Sustainable Chilli (*Capsicum annum* L.) Farming: Coconut Shell Biochar Influence on Growth and Yield Levels in Acid Soils

Comment [N1]: Title Too Long. Preferably: "The Effect of Coconut Shell Biochar on the Growth and Yield of Chili (Capsicum annum L.) in Soil....... " "

Comment [N2]: What type of acid soil to use. Name the land order

ABSTRACT

The utilization of coconut shell biochar in acidic soils has shown promise in enhancing the growth and yield of chilli (*Capsicum annum* L.), presenting a sustainable solution for improving crop productivity in challenging environments. This study investigates the specific effects and potential benefits of biochar application on chilli cultivation in acidic soil conditions. A field experiment was conducted at ZARS, UAS, GKVK Bengaluru-65 during *Rabi* season 2020-21, to assess the "Effect of coconut shell biochar on growth of chilli in acid soils". The experiment was laid out in an RCBD with eight treatments replicated thrice. The results revealed that biochar application significantly increased the growth parameters of chilli. Significantly higher plant height (72.67 cm), number of leaves per plant (107.83), number of primary branches per plant (6.87), and chilli fruit length (8.12 cm) were recorded in treatment recommended NPK + Biochar @ 30 t ha-1 and was found on par with different levels of biochar applied plots (Recommended NPK + Biochar @ 10, 15, 20 and 25 t ha^{-1}) in most of the growth parameters. But the diameter of chilli fruits was found non-significant with the different treatments. The lowest plant height, number of leaves, number of branches per plant, fruit length, and diameter were found in treatment absolute control. Results showed significant enhancements in plant height, number of branches, leaves, flowers, and fruit yield with biochar use, particularly at 30 t ha^{-1}. These improvements are attributed to biochar's ability to improve soil pH, nutrient availability, water retention, and microbial activity. The potential of biochar as a sustainable solution for enhancing crop productivity in challenging acidic soil conditions.

Comment [N3]: The truth is Chile. Change all Chilli to Chile i

Comment [N4]: eIt's best to calculate it as a percentage

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Keywords: Chilli, Coconut Shell Biochar, Acid Soils, Field Experiment

Introduction

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Healthy soil is crucial for ecosystem stability, serving as a carbon reservoir vital to the global carbon cycle. Human activities treating soil merely as a commodity have depleted its organic matter, reducing productivity. To counter this, environmentally friendly practices like biochar use are promoted for sustainable soil fertility and plant growth. The production of chilli (*Capsicum annuum*) in India is a significant and integral part of the country's agricultural landscape. Chilli, is one of the most widely cultivated and consumed spices in India. It plays a crucial role in Indian cuisine, adding flavor, color and spiciness to a multitude of dishes. Chilli cultivation in India has a rich history, dating back centuries, and continues to be a major contributor to the country's agricultural economy. This food is very low in saturated fat, cholesterol and sodium. A serving of pepper (45 g) gives 18 kcal of energy (Herbazest, 2019). It is also a good source of dietary fiber, thiamine, riboflavin, niacin, folate, vitamin A, C, K, B6, iron, magnesium, phosphorous, potassium, copper, and manganese. The researchers found that the chemical capsaicin has anti-oxidant properties that fight the damage caused to the liver. Enzymes isolated from chilli fruits are used to treat certain types of cancer (Spice Board, 2019).

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India is considered a secondary centre of diversity, especially for the extensively cultivated species, *Capsicum annuum* (Dhaliwal *et al*., 2014).

India being the world's largest producer, consumer, and exporter of chillies has the largest area of 7.33 lakh ha (18.11 lakh acres) accounting for 42.8 percent of the world area. India is the world leader in chilli production with 17.64 lakh tonnes followed by China (3.21 lakh tonnes), Ethiopia (2.94 lakh tonnes), Thailand (2.47 lakh tonnes), and Pakistan (1.48 lakh tonnes) in 2018-19 (Anon, 2021). According to 2019-20 first advance estimates, Indian chilli occupied an area of 7.33 lakh hectares (18.11 lakh acres) with a production of 17.64 lakh tonnes and productivity of 2400 Kg per hectare (971 Kg per acre). In India, major chilli producing states are Andhra Pradesh (6.30 lakh tonnes), Telangana (3.04 lakh tonnes), Madhya Pradesh (2.18 lakh tonnes), Karnataka (1.95 lakh tonnes) and West Bengal (1.06 lakh tonnes) accounting for 35, 17, 12, 11 and 6 percent of all India production respectively. (Anon, 2021). Moisture stress, low organic matter content, and soil acidity are the major factors affecting chilli yields.

