Pertanika J. Trop. Agric. Sci. 49 (1): 111 - 126 (2026)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Possibilities of Applications and the Interest in Adopting Biochar as a Renewable Source of Nutrients to Increase Crop Productivity and Improve Soil Fertility of Small-scale Farms in Narathiwat Province, Thailand

Siranee Wongkrachang[1]* and Rommana Chimniam[2]

[1]*Faculty of Agriculture, Princess of Naradhiwas University, 90600 Narathiwat, Thailand*
[2]*Land Development Office District 12, 90100 Songkhla, Thailand*

ABSTRACT

This study assessed the potential application of biochar as a renewable nutrient source to enhance soil fertility and crop productivity in small-scale farming systems in Narathiwat Province, Thailand. A field experiment using five treatments—control (no amendment), rice husk biochar, rubber wood biochar, oil palm bunch biochar, and raw organic residues—was conducted on baby corn (Zea mays L. var. saccharata) grown in sandy soil. Oil palm bunch biochar significantly improved plant height, biomass, and yield compared to the other treatments, while also increasing soil organic matter and nutrient availability. A complementary survey of 30 local farmers revealed that 30% had already adopted biochar, and 43.33% expressed interest in its future use. Among the interested group, 73% believed adoption could increase if simpler application methods and more accessible equipment were developed. These findings demonstrate the promise of oil palm bunch biochar as an effective and sustainable soil amendment, particularly for improving sandy soil conditions in smallholder farming systems.

Keywords: Baby corn, biochar, farmer adoption, sandy soil, soil fertility

ARTICLE INFO

Article history:
Received: 11 January 2025
Accepted: 28 January 2026
Published: 24 February 2026

DOI: https://doi.org/10.47836/pjtas.49.1.07

E-mail addresses:
ingongsam@hotmail.com (Siranee Wongkrachang)
Bobo_chim@hotmail.com (Rommana Chimniam)
* Corresponding author

INTRODUCTION

Thailand is one of the countries rich in natural resources, and agriculture is a key sector that supports the economy. Agricultural production from Thailand is not only for domestic consumption but also contributes significantly to global food production. Thailand ranks as the second-largest exporter of rice in the global market.

e-ISSN: 2231-8542

Moreover, the Thai government has supported innovation and new technologies to enhance agricultural productivity. However, increased agricultural activity has also led to the rapid accumulation of agricultural residues (Koul et al., 2022). In 2023, Thailand generated substantial waste from three major economic crops: rice, para rubber, and oil palm. Rice production amounted to 25.80 million tons, resulting in 5.16 million tons of rice husks. Para rubber, a key export commodity, contributes to approximately 500,000 rai of replanting annually due to declining latex yields in trees over 25 years old, producing around 8 million tons of rubber sawdust. Additionally, oil palm production generated approximately 80,000 tons of oil palm bunches annually. If not managed properly, this accumulation of crop waste poses serious threats to ecosystems and contributes to climate change (Boluda-Verdú et al., 2022). To address these challenges, research shows that agricultural waste can be converted into biochar (Lin et al., 2021; Rathore et al., 2021; Rathod et al., 2023; Van Nguyen et al., 2022; Wang & Wang, 2019a). Biochar, a carbon-rich material produced via pyrolysis of organic residues such as rice husks, sawdust, and oil palm bunches at temperatures above 300°C in the absence of oxygen, can be used to improve soil fertility and environmental health (Panwar et al., 2019; Patel et al., 2021).

Applying biochar to soil has been shown to improve soil structure, fertility, and water-holding capacity, and to boost crop yields with minimal environmental impact (Dai et al., 2020; Hien et al., 2021; Mylavarapu et al., 2013; Neogi et al., 2022; Piash et al., 2023; Siedt et al., 2021; Verheijen et al., 2019; Wang et al., 2022). This potential is especially valuable in Narathiwat Province, where many farmers operate on sandy soils with low fertility. According to the Land Development Department (2024), about 22,135 rai of land in the province is affected by poor soil conditions, exacerbated by long-term chemical fertiliser use. Biochar, being rich in stable carbon, can remain in the soil for extended periods, offering long-term benefits (Agegnehu et al., 2016; Das et al., 2020; Li et al., 2017; Majumder et al., 2019; Qian et al., 2020; Samoraj et al., 2022). Furthermore, crop residues from para rubber, oil palm, and rice, which are abundantly available in the region, can be utilised for biochar production, reducing waste and reliance on chemical fertilisers. Although many studies have reported the agricultural benefits of biochar (Jiang et al., 2021; Maroušek & Trakal, 2022; Mohammadi et al., 2017; Neogi et al., 2022; Rombel et al., 2022; Vochozka et al., 2016; Wang et al., 2022), few have explored its adoption by farmers. This research thus aims to fill that gap by evaluating the effects of different types of biochar on crop performance and by analysing farmers' awareness, interest, and adoption of biochar technology.

