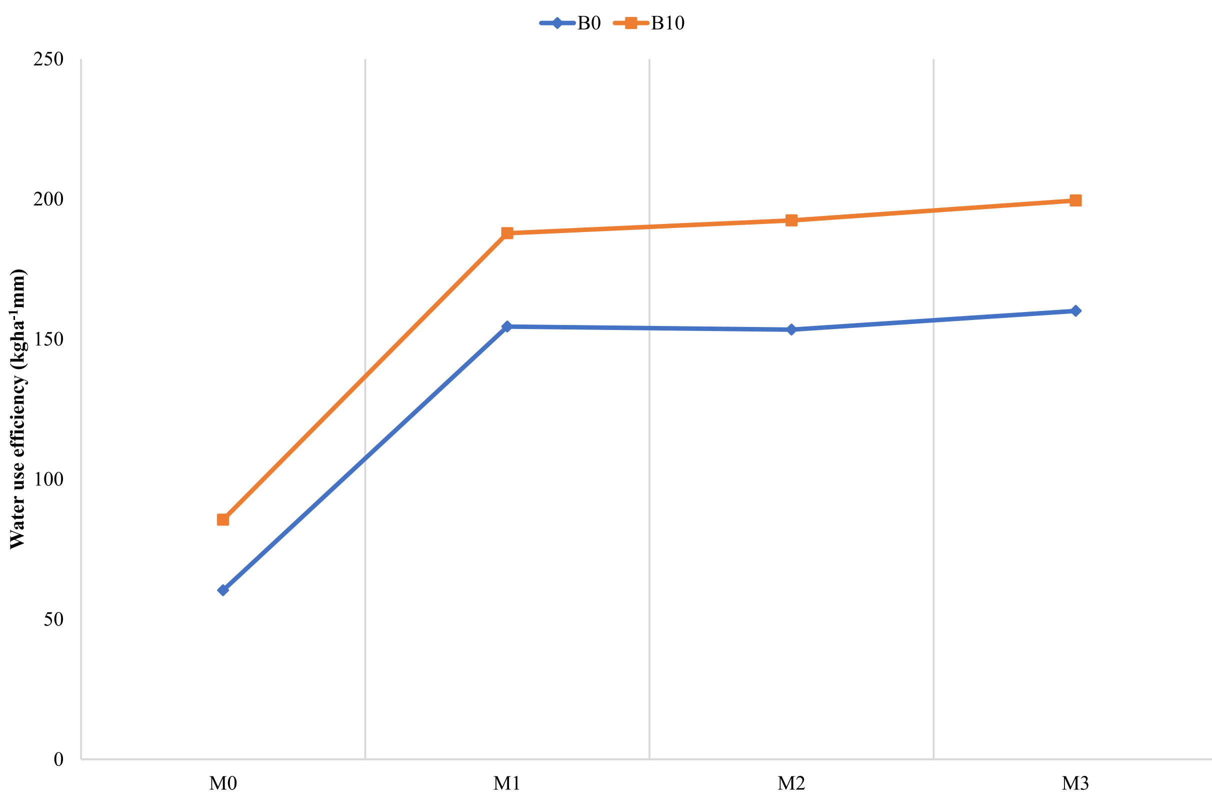

Fig 6. Effect of biochar and compost on water use efficiency.

biochar over the no biochar (Table 3). The porous nature and high surface area of biochar might decrease the soil bulk density and increased the aggregate stability and water retention and reduced the evapotranspiration (Day et al., 2005; Ogawa et al., 2006; Yu et al., 2006). Other researchers (Dugan et al., 2010; Githinji, 2014; Abel et al. 2013; Mukherjee and Lal, 2013; Herath et al., 2013) have also reported a significant improvement in the soil physical properties with as low as 1% addition of the biochar. Abrol et al. (2016) have found a decreased bulk density with the use of biochar under the non-calcareous loamy sand soils. Similarly, Omondi et al. (2016) have observed that under the coarse-textured and low fertility soils, there was significantly higher water holding capacity of about 15.1% and aggregate stability of 8.2% after the biochar addition. Herath et al., 2013; Laird et al., 2010 noted the positive effect of biochar amendment to soil on bulk density, porosity and saturated hydraulic conductivity.