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In recent years, biochar has emerged as a carbon source and an amendment along with chemical fertilizers and holds a promise in improving the yield of crops without causing hazards to soil and the environment. Biochar, produced by pyrolysis, is the thermal decomposition of organic compounds at a temperature range of 300-800° C under limited or no supply of oxygen. Using biochar in agriculture can be a modern agro-technology that can help reduce greenhouse gas emissions, enhance soil carbon sequestration, and increase crop yield. Agricultural and forestry residues are a potential source of biomass to the soil, but these residues undergo faster decomposition and will adversely affect soil organic carbon stores and soil fertility (Lal, 2004 Wilhelm *et al*., 2004). Pyrolysis of residues (thermo-conversion in the absence of oxygen) may offer an alternative to produce energy as well as return carbon and nutrients to the soil (Laird, 2008).

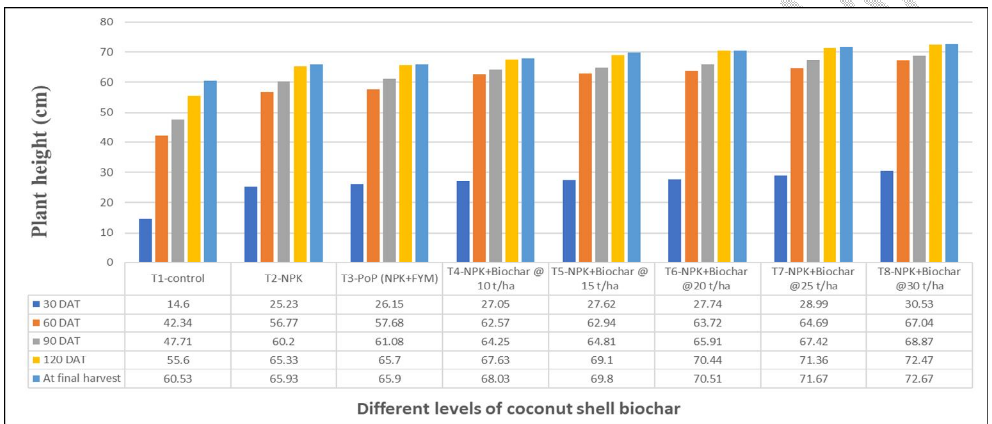
MATERIAL AND METHODS

A field experiment was conducted in ZARS, UAS, GKVK, Bengaluru (13º04'37.7"N 77º34'04.2"E) during *Rabi* 2020-21 with a test crop chilli. The recommended dose of fertilizer (150:75:75 kg ha^{-1} N, P_2O_5, K_2O) was applied as a basal dose with a recommended spacing of 75 × 45 cm and the seed rate was 30,000 seedlings/ha. A randomized complete block design was used with eight treatments and three replications. Various grades of biochar are available and the locally produced coconut shell biochar has been used in the present investigation. The coconut shell biochar was developed at a comparatively higher temperature (around 600° C) in a limited supply of oxygen and it was purchased from company Kalpatharu Products, Tiptur, Tumkur district, Karnataka. To calculate fruit yield (t ha^{-1}) and dry biomass yield (t ha^{-1}) weight of mature green fruits obtained from each plant through all pickings was recorded and the biomass was collected separately from the net crop fields (sample of 5 tagged plants) and it was oven dried. Leaf, stem and root dry weight was estimated and expressed in kg ha^{-1}.