This study focuses on baby corn (*Zea mays* L. var. *saccharata*), a crop with a short growth cycle, economic importance for small-scale farmers, and high sensitivity to soil fertility, making it an ideal test crop. The research objectives are to measure the effects of various biochar types on baby corn growth and yield in sandy soil, and to assess farmer acceptance of biochar use. The findings are expected to provide insights that support sustainable agricultural practices, economic viability, and environmental protection for small-scale farmers in Narathiwat Province.

MATERIALS AND METHODS

Comparison of Different Waste of Biochar on Plant Growth, Yield, and Soil Fertility

The purpose of this experiment was to find the best waste residue that increases the growth and yield of baby corn.

Experimental Design and Treatments

This study used a completely randomised design (CRD). Seven treatments and four replications were examined in this experiment.

- Treatment 1: Control (sandy soil)
- Treatment 2: Rice hull biochar
- Treatment 3: Rubber sawdust biochar
- Treatment 4: Oil palm bunch biochar
- Treatment 5: Rice hull
- Treatment 6: Rubber sawdust
- Treatment 7: Oil palm bunch

Treatment 2-7 was prepared using sandy soil well mixed with different materials at a ratio of 1:1 (by weight).

Baby corn (*Zea mays* L. var. *saccharata*) seeds were obtained from the Department of Agriculture, Thailand. Seeds were germinated in nursery trays and transplanted after 10 days. Baby corn seedlings were planted in each plot in triplicate. After 1 week, only one seedling was planted in each pot and watered at field capacity. Fertiliser was applied as a compound Fertiliser N:P_2O_5: K_2O, 15:15:15, 50 kg/rai before planting, and 46-0-0, 50 kg/rai, 25 d after planting.

The biochar used in this experiment was prepared by pyrolysis of rice hulls, rubber sawdust, and oil palm bunches at 450°C for 3 hours in a limited oxygen environment, following standard biochar preparation protocols.

Data Collection

The measured plant growth indexes and yield included:

Plant Height - The plant height was measured regularly every 1 week from ground level to the highest part of the leaf.

Number of Leaves - The number of leaves was counted manually each week during the vegetative growth period until 55 days.

Stem Diameter was measured 5 cm above the soil surface using a digital vernier calliper.

Stem Fresh-Dry Weight - At the end of the experiment (55 days), aboveground biomass was collected and weighed. The stem was then oven-dried at 80°C for 72 h, and the dry weight was recorded.

Root Length - At 55 days, the longest root from each plant was measured from the base to the tip.

Yield Weight - Yield per corn was recorded using an electronic balance, measured both before and after husking.

Soil Collection and Analysis

Soil used was the Ban Thon soil series: Bh (sandy, siliceous, superactive, ortstein, isohyperthermic, Typic Haplorthods) collected from Mueang District, Narathiwat, at 0–15 cm depth. Samples were air-dried and sieved through a 2 mm sieve. Chemical analysis included pH (pH meter), organic matter (Walkley and Black), total N (Kjeldahl), available P (Bray II), and available K (NH_4OAc, pH 7.0) following Sparks et al. (2020).

Statistical Analysis

The data were analysed using SPSS software. One-way ANOVA and Duncan's Multiple Range Test (DMRT) were used to determine significance at $p < 0.05$. For descriptive survey data, frequency and Pearson's correlation were used.

The Adoption and Barriers of using Biochar by Farmers

Data Collection and Analysis

A field survey of 30 farmers in Narathiwat Province was conducted to assess biochar adoption. A standardised questionnaire with 13 items across four dimensions—economic, social, environmental, and barriers to adoption—was administered using a Likert scale (3 = very important; 2 = important; 1 = unimportant).

Descriptive statistics such as frequency and percentage were used, and Pearson correlation analysis was performed to explore associations.

Guideline for the Utilisation of Biochar in Sandy Soil

Data Collection and Analysis

Content analysis was used to interpret farmer feedback regarding biochar adoption and to identify practical guidelines and challenges.

