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Combined Effect of Biochar and Mycorrhiza Fungi on Wheat (*Triticum aestivum* L.) Growth and Performance in Calcareous Soil

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ABSTRACT
The performance of wheat (*Triticum aestivum* L.) in calcareous soil is challenging due to a lack of sufficient nutrient availability for the plants. Thus, the objective of this study is to determine the effect of the combined application of biochar and mycorrhiza fungi on wheat (*Triticum aestivum* L.) growth and performance in calcareous soil. The experiment of this study consists of sixty-four treatments (two levels of mycorrhiza, two types of manures, and four levels of biochar) using a factorial and completely randomized design (CRD) with four replicates. The results showed that Cattle 1 $t.h^{-1}$+Mycorrhiza treatment produced the maximum plant height (68.50 cm), the weight of the shoot after drying (3.95 g), and root length (39.95 cm) after harvested, however Poultry 3$t.h^{-1}$+Mycorrhiza record percentage N in seeds (1.62%), percentage protein in seeds (9.34%), the weight 1000 seeds (49.23 g). In contrast, Poultry 1 $t.h^{-1}$+Mycorrhiza produced the minimum plant height (45.00 cm), percent N in seeds (0.73%), percent protein in seeds (4.24 %), the weight of the shoot after drying (1.97 g), the weight 1000 seeds (38.18 g), and root length (27.25 cm). This indicates that Cattle 1 $t.h.^{-1}$+Mycorrhiza has a higher effect on the performance of wheat compared to Poultry 1 $t.h^{-1}$+Mycorrhiza among other treatments. In conclusion, the findings showed that combinations of biochar and mycorrhizal fungi have a significant effect on the growth and performance of wheat plants in calcareous soil. Therefore, Cattle1 $t.h.^{-1}$+Mycorrhiza can be used by farmers to improve their wheat performance in calcareous soil in Iraq.

التأثير المشترك للفحم الحيوي وفطريات المايكورايزا على نمو وأداء القمح (*Triticum aestivum* L.) في التربة كلسية

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الخلاصة

يعتبر أداء القمح(*Triticum aestivum L.*) في التربة الكلسية تحديًا بسبب نقص المغذيات الكافية للنباتات. وبالتالي ، فإن الهدف من هذه الدراسة هو تحديد تأثير التطبيق المشترك للفحم الحيوي والفطريات المايكورايزا على نمو القمح (*Triticum aestivum L.*) وأدائه في التربة الكلسية. تتكون تجربة من أربعة وستين وحدة التجريبية (مستويين من الفطريات المايكورايزا ، نوعان من السماد الطبيعي ، وأربعة مستويات من الفحم الحيوي) باستخدام التصميم العشوائي العاملي الكامل (CRD) بأربع مكررات. أظهرت النتائج أن Cattle 1 t. h^{-1}+Mycorrhiza أنتجت أقصى ارتفاع للنبات (68.50 سم) ووزن الساق بعد التجفيف (3.95 جم) وطول الجذر (39.95 سم) بعد الحصاد ، أما Poultry 3 t. h^{-1}+Mycorrhiza سجلت اعلي نسبة N في البذور (1.62٪) ، نسبة البروتين في البذور (9.34٪) ، الوزن 1000 بذرة (49.23 جم). في المقابل ، Poultry 1 t.h^{-1} +Mycorrhizaأنتجت أقل ارتفاع للنبات (45.00 سم) ، نسبة النيتروجين في البذور (0.73٪) ، نسبة البروتين في البذور (4.24٪) ، وزن الفرع بعد التجفيف (1.97 جم) ، الوزن 1000 بذرة (38.18 جم) ، طول الجذر (27.25 سم). يشير هذا إلى أن Cattle 1 t. h^{-1}+Mycorrhiza لها تأثير أعلى على أداء القمح مقارنة Poultry 1t.h^{-1}+Mycorrhiza من بين العلاجات الأخرى. في الختام، أوضحت النتائج أن توليفات الفحم الحيوي والفطريات الفطرية لها تأثير معنوي على نمو وأداء نباتات القمح في التربة الكلسية. لذلك، يمكن للمزارعين استخدام Cattle1 t. h^{-1} + Mycorrhiza لتحسين أداء القمح في التربة كلسية في العراق.

كلمات مفتاحية: الفحم الحيوي، التربة الجيرية، نمو، الفطريات الفطرية و أداء قمح.