RESULT AND DISCUSSION

Plant height (cm) of chilli

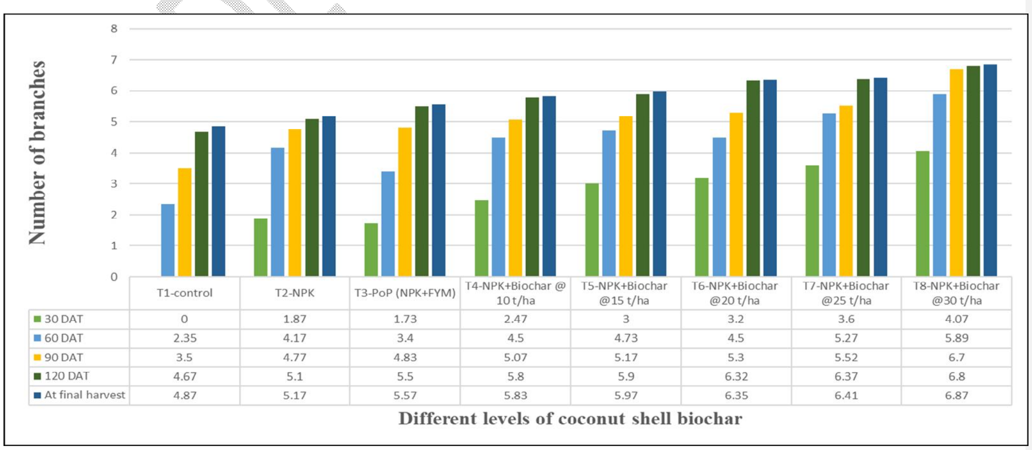
The plant height (cm) of chilli as influenced by different biochar rates at different growth stages. With different treatments, plant height varied greatly at all growth stages (**Fig. 1)**. Plant height gradually increased with crop age rise up to 120 days after transplanting and subsequently a slighter lower increase until harvest. At 30 DAT, the treatment which received recommended NPK + coconut shell biochar @ 30 t ha^{-1} (T_8) recorded significantly higher plant height (30.53 cm) compared to T_3 (26.15 cm) which was package of practice (Recommended NPK + FYM 25 t ha^{-1}). However, T_8 (Recommended NPK + coconut shell biochar @ 30 t ha^{-1}) was on par with T_7 (28.99 cm), T_6 (27.74 cm), T_5 (27.62 cm) and T_4 (27.05 cm) received recommended NPK + coconut shell biochar @ 25 t ha^{-1}, recommended NPK + coconut shell biochar @ 20 t ha^{-1}, recommended NPK + coconut shell biochar @ 15 t ha^{-1} and recommended NPK + coconut shell biochar @ 10 t ha^{-1} respectively. Lowest value was reported in T_1 which was absolute control (14.60 cm) which did not obtain any external nutrient and biochar sources. Similar trends were also followed in the plant height of chilli at 60 DAT, 90 DAT, 120 DAT and at harvesting stage.



	T1-control	T2-NPK	T3-PoP (NPK+FYM)	T4-NPK+Biochar @ 10 t/ha	T5-NPK+Biochar @ 15 t/ha	T6-NPK+Biochar @20 t/ha	T7-NPK+Biochar @25 t/ha	T8-NPK+Biochar @30 t/ha
30 DAT	14.6	25.23	26.15	27.05	27.62	27.74	28.99	30.53
60 DAT	42.34	56.77	57.68	62.57	62.94	63.72	64.69	67.04
90 DAT	47.71	60.2	61.08	64.25	64.81	65.91	67.42	68.87
120 DAT	55.6	65.33	65.7	67.63	69.1	70.44	71.36	72.47
At final harvest	60.53	65.93	65.9	68.03	69.8	70.51	71.67	72.67

Fig. 1: Effect of coconut shell biochar application on plant height (cm) at 30DAT, 60DAT, 90DAT, 120DAT and at final harvest stages of chilli

Note: CD value for plant height at 30, 60, 90, 120 DAT and at final harvest is 4.36, 7.27, 7.50, 6.34 and 5.66 respectively



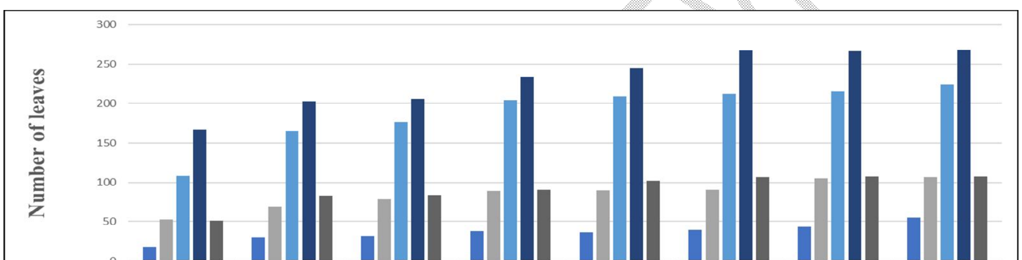
	T1-control	T2-NPK	T3-PoP (NPK+FYM)	T4-NPK+Biochar @ 10 t/ha	T5-NPK+Biochar @15 t/ha	T6-NPK+Biochar @20 t/ha	T7-NPK+Biochar @25 t/ha	T8-NPK+Biochar @30 t/ha
30 DAT	0	1.87	1.73	2.47	3	3.2	3.6	4.07
60 DAT	2.35	4.17	3.4	4.5	4.73	4.5	5.27	5.89
90 DAT	3.5	4.77	4.83	5.07	5.17	5.3	5.52	6.7
120 DAT	4.67	5.1	5.5	5.8	5.9	6.32	6.37	6.8
At final harvest	4.87	5.17	5.57	5.83	5.97	6.35	6.41	6.87