Results revealed that infiltration rate had a significant correlation with MWD (0.915*), MWHC 0.876* and HC (0.935**), an increase in soil water content and aggregation that would improve plantgrowth (Carter et al., 2004; Evanyloet al., 2008; Zhang et al. 2014). Adekiya et al. (2018) have noted that incorporation of biochar alone or in combination with poultry manure decrease the soil BD and increase the soil moisture and porosity. Both the biochar and compost application having numerous benefits such as (i)

Table 4
Effect of biochar and compost application on plant growth and yield.

Treatments	Knob diameter (cm)	Plant height (cm)	Yield (q/ha)
Biochar			
B0	5.65a	41.33	169.5a
B1	6.90b	44.43	183.9b
LSD ($p < 0.05$)	1.018	NS	11.5
Compost			
M0	4.48d	37.08c	125.55c
M1	5.52c	42.96b	185.35b
M2	6.92b	43.83b	191.30b
M3	8.18a	47.63a	204.55a
LSD ($p < 0.05$)	0.72	3.0	8.1
Interaction	NS	NS	9.5

B0 = no biochar; B1 = 2 t/ha biochar; M0 = control; M1 = 100 % N through FYM; M2 = 100 % N through VC; M3 = 50 % N through FYM + 50 % N through VC.
Mean values followed by different lower case letters in each group are statistically different at $P \leq 0.05$ sing LSD (0.05) test.

the enhanced soil nutrient use efficiency; (ii) increased water holding capacity; (iii) increased carbon sequestration; (iv) reduced nutrient leaching, (v) reduction of fertilizer inputs, and (vi) stabilizing the soil structure (Liu et al. 2012; Agegnehu et al., 2015; Schmidt et al., 2014). Maximum aggregate stability, water holding capacity, infiltration rate, and hydraulic conductivity were attained under FYM + VC in combination with the biochar. This could be due to the reason that the organic amendments and biochar would act as the cementing materials for forming the stable soil aggregates.

When the biochar was incorporated into the soil, it was found to function as a suitable binding agent that would connect the soil micro aggregates to form macro-aggregates. This has also lead to an increase in the diameter of the soil aggregates of biochar amended soils (Cheng et al., 2006), and therefore, changes the pore size distribution and also the aggregate stability of a soil. Similarly, Lu et al. (2014) observed that rice husk biochar increased soil pore by 20% and aggregation by 8–36% might be due to retaining water in its small pores and assist water to infiltrate from the ground surface to the top soil after heavy rain (Asai et al., 2013) Abrol et al., 2016). Omondi et al. (2016) have also shown an increase in the aggregate stability of about 8.2% (n = 10) after the addition of biochar. Application of biochar along with the organic amendment has increased the cumulative infiltration and soil infiltration rate.

Our findings have demonstrated that the compared with no biochar, plant height, knob diameter and yield of knolkhol have significantly increased with biochar (Table 4). Compost application with biochar has exhibited more prominent role in improving the crop performance over sole application of compost, which could be explained by the fact that the porous structure and large surface area change the availability of nutrients and physical properties (Agegnehu et al., 2016) and soil organic matter (Abiyen et al. 2011). Maximum yield was attained with the treatment comprising of FYM + VC and biochar, while the minimum was attained under control. This was due to the reason that the incorporation of biochar and compost together would improve the nutrient availability of a soil. The results obtained in this study would agree with the findings made by Manolikaki and Diamadopoulos (2019), who found an enhancement in the plant growth with the addition of rice husk biochar and manures. Previous studied showed that biochar addition in coarse textured and degraded has the potential to increase the crop yield (Lashari et al., 2013; Jeffery et al., 2012) and field experiments (Manolikaki and Diamadopoulos, 2019). A rapid decomposition and mineralization of the organic fertilizers, with mostly released back to the atmosphere were found to require a repeated high dose and cost of manure application (Srivastava et al., 2014). The biochar would certainly act as a slow releasing fertilizer to the crop which would help in providing good growth to the plant. Significant correlations were found to exist among the soil aggregates, infiltration rate, hydraulic conductivity, maximum water holding capacity, water use efficiency and other parameters as influenced by the biochar, FYM and vermicompost application. Different parameters were found to have a significant correlation with knolkhol yield and monetary returns based on the study. This has indicated that an improvement in the soil hydraulic parameters due to an application of different combinations of FYM, vermicompost and biochar has resulted with higher knolkhol yield in different treatments. However, there is a need to standardize the relationships based on long-term studies under similar soil and agro-climatic conditions. Other studies showed that biochar injunction with manures enhanced crop growth, soil fertility and carbon sequestration due to its recalcitrant's aromatic and aliphatic compounds (Agegnehu et al., 2016; Solaiman and Anawar, 2015; Schulz and Glaser, 2012; Abiyen et al., 2011). Biochar and manure mixture would significantly increase the efficiency of organic com-