INTRODUCTION

Biochar is a carbonaceous substance obtained by pyrolyzing feedstock from biomass (Lima *et al.*, 2021). It is added to soils in order to improve fertility and mitigate greenhouse gas emissions. Biochar has the ability to alter the physical and chemical properties of soils, thereby influencing their fertility. On the other hand, biochar prevents the degradation of chemical and biochemical substances (Ali *et al.*, 2019). The use of biochar as a soil amendment is currently gaining considerable attention due to its ability to enhance soil nutrients. It has the ability to retain water, decompose slowly, and have a high level of sustainability (Taheri *et al.*, 2023).

Biochar absorbs nutrients from poultry or cattle manure while also reducing odors. The poultry or cattle biochar application improves soil quality by raising the soil pH, moisture-holding ability, cation-exchange capacity, and microbial flora (Liu *et al.*, 2021). Basic cation availability as well as phosphorus and total nitrogen concentrations have all increased in the soil after the addition of biochar (Zahra *et al.*, 2022). Biochar is a sustainable product with great promise for improving the health and fertility of agricultural soils. Biochar and its impact on soils can lessen the requirement for synthetic fertilizers. It has been demonstrated that biochar, which depends on its porosity and surface charge, enhances the soil's ability to retain nutrients in calcareous soil (Ali, Saudi, & El-Sadek, 2023). Biochar improves soil nitrogen and phosphorus retention by minimizing leaching and gaseous loss, depending on the pyrolysis and feedstock conditions. Plant reactions to biochar may potentially be influenced by feedback from its effects on soil microorganisms (Hammer *et al*., 2015).

The Kurdistan region of Iraq is characterized by calcareous soils. Research has shown the adverse effect of calcareous soil on plant growth and performance (Belal, El Sowfy, & Rady, 2019). The calcareous soils are typical of semi-arid and arid climates with low rainfall. Micronutrients are deficient in calcareous soils. Calcium accumulation can result in calcium carbonate precipitating around roots. Wheat production in the Iraqi Kurdistan region is at risk as a result of the increasingly severe system and the stunted growth of plants caused by a lack of sufficient nutrient availability in calcareous soils. Production of wheat has been reduced due to poor soil fertility and a deficiency in organic matter that significantly hinders wheat development and performance (Karatayev *et al.,* 2022). Additionally, warmer temperatures hasten the phenological development of wheat, which reduces biomass performance since there is less radiation absorption and nutrient uptake, both of which are detrimental to wheat performance (Kaler *et al.,* 2022). Wheat is grown in almost every region of the world and is a major source of food and income for millions of smallholder farmers (Karatayev *et al.*, 2022). An estimated 35% of people worldwide rely on wheat as their main crop (Erenstein *et al.*, 2022). It has been a primary source of nutrition for the main civilizations of Europe, Asia, and Africa for the past 7,000 years (Rajaram & Braun, 2008; Tadesse *et al.,* 2017). Currently, more land is used to grow wheat than any other commercial crop, and it continues to be the primary source of grain for human consumption (Pequeno *et al*., 2021).

Arbuscular mycorrhizal fungus availability affects wheat growth (Watts-Williams *et al.*, 2022). These organisms work in harmony with plant roots to increase plant resilience to stress and nutrient availability (Zhang *et al.* 2019). Additionally, these fungi can strengthen plant roots by promoting adventitious root initiation, auxin exchange, and the growth of root hair. Mycorrhizal fungi have been shown to considerably increase crop growth, nitrogen uptake, and performance (Liu *et al.*, 2022). Nutrient availability for crops in arid environments may be improved by using biochar and plant growth promoters. Although biochar has the potential to be used in soil management applications, we know very little about how these materials alter the physical, chemical, and biotic components of the soil when compared to other soil modifications. Nutrient loss and leaching of organic matter from tropical soils are the main causes of deterioration that affect wheat growth and performance. Therefore, the objective of this study is to determine the effect of the combined application of biochar and mycorrhizal fungi on wheat (*Triticum aestivum*) growth and performance in calcareous soil.

MATERIALS and METHODS

Experimental Design

In this study, a total of sixteen treatments—two levels of mycorrhizae, two types of manures, and four levels of biochar—were employed. Four replicates of the treatments were used in a factorial and completely randomized design (CRD). Table 1 displays the experimental design of this study. The treatments were carefully applied and thoroughly mixed with the unsterilized calcareous soil (from the Bakrajo field). Fill pots after a thorough cleaning with the improved soil. When irrigation is necessary, the wheat seeds are planted at the recommended depth. The soil was collected from the field experiment. The soil was air dried, sieved (4 mm), weighed, and manually mixed in the treatment's plastic pots carrying 5 kg of soil. Biochar doses were 0, 1, 2, and 3 tons/hectare.