Fig. 2: Effect of coconut shell biochar application on number of branches per plant at 30DAT, 60DAT, 90DAT, 120DAT and at final harvest stages of chilli.

Note: CD value for number of branches per plant at 30, 60, 90, 120 DAT and at final harvest is 1.28, 0.84, 1.62, 0.65 and 0.53 respectively.

Effect of coconut shell biochar on number of branches per plant of chilli

Application of recommended NPK + coconut shell biochar @ 30 t ha^{-1} (T_8) had a significantly higher number of branches per chilli plant (4.07) at 30 DAT and it was on par with treatment T_7 (3.60) and T_6 (3.20) received recommended NPK + coconut shell biochar @ 25 t ha^{-1} and recommended NPK + coconut shell biochar @ 20 t ha^{-1} compared to treatment T_3 (1.73) which was a package of practice (Recommended NPK + FYM 25 t ha^{-1}) (**Fig. 2)**. The lowest number of branches per plant (0.00) was recorded in treatment absolute control (T_1). The findings of the number of branches per plant of chilli at 60 DAT, 90 DAT, 120 DAT and at harvest also followed a similar trend as that at 30 DAT.



	T1-control	T2-NPK	T3-PoP (NPK+FYM)	T4-NPK+Biochar @ 10 t/ha	T5-NPK+Biochar @15 t/ha	T6-NPK+Biochar @20 t/ha	T7-NPK+Biochar @25 t/ha	T8-NPK+Biochar @30 t/ha
30 DAT	17.87	30.08	31.67	37.67	36.53	39.73	43.13	55.13
60 DAT	52.77	68.9	77.87	88.95	89.67	90.53	104.93	106.63
90 DAT	107.9	164.63	176.04	204.33	208.83	211.67	215.07	224.1
120 DAT	166.72	202.9	205.47	234.43	245.27	267.53	266.93	268.57
At final harvest	51.37	83	83.67	90.8	102.27	106.97	107.07	107.83

Fig. 3: Effect of coconut shell biochar application on number of leaves per plant at 30DAT, 60DAT, 90DAT, 120DAT and at final harvest stages of chilli.

Note: CD value for number of leaves per plant at 30, 60, 90, 120 DAT and at final harvest is 12.95, 19.95, 33.19, 19.82 and 21.71 respectively

Number of leaves per plant of chilli

At different growth stages of chilli, the number of leaves per plant varied with the different treatments (**Fig. 3)**. Number of leaves gradually increased with crop rise up to 120 days after transplanting and later decreased until harvest. At 30 DAT, the significantly highest number of leaves per plant (55.13) was recorded in the treatment T_8 received recommended NPK + coconut shell biochar @ 30 t ha^{-1} which was on par with T_7 (43.13) which received recommended NPK + coconut shell biochar @ 25 t ha^{-1} compared to T_3 (Package of practice) which had 31.67 number of leaves per plant. The lowest number of leaves was recorded in the treatment T_1 (17.87) which is absolute control. The variation in the number of leaves per plant with the different treatments at 60 DAT, 90 DAT, 120 DAT and at harvest also followed the similar trend as that of 30 DAT.

Number of days taken to first flowering

Application of biochar had no significant effect on the days for first flowering in chilli (**Table 1)**. However, treatment T_1 (Absolute control) and T_2 (Recommended NPK) had taken the lowest number of days for initial flowering (41 days). The highest number of days for initial flowering was taken in the treatment T_8 and T_7 (43 days) which received recommended NPK + coconut shell biochar @ 30 t ha^{-1} and recommended NPK + coconut shell biochar @ 25 t ha^{-1} respectively.