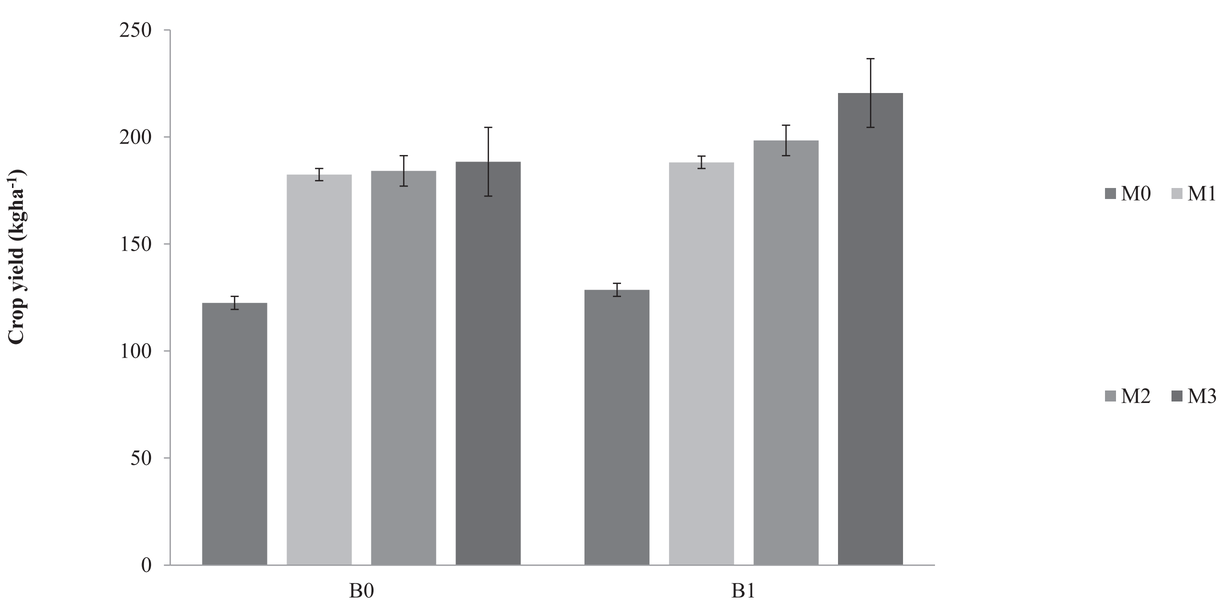

Fig 7. Effect of biochar and compost on crop yield.