Table 1: Experimental design of this study

Mycorrhiza		Non mycorrhiza	
0 t ha^{-1} Cattle Manure Biochar	0 t ha^{-1} Poultry Manure Biochar	0 t ha^{-1} Cattle Manure Biochar	0 t ha^{-1} Poultry Manure Biochar
1 t ha^{-1} Cattle Manure Biochar	1 t ha^{-1} Poultry Manure Biochar	1 t ha^{-1} Cattle Manure Biochar	1 t ha^{-1} Poultry Manure Biochar
2 t ha^{-1} Cattle Manure Biochar	2 t ha^{-1} Poultry Manure Biochar	2 t ha^{-1} Cattle Manure Biochar	2 t ha^{-1} Poultry Manure Biochar
3 t ha^{-1} Cattle Manure Biochar	3 t ha^{-1} Poultry Manure Biochar	3 t ha^{-1} Cattle Manure Biochar	3 t ha^{-1} Poultry Manure Biochar

Study Area and Soil sample

This research was carried out in the department of soil and water sciences and the plastic house of the college of agricultural sciences at the University of Sulaimani in Bakrajo in 2021. The soil used in this study belongs to the silty clay loam (Vertisols order). The soil was collected from the research field experiment of the College of Agricultural Sciences at a depth of 15–30 cm in November 2021 (35032’18” N, 45021’58” E), and the soils were low in phosphorus content. Table 2 shows the physical and chemical properties of the sampled soil.

Table 2: Physical and chemical properties of the sampled soil

Properties	Study soil
Sand g kg^{-1}	78.8
Silt g kg^{-1}	523.2
Clay g kg^{-1}	398.0
Texture class	Silty Clay (S.C)
pH	7.37
EC $ds.m^{-1}$ at 25^0c	0.37
Organic Matter g kg^{-1}	6.30
Carbonate Calcium$CaCO_3$ g kg^{-1}	232.6
Available Phosphorus ppm	11.33
Soluble K mmol l^{-1}	0.31
Zn mg kg^{-1}	0.5
Total N mg kg^{-1}	1.26
Na mg kg^{-1}	40.8

Mycorrhiza Inoculation

Arbuscular mycorrhizal fungi (AMF) (Glomus intraradices) were obtained from Dr. Anwar Othman Mohammad, University of Sulaimani. The inoculum was prepared by adding 75 g of mycorrhiza to a pot, watering it, and maintaining it at 70% field capacity. Commercial wheat seeds were obtained, and surface sterilized using 0.1% HgCl2 for 10 min. The wheat seeds were sown in sterilized plastic pots containing 4 kg of sterilized soil in an autoclave at 121 °C and 15 bar pressure for 2 hours for three days. Following two months, the plants infected with mycorrhizal fungus were observed under microscopic conditions using an established method (Phillips and Hayman 1970). After the removal of the shoots, the roots were chopped and mixed with the same soil in which the plants were grown. The final mixture of soil containing fungus propagules, spores, and infected root segments was used as mycorrhizal fungus inoculums.

Preparation of Biochars

Biochar was prepared using a pyrolysis process (which is a thermochemical and anaerobic process that occurs at higher temperatures) of air-dried cow manure and chicken manure (at 300 °C for 10 min in a muffle furnace) according to Sikder and Joardar (2019). The chemical properties of the biochar are given in Table 3.

Table 3: The chemical properties of the biochars.

Properties	Poultry biochar	Cattle biochar
pH	9.25	8.75
EC ms cm^{-1}	9.3	7.8
Nitrogen %	5.6	3.5
Available Phosphorus (ppm)	7.220	4.610
Potassium (ppm)	9.530	8.545
Zn (ppm)	84.5	75.3
Mn (ppm)	41.1	33.2
Cu (ppm)	13.8	10.9
Fe (ppm)	321.4	225.7

Growth Index determination

Plant height was measured in centimeters from the base of the plant to the apical point of the plant using a meter rule in centimeters (cm), and the mean of the plant length was computed. The total dry weight of the shoot was calculated based on the total dry weight of the leaves and stem from each plant after drying them in an oven at 65 °C.