Table 1: Effect of coconut shell biochar application on number of days taken for first flowering in chilli

Treatments	Days taken for first flowering
T1 - Absolute Control	41
T2 - Recommended NPK	41
T3 - Package of Practice (NPK + FYM 25 t ha^{-1})	42
T4 - Recommended NPK + coconut Shell Biochar @ 10 t ha^{-1}	42
T5 - Recommended NPK + coconut Shell Biochar @ 15 t ha^{-1}	42
T6 - Recommended NPK + coconut Shell Biochar @ 20 t ha^{-1}	42
T7 - Recommended NPK + coconut Shell Biochar @ 25 t ha^{-1}	43
T8 - Recommended NPK + coconut Shell Biochar @ 30 t ha^{-1}	43
SEm ±	**1.61**
CD @ 5%	**NS**

Number of flowers per plant

At different growth stages of chilli, the number of flowers per plant had varied with the different treatments (**Fig. 4)**. The number of flowers per plant varied significantly at 60 DAT and at 90 DAT, but it varied non-significantly at 30DAT, 120 DAT and at harvest stage of chilli. Application of recommended NPK + coconut shell biochar @ 30 t ha^{-1} (T_8) had a significantly higher number of flowers per plant (18.00) at 60 DAT compared to T_3 (8.87) which was Package of Practice. Significantly lowest number of flowers (3.07) was recorded in treatment absolute control (T_1). A similar trend was followed for several flowers per plant at 90 DAT. The highest number of flowers at 30 DAT (1.67), 120 DAT (3.67), and at harvest (0.83) was recorded in treatment recommended NPK + coconut shell biochar @ 30 t ha^{-1}, and the lowest number of flowers 0.00, 0.73 and 0.00 was recorded in T_1 (absolute control) at 30 DAT, 120 DAT and at harvest respectively.

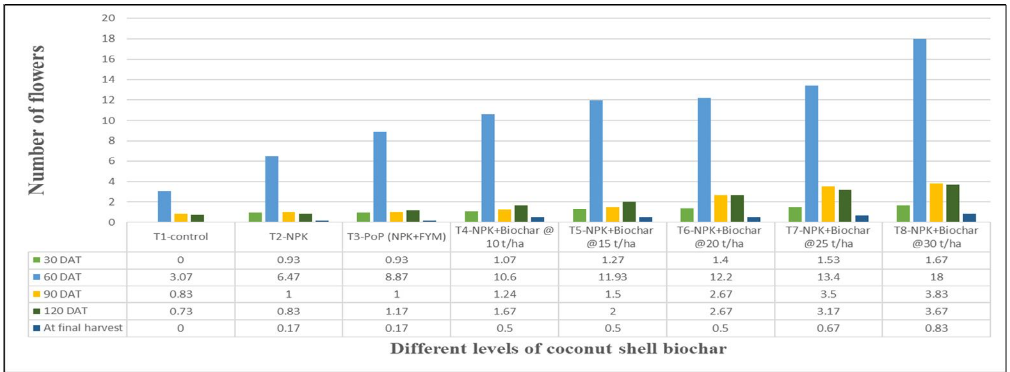


Fig. 4: Effect of coconut shell biochar application on number of flowers per plant at 30DAT, 60DAT, 90DAT, 120DAT and at final harvest stages of chilli.

Note: CD value for number of flowers per plant at 60 and 90 DAT is 5.00 and 2.51 respectively. At 30 and 120 DAT and at final harvest number of flowers per plant was found non-significant (NS).

There was a significant increase in the growth parameters *viz*., Plant height, number of leaves per plant, number of branches per plant and number of flowers per plant of chilli by application of recommended NPK + coconut shell biochar @ 30 t ha^{-1} (T_8) which was on par up to the lowest level of biochar application that is recommended NPK + coconut shell biochar @ 10 t ha^{-1} in most of the growth parameters. There were several factors which lead to improved crop growth attributes with the addition of biochar. Those factors will operate either individually or at the same time. In fact, a decrease in soluble Al and Fe, an increase in pH, a controlled and slow release of plant nutrients and increased nutrient availability, an increased supply of plant water and enhanced microbial activity have played a major role and helped to boost the growth parameters of crop which were mainly influenced by biochar treatments. Biochar addition improved the growth of chilli when compared to non-biochar treatments, this is because, in unamended soil the lower pH will cause root damage and reduces uptake of nutrients, whereas biochar addition increases pH and reduces the harmful effects on plants. The application of FYM in the treatment T_3 (Recommended NPK + FYM 25 t ha^{-1}) also increased the growth parameters as it adds organic carbon content to the soil, but increase in growth parameters was not as high as the biochar treatments, this is mainly because of the decreased pH of the soil brought by the decomposition of FYM in early stages by formation of organic acids. This makes the soil more acidic and hence decreases the nutrient concentration and plant growth when compared to biochar treatments. Hong *et al*. (2016) noticed the application of biochar increased the plant height, plants diameter, roots length, number of branches, leaves area, fruit length, fruit weight per chilli plant when compared to plants not received biochar.