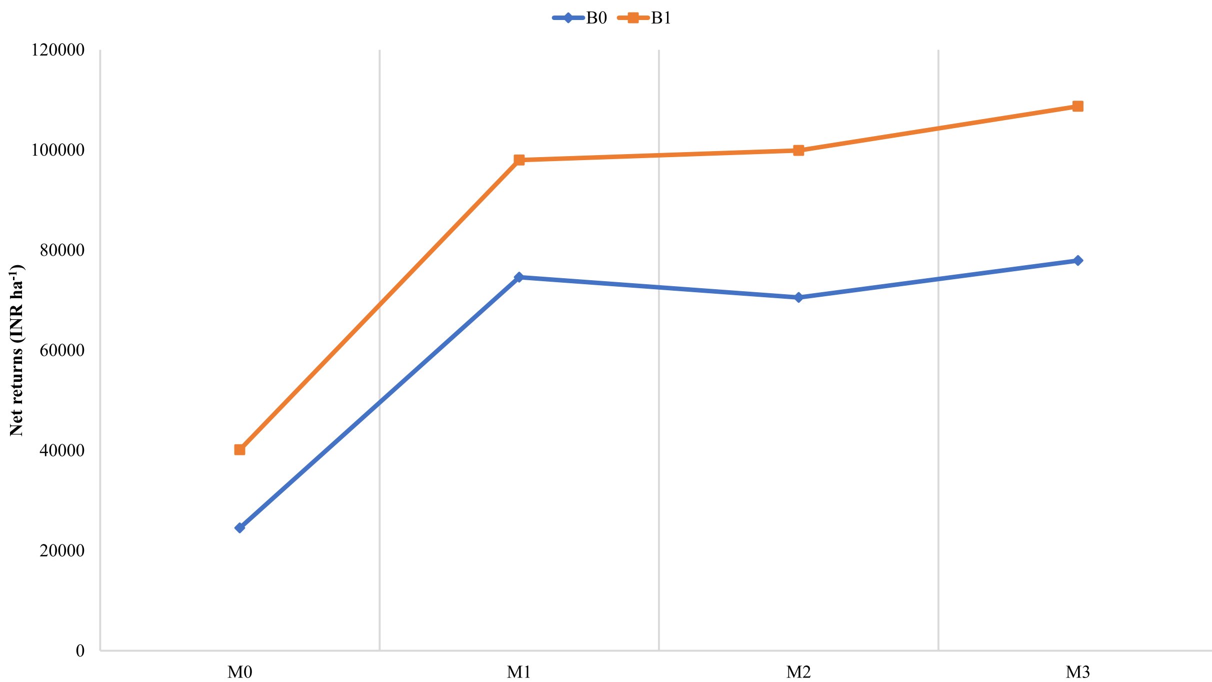

Fig 8. Effect of biochar and compost on net return.