Plant Total Nitrogen

Plant total nitrogen was determined with the Dumas method (Purcell and King 1996). Sieve a plant sample with a 0.2-mm mesh and weigh approximately 0.05 g of sieved plant samples; place them in a thin aluminum container and close it. After that, the total nitrogen was read by Dumatherm.

Seed Digestion

About 0.5 g of plant sample was weighed and placed in a special plastic tube, followed by 10 ml of HNO_3 concentration. Closed neatly and thoroughly to remove any acid, then covered with a metal cover and placed in a machine container holding 40 tubes, digestion began in the microwave machine Microdalga CEM model (MARS 6 240/50). After cooling, it was carefully opened in the hood to pass the gas and placed in another tub containing nearly 5 ml of distilled water, which was slowly filled to 25 ml with distilled water (Kacar 1994). This solution was used to determine the elements.

Statistical Analysis

The data are displayed as Mean and were analyzed using analysis of variance (ANOVA). Duncan's test was used to compare the mean differences between the groups. Data analysis was done using IBM SPSS Statistics version 24. The level of significance was set at $p \leq 0.05$.

RESULTS AND DISCUSSION

The combined treatments show that biochar and Mycorrhiza have significant effect on growth index of wheat plants in calcareous soil. Figure 1 shows the results of effect of biochar and Mycorrhiza on plant height. The treatment with cattle +M produced greater plant height (mean = 47.93) than those treated with cattle-M (mean = 46.25), poultry +M (mean=46.68), and poultry-M (mean = 44.75). This suggests that the cattle +M had better growth due to combined effect of biochar and Mycorrhiza. According to Jabborova *et al*. (2021a), arbuscular mycorrhizal fungus and biochar can enhance soil qualities, support microbial activity, and encourage plant growth. Water-soluble organic matters that promote seed germination and plant growth are a major component of the mechanisms causing the beneficial effects (Chintala *et al.*, 2014). However, there is no significant difference between plant height for cattle-M and poultry + M treatments, which suggest that relatively, equal effect. This could cause by interaction effect in both treatments. Upadhyay (2015) indicated that mycorrhizal rates and biochar individuals had significant effects, but their combinations had little effect on plant growth.

Figure 2 displays the results of effect of biochar levels and Mycorrhiza in tons per hectare ($t.h.^{-1}$) application on plant height. The results show that soil with cattle manure treatments, that is, cattle 3 $t.h.^{-1}$ and cattle 2 $t.h.^{-1}$ had significantly higher mean of plant height of 50.5 and 49.5, respectively compared to other treatments. That soil treated with poultry produced lower plant height. This suggests that the combination of biochar level and mycorrhiza improve the plant height thereby increasing the wheat growth. This finding is similar to that reported by Rahayu, Nurmalasari, and Aini (2022). These authors showed that at seven weeks following planting, animal waste biochar application enhanced maize development in terms of plant height, leaf count, stem diameter, and dry weight.