Effect of coconut shell biochar on yield parameters of chilli

Significantly highest number of fruits per plant was observed in T_8 (193.07) which received recommended NPK + coconut shell biochar @ 30 t ha^{-1} which was on par with the least level of biochar applied treatment recommended NPK + coconut shell biochar @ 10 t ha^{-1} that is

T_4 (183.82) compared to the package of practice (T_3) which had 164.71 fruits per plant of chilli (**Table 2**). The lowest number of fruits (117.63) was observed in treatment T_1, which did not receive an external source of nutrients and biochar. The weight of fresh chilli fruits per plant varied significantly with different biochar levels. The highest fresh weight (1195.53 g) of chilli was observed in treatment recommended NPK + coconut shell biochar @ 30 t ha^{-1} (T_8) which was on par with T_7 (Recommended NPK + coconut shell biochar @ 25 t ha^{-1}), T_6 (Recommended NPK + coconut shell biochar @ 20 t ha^{-1}), T_5 (Recommended NPK + coconut shell biochar @ 15 t ha^{-1}) and T_4 (Recommended NPK + coconut shell biochar @ 10 t ha^{-1}) recorded the fresh weight of chilli 1187.10, 1162.07, 1107.17 and 1104.27 grams respectively, compared to T_3 (950.77 g) which received recommended NPK + FYM. Significantly lower weight was recorded in T_1 (721.13 g), absolute control.

Table 2. Effect of coconut shell biochar application on yield attributes of chilli at harvest

Treatments	Green Fruits	Fresh weight of green fruits (g)	Dry weight of red fruits (g)	Fruit length	Fruit diameter
	per plant	per plant	per plant	cm	cm
T1 - Absolute Control	117.63	721.13	56.75	7.85	1.32
T2 - Recommended NPK	144.66	839.63	86.24	7.95	1.33
T3 - Package of Practice (NPK + FYM 25 t ha^{-1})	164.71	950.77	90.54	8.01	1.34
T4 - Recommended NPK + coconut Shell Biochar @ 10 t ha^{-1}	183.82	1104.27	106.70	8.02	1.34
T5 - Recommended NPK + coconut Shell Biochar @ 15 t ha^{-1}	184.99	1107.17	107.15	8.03	1.34
T6 - Recommended NPK + coconut Shell Biochar @ 20 t ha^{-1}	189.80	1162.07	110.58	8.08	1.35
T7 - Recommended NPK + coconut Shell Biochar @ 25 t ha^{-1}	192.30	1187.10	112.29	8.10	1.35
T8 - Recommended NPK + coconut Shell Biochar @ 30 t ha^{-1}	193.07	1195.53	113.93	8.12	1.35
SEm ±	**5.53**	**45.17**	**5.07**	**0.07**	**0.03**
CD @ 5%	**16.78**	**137.01**	**15.39**	**0.24**	**NS**

Application of Recommended NPK + coconut shell biochar @ 30 t ha^{-1} (T_8) reported significantly higher dry weight (113.93 g) of fruits per plant which was on par with T_4 (106.70 g) received recommended NPK + coconut shell biochar @ 10 t ha^{-1} compared to the package of practice (90.54 g). Significantly lower dry weight (56.75 g) of chilli per plant was observed in treatment absolute control. Fruit length of chilli varied significantly with the application of different levels of biochar. Significantly higher length of fruits was observed in T_8 (8.12 cm) which received recommended NPK + coconut shell biochar @ 30 t ha^{-1} was on par with T_7 (8.10

cm) which received recommended NPK + coconut shell biochar @ 25 t ha^{-1} compared to absolute control (T_1) which had lowest fruit length of 7.85 cm. The diameter of chilli fruits was non-significant at different levels of application of the biochar. However, the higher fruit diameter (1.35 cm) was observed in T_6 (Recommended NPK + coconut shell biochar @ 20 t ha^{-1}), T_7 (Recommended NPK + coconut shell biochar @ 25 t ha^{-1}) and T_8 (Recommended NPK + coconut shell biochar @ 30 t ha^{-1}). Lower fruit diameter was observed in absolute control (1.32 cm).