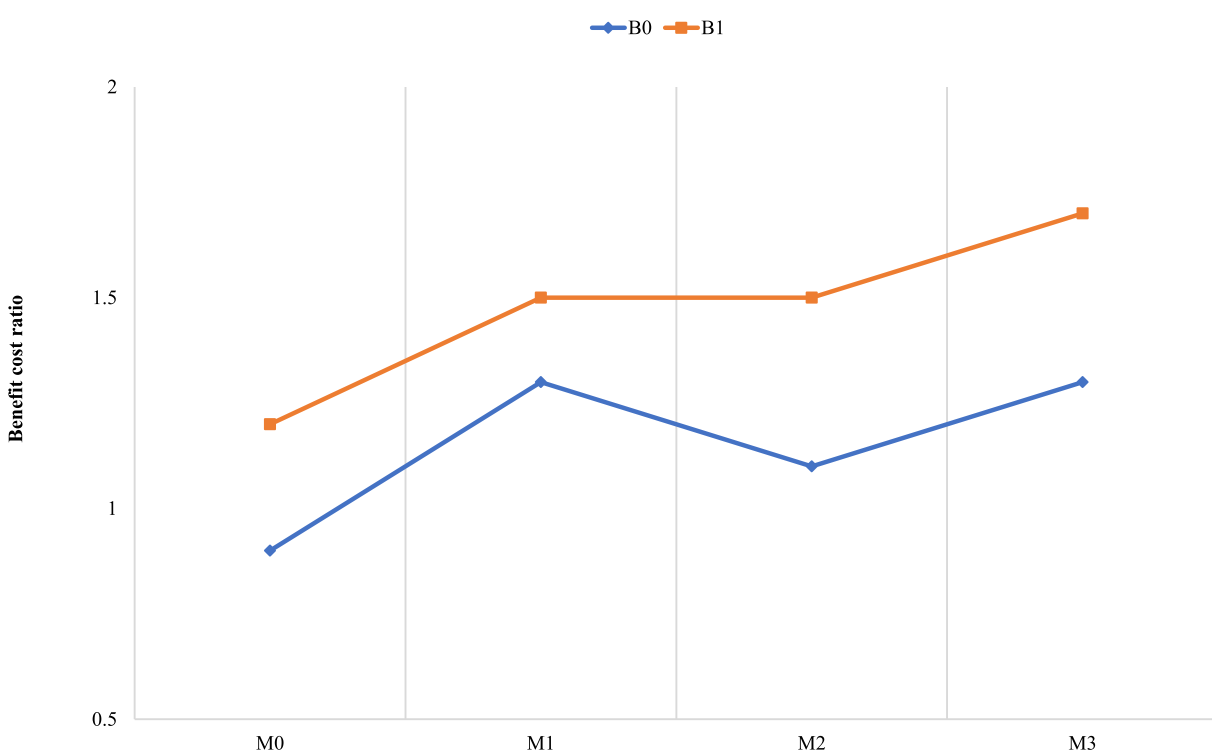

Fig 9. Effect of biochar and compost on B:C ratio.

post by preventing the rapid decomposition and also the mineralization of organic materials under different tropical conditions (Lehmann et al., 2003). This could be credited to the ability of the biochar to increase the efficiency of the utilization of the nutrients that are present in both FYM and VC. Sandhu and Kumar (2017) have reported about an increased efficiency of the biochar with compost and cover crop compared to the sole application. Highest net returns and B:C ratio were attained under the plot that has received FYM + VC in conjunction with biochar over control (Fig. 9-10). Wang et al., (2018) have concluded that the amended biochar application gave an increase in the net returns by 41–78% for rice and 34–77% for wheat based on a study of six years.

Table 5
Correlation matrix of soil properties, crop growth components and monetary returns. Correlation matrix.

	AS	BD	IR	MWD	MWHC	HC	WUE	KD	PH	YIELD	NR	BCR
AS	1.000											
BD	−0.800	1.000										
IR	0.956	−0.822	1.000									
MWD	0.862	−0.904	0.915	1.000								
MWHC	0.799	−0.888	0.876	0.843	1.000							
HC	0.985	−0.728	0.935	0.776	0.755	1.000						
WUE	0.964	−0.673	0.897	0.786	0.689	0.956	1.000					
KD	0.893	−0.868	0.938	0.921	0.922	0.838	0.777	1.000				
PH	0.977	−0.880	0.974	0.905	0.889	0.950	0.926	0.922	1.000			
YIELD	0.987	−0.718	0.940	0.791	0.745	0.997	0.974	0.833	0.953	1.000		
NR	0.959	−0.715	0.906	0.821	0.742	0.935	0.992	0.807	0.941	0.956	1.000	
BCR	0.834	−0.762	0.853	0.855	0.837	0.774	0.863	0.795	0.884	0.802	0.914	1.000

AS: Aggregate stability BD: Bulk density IR: Infiltration rate.
MWD: Mean weight diameter MWHC: Maximum water holding capacity.
HC: Hydraulic conductivity WUE: Water use efficiency KD: Knob diameter.
PH: Plant height NR: Net returns BCR: Benefit-cost ratio.
Critical correlation coefficient at $p < 0.05$ level with 6 degrees of freedom = 0.811.
Critical correlation coefficient at $p < 0.01$ level with 6 degrees of freedom = 0.917.

5. Conclusion

The results based on our study have indicated that the biochar addition with compost have positive effect on soil hydro-physical properties, water use efficiency, crop yield and the monetary returns under the sandy clay loam soil in the sub-tropical conditions. The farmers can profitably produce knolkhol without using the chemical fertilizers and harming the soil ecosystem with respect to an improvement in the soil bulk density, water retention, aggregation and crop growth.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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