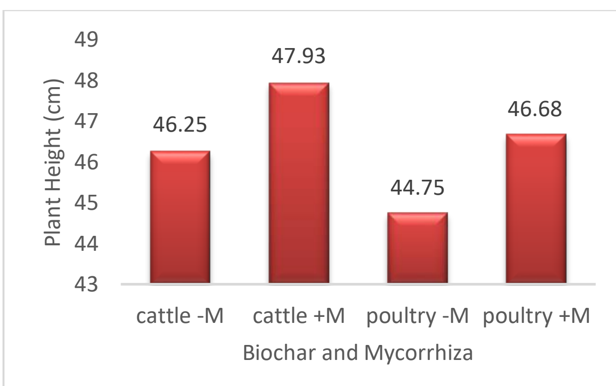

Figure 1: Effect of biochar and Mycorrhiza on plant height

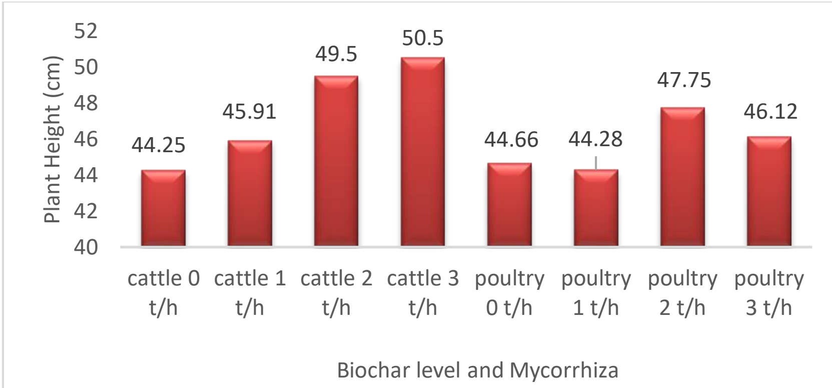

Figure 2: Effect of biochar levels and Mycorrhiza on plant height

Figure 3 depicts the results of the effect of biochar and mycorrhiza on root length. The poultry-M treatment produced the highest root length (mean = 27.25), while the cattle +M treatment produced the lowest root length (mean = 23.21). This result is contrary to those of plant height, which indicates different effect of the combined treatment on plant growth. This may be due to likelihood of release of nutrient available to the wheat plants. However, the results of the effect of biochar levels and Mycorrhiza in tonnes per hectare ($t.h.^{-1}$) application on root lengths (Figure 4) showed that 1 $t.h.^{-1}$+M (mean = 33.50) and 2 $t.h.^{-1}$-M (mean = 37.12) produced the highest root lengths compared to other treatment. The control (0 $t.h.^{-1}$-M) had the lowest root length, followed by 2 $t.h.^{-1}$+M and 3 $t.h.^{-1}$+M. This suggests that combination of biochar and mycorrhiza at low application had significant effects on wheat growth in calcareous soil. According to Martnez-Gómez, Poveda, and Escobar (2022), the continuous application of 20 tons ha^{-1} of chicken biochar promote plant development and increased soil N uptake by 14 percent to 26 percent and by 7 percent to 11 percent. With two levels of treatment, another study used a factorial randomised block design. Level 1 involved applying biochar at rates of 0 tons per hectare, 4 tons per hectare, 8 tonnes per hectare, and 12 tons per hectare improve the plant growth (Kalus, Koziel, & Opaliński, 2019).