Significant increase in yield parameters such as number of fruits per plant, fresh weight of fruits per plant, dry weight of fruits per plant, fruit length and fruit diameter were reported highest in recommended NPK + coconut shell biochar @ 30 t ha^{-1}. This may be attributed to more retention of plant nutrients in soil due to high cation exchange capacity and higher soil porosity, thus improved more nutrient availability and their supply by application of higher biochar levels. Biochar has been found to increase the efficiency of fertilizer usage by reducing the nutrient losses through leaching and fixation because biochar has both cationic (CEC) and anionic (AEC) exchange sites, as stated by Dong *et al*. (2015); Chan *et al*. (2007); Chan *et al*. (2008); and Taghizadeh - Toosi *et al*. (2012). The coconut shell biochar contains a high amount of total carbon, potassium, phosphorus, calcium and magnesium which improves the soil's physical, chemical and biological properties thus a significant increase in the yield parameters was recorded. Akca and Namli (2015) reported that higher fresh and dry weight of chilli pepper values were found in poultry litter biochar treated soil compared to untreated soil. Ibrahim *et al*. (2013) stated that the fruit length and fruit diameter of tomato plants increased by biochar addition.

Green fruit yield of chilli (t ha^{-1})

The incorporation of various biochar levels significantly influenced the yield of green chilli (**Table 3)**. Significantly higher fruit yield was reported in T_8 (31.54 t ha^{-1}) where Recommended NPK + coconut shell biochar @ 30 t ha^{-1} was applied which is on par with T_7 (30.60 t ha^{-1}), T_6 (30.32 t ha^{-1}), T_5 (29.89 t ha^{-1}) and T_4 (29.65 t ha^{-1}) received recommended NPK + coconut shell biochar @ 25 t ha^{-1}, recommended NPK + coconut shell biochar @ 20 t ha^{-1}, recommended NPK + coconut shell biochar @ 15 t ha^{-1} and recommended NPK + coconut shell biochar @ 10 t ha^{-1} respectively compared to Package of practice (T_3) which had 25.87 t ha^{-1} of green chilli. Significantly lowest yield (15.73 t ha^{-1}) was recorded in absolute control (T_1).

Table 3. Effect of coconut shell biochar application on green fruit yield (t ha^{-1}) of chilli

Treatments	Green Fruit yield t ha^{-1}
T1 - Absolute Control	15.73
T2 - Recommended NPK	22.59
T3 - Package of Practice (NPK + FYM 25 t ha^{-1})	25.87
T4 - Recommended NPK + coconut Shell Biochar @ 10 t ha^{-1}	29.65
T5 - Recommended NPK + coconut Shell Biochar @ 15 t ha^{-1}	29.89
T6 - Recommended NPK + coconut Shell Biochar @ 20 t ha^{-1}	30.32

T7 - Recommended NPK + coconut Shell Biochar @ 25 t ha^{-1}	30.60
T8 - Recommended NPK + coconut Shell Biochar @ 30 t ha^{-1}	31.54
SEm ±	**1.37**
CD @ 5%	**4.06**

Biomass yield (kg ha^{-1}) of chilli

Biomass yield differed greatly as a consequence of biochar treatment at various concentrations. Application of recommended NPK + coconut shell biochar @ 30 t ha^{-1} reported significantly highest total biomass yield (4607.21 kg ha^{-1}) which was on par with T_7 (Recommended NPK + coconut shell biochar @ 25 t ha^{-1}) and T_6 (Recommended NPK + coconut shell biochar @ 20 t ha^{-1}) which had total biomass yield of 4544.89 kg ha^{-1} and 4409.12 kg ha^{-1} respectively, compared to T_3 (3633.46 kg ha^{-1}) that received recommended NPK + FYM 25 t ha^{-1}. The lowest total biomass was reported in T_1 (2185.80 kg ha^{-1}) which did not receive an external source of nutrients and biochar. A similar trend was seen in the dry biomass of leaf, stem, roots, and chilli at different treatment combinations (**Table 4)**.