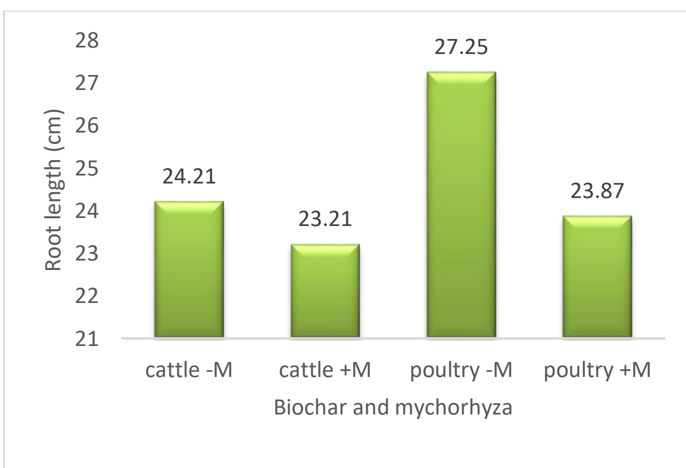

Figure 3: Effect of biochar and mycorrhiza on root length

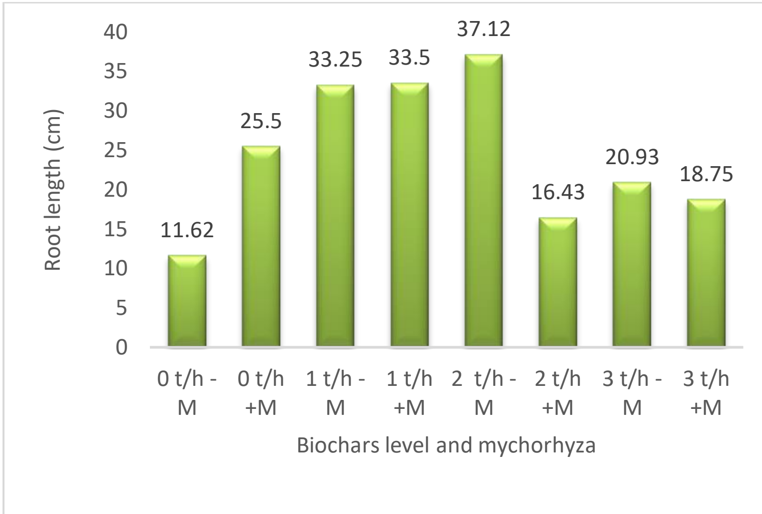

Figure 4: Effect of biochar levels and mycorrhiza on root length

Based on these on these explained above, the Cattle 1 t.h.$^{-1}$+Mycorrhiza treatment appeared to give the optimal growth of wheat plants. In terms of plant height and root length, Cattle 1 t.h.$^{-1}$+Mycorrhiza treatment had the highest results due to its interaction with inoculation. Growth results showed that mycorrhizal inoculation and cattle manure in field-grown wheat could be used in farming to enhance plant growth and grain yield. Cattle manure increases the amount of organic carbon, nitrogen, phosphorus, potassium, calcium, and sodium in the soil (Zahra *et al.*, 2022). These are macronutrients with great essential effects on plant growth and development. However, compared to poultry manure, cattle manure has significantly less nitrogen, making it safe to feed straight to the soil without harming plants (Aranguren *et al.*, 2021). Additionally, it provides a tonne of organic matter and helpful microbes. Furthermore, the presence of mixed mycorrhizae in the cattle manure could be another factor supporting the wheat height increment in the current study. Mycorrhizae often enhance the health of plants and their roots, which may make diseases less destructive (Boutasknit *et al.*, 2022). Plants with mycorrhizae are better equipped to fend off infections from plant diseases (Jasim & Kamal, 2022). According to Jasim & Kamal (2021), mycorrhiza binds to plant roots and draws nutrients from the soil that the root system would not otherwise be able to get. This fungus-plant interaction promotes plant growth and hastens root formation.

However, the increase in wheat root length in poultry-M treatment may be caused by the high soil moisture and high nitrogen content of the poultry biochar, which increase the nutrients around the roots of the plants, improve root absorption, and promote plant growth by making more nutrients available. This will lead to an increase in root length (Agbede, Adekiya, & Eifediyi, 2017). Mycorrhizae interaction with poultry can also enhance root surface area, which enables plants to absorb water and nutrients from a huge soil volume more effectively (Zarea & Karimi, 2022). Another explanation for this effect of poultry-M treatment in the present study is the nature of poultry biochar conversion in the soil. The easy conversion of poultry biochar to important nutrients (N, P, and K), immobile nutrients (P, Cu, Zn, etc.), and a high rate of photosynthesis can facilitate some plant growth and increased shoot dry weight (Liu *et al.*, 2022).

Table 4 presents the results of the combined effect of biochar and mycorrhiza on the performance of the wheat plant. Cattle 1 $t.h.^{-1}$+Mycorrhiza (68.50 cm) and Cattle 1 $t.h.^{-1}$-Mycorrhiza (65.25 cm) produced the highest plant height before harvesting compared to Poultry 1 $t.h.^{-1}$+Mycorrhiza (45.00 cm) and Poultry 1 $t.h.^{-1}$-Mycorrhiza (44.50 cm) that had the lowest plant height. This indicates that the Cattle 1 $t.h.^{-1}$+Mycorrhiza treatment have a greater effect on the performance of wheat hight plant than other treatments in a calcareous soil. Similarly, poultry 3$t.h^{-1}$+Mycorrhiza (1.62%) and Cattle 3 $t.h^{-1}$-Mycorrhiza 1.51%) produced the maximum N in seeds after harvested of compared to Poultry 1 $t.h^{-1}$+Mycorrhiza (0.73%) and Poultry 3 $t.h^{-1}$-Mycorrhiza (0.74%) that had the lowest N in seeds (Table 4). This indicates that the poultry 3 $t.h^{-1}$-Mycorrhiza treatment has a greater effect on the performance of wheat than other treatments, which shows its better performance. A study found that plants treated with biochar grew 66.6 percent taller, with 45.1 percent more leaves and 359 percent more nodules, than plants treated with control (Jabborova *et al.*, 2021b).