Table 4. Effect of coconut shell biochar application on biomass yield (kg ha^{-1}) of chilli

Treatments	Biomass yield (kg ha^{-1})				
	Leaf	**Stem**	**Root**	**Dry chilli**	**Total**
T1 - Absolute Control	7.62	350.49	125.02	1702.67	2185.80
T2 - Recommended NPK	11.96	656.1	234.45	2587.33	3489.84
T3 - Package of Practice (NPK + FYM 25 t ha^{-1})	12.06	666.83	238.24	2716.33	3633.46
T4 - Recommended NPK + coconut Shell Biochar @ 10 t ha^{-1}	14.87	722.63	258.66	3201.00	4197.16
T5 - Recommended NPK + coconut Shell Biochar @ 15 t ha^{-1}	15.16	745.07	266.35	3220.33	4246.91
T6 - Recommended NPK + coconut Shell Biochar @ 20 t ha^{-1}	15.33	792.73	283.39	3317.67	4409.12
T7 - Recommended NPK + coconut Shell Biochar @ 25 t ha^{-1}	15.69	854.87	305.66	3368.67	4544.89
T8 - Recommended NPK + coconut Shell Biochar @ 30 t ha^{-1}	16.69	864.17	308.35	3418.00	4607.21
SEm ±	**0.36**	**19.24**	**8.90**	**168.87**	**217.82**
CD @ 5%	**1.03**	**57.84**	**27.01**	**503.61**	**659.82**

Yield is primarily based on the carbohydrate production and mobilization, uptake of nutrients and water from the soil. It is a complex character which involves various environmental factors during the crop growth period and various interactions between internal and external factor. Significant improvement in green fruit yield and biomass yield was reported in recommended NPK + coconut shell biochar @ 30 t ha^{-1}. This may be due to the increased biochar rate, which increases more soil C status, the availability and supply of more nutrients and the content of moisture in the soil. Increased productivity of crop with the addition of biochar may be attributed to increased pH, base saturation and CEC of soil, P availability, nutrient retention, increased plant-available water, and enhanced soil microbial activity. Which ultimately might have increased the fruit and biomass yield of chili.

Higher fruit and biomass yield might be due to enhanced total uptake of essential nutrients and its translocation to economic parts in addition to the improvement in yield attributing characteristics like fruit length, diameter, and fruits per plant. Damayanthi *et al.* (2020) recoded the highest fresh weight of chilies was obtained in the treatment of chicken biochar which increased weight by 18.13% compared to the treatment without biochar. Hanpattanakita *et al.* (2021) reported that the yield of red chili was significantly greater for the biochar-treated soil than in control plot. Dapa *et al.* (2019) also reported that the chilli fresh stem weight, leaf weight and fruit weight significantly increased by biochar addition.

Comment [N10]: Add an explanation of why biochar can increase fertility in acid soil. Because Biochar has pores and functional groups. Take a quote from Lehman,

Comment [N11]: Is chicken manure also used as biochar?

CONCLUSION

Comment [N12]: Conclusions are made per point, and explain what percentage increase in the parameters studied, compared to control. It also explains which treatment is best.

The application of coconut shell biochar at different rates significantly influenced the growth and yield parameters of chilli (Capsicum annum L.) in acidic soils. Biochar-treated plants exhibited increased plant height, number of branches, number of leaves, number of flowers, and fruit yield compared to non-biochar treatments, with the highest improvements observed at the recommended $T_{8,}$ NPK + coconut shell biochar rate of 30 t ha^{-1}. These enhancements can be attributed to various factors such as improved soil pH, nutrient availability, water retention and microbial activity facilitated by biochar incorporation. Overall, the incorporation of recommended NPK + coconut shell biochar @ 30 t ha^{-1} showed the most significant enhancement in chilli plant growth and yield, making it a promising agricultural practice for optimizing crop productivity. The findings suggest that biochar application, particularly at higher rates, holds promise for sustainable agriculture by enhancing crop productivity in acidic soil environments.

Data availability statement:

The data used in this analysis is available upon request from the relevant research institution or organization. Access to the data can be provided upon reasonable inquiry and adherence to ethical guidelines.

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Comment [N13]: f Journal, state DOI.