Moreover, the highest percentage of protein in seeds was noted for poultry 3$t.h^{-1}$+Mycorrhiza (9.34%) and Cattle 3 $t.h^{-1}$-Mycorrhiza (8.69%) treatments, while the lowest were noted for Poultry 1 $t.h^{-1}$+Mycorrhiza (4.24%) and Poultry 3 $t.h^{-1}$-Mycorrhiza (4.28%) treatments compared to other treatments (Table 4). The results show a significant effect of poultry 3$t.h^{-1}$+Mycorrhiza application on the percentage of protein in seeds in a calcareous soil over other treatments. Likewise, the maximum weight of shoot after drying was noted for Cattle 1 $t.h.^{-1}$+Mycorrhiza (3.95 g) and Cattle 1 $t.h.^{-1}$-Mycorrhiza (3.76 g) treatments, while the minimum was noted for Poultry 1 $t.h.^{-1}$+Mycorrhiza (1.97 g) and Poultry 1 $t.h.^{-1}$-Mycorrhiza (1.66 g) treatments compared to other treatments (Table 4). The results show a significant effect of Cattle 1 $t.h.^{-1}$ + Mycorrhiza application on the weight of the shoot after drying in calcareous soil over other treatments. Moreover, the Cattle 1 $t.h.^{-1}$+Mycorrhiza also produced higher weight 1000 Seed (41.48 g) and Root Length (39.82 cm) compared to other treatments, shown in Table 4. Altogether, all these performances parameter showed the excellent effect of combined Cattle 1 $t.h.^{-1}$+Mycorrhiza on wheat growth in calcareous soil. The poultry 1 $t.h^{-1}$-Mycorrhiza treatment appeared to have a minimal effect on wheat growth and performance in calcareous soil. This may be due to the limiting nature of essential nutrients, such as P, in the calcareous soil, which affects the growth and performance of wheat. The combined effect of mycorrhiza and the composition of poultry manure may have some adverse effects on the availability of nutrients for wheat in calcareous soil. Due to its alkaline composition, reactivity, and pH, calcareous soil typically has lower nutrient availability. According to Luo *et al*. (2023), P is retained and immobilized in calcareous soils as a result of precipitation and adsorption. Since soil pH is presumed to be a key factor influencing the sorption of P, poultry manure may have lower P adsorption in calcareous soils. In calcareous soils, Ca build-up can result in $CaCO_3$ precipitating surrounding roots (Ali, Saudi, & El-Sadek, 2023), which can stunt plant growth by causing chlorosis due to lime.

Table 4: Effect of the combined biochar and mycorrhiza on performance of wheat plant

Treatments	Plant height (cm)	% N in seeds	% Protein in seeds	Weight of shoot after drying (g)	Weight 1000 Seeds (g)	Root Length (cm)
Cattle 0 $t.h^{-1}$ -Mycorrhiza	40.25 ^{e}	1.14 ^{e}	6.58 ^{e}	1.41 ^{e}	42.00 ^{a}	24.62^{ef}
Cattle 0 $t.h^{-1}$ +Mycorrhiza	42.25 ^{de}	1.31 ^{cd}	7.57 ^{cd}	1.44 ^{e}	40.92 ^{a}	25.50 ^{e}
Cattle 1 $t.h^{-1}$ -Mycorrhiza	65.25 ^{a}	1.22 ^{de}	7.01 ^{de}	3.76 ^{a}	39.94 ^{a}	32.65^{b}
Cattle 1 $t.h^{-1}$ +Mycorrhiza	68.50 ^{a}	1.34 ^{cd}	7.73 ^{cd}	3.95 ^{a}	49.23 ^{b}	39.82 ^{a}
Cattle 2 $t.h^{-1}$ -Mycorrhiza	57.00 ^{bc}	1.50 ^{ab}	8.67 ^{ab}	2.04 ^{c}	40.15 ^{a}	30.50 ^{c}
Cattle 2 $t.h^{-1}$ +Mycorrhiza	59.50 ^{b}	1.24 ^{de}	7.13 ^{de}	2.81 ^{b}	40.21 ^{a}	17.50 ^{g}
Cattle 3 $t.h^{-1}$ -Mycorrhiza	51.50 ^{c}	1.51 ^{ab}	8.69 ^{ab}	3.03 ^{ab}	39.94 ^{a}	22.00 ^{de}
Cattle 3 $t.h^{-1}$ +Mycorrhiza	49.50 ^{d}	1.43 ^{bc}	8.26 ^{bc}	2.32^{bc}	40.29 ^{a}	16.12 ^{g}
Poultry 0 $t.h^{-1}$ -Mycorrhiza	38.56 ^{f}	1.14 ^{e}	6.58 ^{e}	1.41 ^{e}	42.00 ^{a}	21.62 ^{f}
Poultry 0 $t.h^{-1}$ +Mycorrhiza	30.77 ^{g}	1.31 ^{cd}	7.57 ^{cd}	1.64 ^{e}	40.92 ^{a}	25.50 ^{e}
Poultry 1$t.h^{-1}$ -Mycorrhiza	44.50 ^{de}	0.97 ^{f}	5.59 ^{f}	1.66 ^{e}	39.98 ^{a}	27.75 ^{de}
Poultry 1 $t.h^{-1}$ +Mycorrhiza	45.00 ^{de}	0.73 ^{g}	4.24 ^{g}	1.97^{ce}	38.18 ^{a}	27.25 ^{de}
Poultry 2 $t.h^{-1}$ -Mycorrhiza	48.25 ^{cd}	1.19 ^{de}	6.84 ^{de}	1.34 ^{ce}	39.64 ^{a}	28.75 ^{d}
poultry 2 $t.h^{-1}$ +Mycorrhiza	47.25 ^{cd}	0.82 ^{g}	4.74 ^{g}	1.55 ^{e}	41.48 ^{a}	25.37 ^{ef}
poultry 3 $t.h^{-1}$ -Mycorrhiza	46.00 ^{de}	0.74 ^{g}	4.28 ^{g}	1.89 ^{ce}	39.20 ^{a}	19.87 ^{de}
Poultry 3 $t.h^{-1}$ +Mycorrhiza	46.25 ^{de}	1.62 ^{a}	9.34 ^{a}	1.77 ^{ce}	41.42 ^{a}	21.37 ^{de}

$^{a-g}$ Means with the same superscript in a column are not significantly differed at $p \leq 0.05$.

In contrast with poultry manure, the findings of this study have also shown that the combination of biochar and mycorrhiza, particularly Cattle1 $t.h.^{-1}$+Mycorrhiza has a significant effect on the performance of the wheat plants in the calcareous soil. The Cattle1 $t.h^{-1}$+Mycorrhiza treatment significantly improved plant height, weight of the shoot after drying, weight 1000 seed, and root length. Mycorrhizae fungus introduction as powdered spores (inoculants) has been indicated to enhance the performance of wheat plants (Ganugi *et al.,* 2019). With the aid of inoculants, mycorrhizae can be increased in abundance in sterile media and deficient soils from a total absence (Yang *et al.,* 2022). The addition of Cattle1 $t.h^{-1}$+Mycorrhiza improves the activity of the mycorrhizal and root systems, increasing the percent protein in seeds and improving nutrient and water availability. Typically, the use of Cattle1 $t.h^{-1}$+Mycorrhiza has a net beneficial impact on crop development. The fungus receives sustenance from the roots by improving P mineral absorption via mycorrhizal fungi. In exchange, the wheat acts as a host plant, which is required for fungal development and propagation because mycorrhizal fungi influence mineral nutrition, water absorption, growth, and disease resistance in their host plants.

CONCLUSION

The findings of this study showed that combinations of biochar and mycorrhizal fungi have a significant effect on the growth and performance of wheat plants in calcareous soil. The findings revealed that cattle 1 t.h^{-1}+Mycorrhiza treatment produced the highest plant height (68.50 cm), the weight of the shoot after drying (3.95 g), and root length (39.95 cm) after harvested. percent N in seeds (1.51%), percent protein in seeds (9.34%), weight of the shoot after drying (3.95 g), weight 1000 seeds (49.23 g), and root length (39.82 cm) after two months of planting. However, poultry 1 t.h^{-1}+Mycorrhiza produced the lowest plant height (44.50 cm), however Poultry 3t.h^{-1}+Mycorrhiza record percentage N in seeds (1.62%), percentage protein in seeds (9.34%), the weight 1000 seeds (49.23 g), In contrast, Poultry 1 t.h^{-1}+Mycorrhiza produced the minimum plant height (45.00 cm), percent N in seeds (0.73%), percent protein in seeds (4.24 %), the weight of the shoot after drying (1.97 g), the weight 1000 seeds (38.18 g), and root length (27.25 cm). Out of sixty four treatments, the Cattle1 t.h.$^{-1}$+Mycorrhiza has the best and most improved plant height , weight of the shoot after drying, weight 1000 seed, and root length compared to other treatments. In terms of field application rate, cattle 3 t/h and cattle 2 t/h had a significant effect on plant height compared to poultry manure applications. In conclusion, Cattle1 t.h.$^{-1}$+Mycorrhiza can be used by farmers to improve their wheat performance in calcareous soil in Iraq.

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