RESULTS AND DISCUSSION

Effect of Biochar on Plant Growth, Yield, and Soil Fertility

Plant Growth

On average, the tallest plant (144.56 cm) was observed in the oil palm bunch, but not in the rice hull biochar and oil palm bunch biochar. The shortest plants (38.22 cm) were observed in the control treatment. The number of leaves per plant was higher in response to oil palm bunch biochar (12.66 leaves), but the minimum average number was observed in the control treatment (8.44 leaves). The highest average stem diameter was observed for the oil palm bunch biochar (2.22 mm), but the lowest average number was observed in the control treatment (0.99 mm). The maximum mean stem fresh and dry weights were obtained with palm bunch biochar (8.43 and 2.20 g), but the minimum average number was obtained with the control treatment (0.27 and 0.10 g). The longest average root length was observed for rice hull biochar (59.17 cm) cm, but the shortest average number was observed in the control treatment (28.78 cm). The effect of biochar on plant growth presented in Table 1 showed that the treatment that was applied with raw waste material

Table 1
The effects of the biochar on the plant growth

Treatment	Height (cm)	Leaf no. (leaves/pot)	Stem diameter (mm)	Stem fresh weight (g)	Stem dry weight (g)	Root length (cm)
Control	38.22 ± 1.52 [d]	8.44 ± 0.32 [d]	0.99 ± 0.03 [e]	0.27 ± 0.04 [d]	0.10 ± 0.03 [c]	28.78 ± 1.20 [c]
Rice hull biochar	135.99 ± 5.29 [a]	11.98 ± 0.46 [b]	2.01 ± 0.10 [b]	5.57 ± 0.80 [c]	1.27 ± 0.09 [b]	59.17 ± 2.50 [a]
Rubber sawdust biochar	78.89 ± 3.41 [b]	10.22 ± 0.37 [c]	1.45 ± 0.09 [c]	2.13 ± 0.33 [d]	0.27 ± 0.05 [c]	33.62 ± 1.70 [c]
Oil palm bunch biochar	132.89 ± 4.93 [a]	12.66 ± 0.52 [a]	2.22 ± 0.15 [a]	8.43 ± 0.90 [a]	2.20 ± 0.15 [a]	54.89 ± 2.20 [b]
Rice hull	61.99 ± 2.78[c]	10.11 ± 0.40 [c]	1.49 ± 0.09 [c]	1.73 ± 0.30 [d]	0.40 ± 0.06 [c]	48.50 ± 1.90 [b]
Rubber sawdust	54.99 ± 2.22 [c]	9.44 ± 0.36 [c]	1.22 ± 0.07 [d]	1.07 ± 0.22 [d]	0.13 ± 0.03 [c]	31.12 ± 1.39 [c]
Oil palm bunch	144.56 ± 5.63 [a]	11.55 ± 0.45 [b]	2.22 ± 0.12 [a]	6.93 ± 0.85 [b]	2.13 ± 0.11 [a]	46.69 ± 2.11 [b]
C.V. (%)	8.91	4.38	4.55	19.65	25.23	11.95
F-test	**	**	**	**	**	**

Note. Numbers followed by the same letter in the same column are not significantly different at the 99% level (DMRT). F-test: ** = significant at $p < 0.01$

and biochar (Treatment 2-7) as an amendment significantly increased plant height, number of leaves, stem diameter, stem fresh and dry weight, and root length when compared with the control. This indicates that the application of biochar improves plant growth (Table 1).

Plant Yield

Table 2 shows the effect of biochar on yield. The individual weight was significantly higher in oil palm bunch biochar, followed by rice hull biochar and oil palm bunch. The types of organic wastes of these plants, rice hulls, and rubber sawdust, can increase plant growth, but this growth does not develop in plant yield. The control, rice hull, and rubber sawdust treatments produced no yield.

The use of biochar enhanced growth parameters and resulted in the highest plant yield. Analysis of average baby corn yield before and after peeling. The best crop performance in terms of yield was observed among the treatments of all biochar treatments that enhanced growth and yield, whereas the lowest yield was recorded with the control. However, all raw wastes, namely rice hull and rubber sawdust, had no effect on yield. However, all of these treatments were significantly higher than that of the control. Biochar amendment significantly increased crop growth, productivity, and soil nutrition. (Abiven et al., 2015; Lychuk et al., 2015; Manirakiza & Seker, 2020). Moreover, Meyer et al. (2021) investigated the effects of biochar and found that it enhanced the soil organic content, soil water storage capacity, and nitrogen content, while also exceeding the average yield of 7%. Applying biochar made from forest biomass to beet fields in Labrador, Canada, improved yields from 2.9 to 11.4 mgha^{-1}, resulting in an average annualised net return over variable costs of \$4953ha^{-1}, four times the average return on potato production of \$965.48 ha^{-1} (Keske et

Table 2
The effects of the biochar on the plant yield

Treatment	Yield before peel (g/corn)	Yield after peel (g/corn)
Control	0.00 ± 0.00 ^{d}	0.00 ± 0.00 ^{d}
Rice hull biochar	5.50 ± 0.66 ^{b}	1.50 ± 0.24 ^{b}
Rubber sawdust biochar	1.20 ± 0.29 ^{c}	0.89 ± 0.21 ^{c}
Oil palm bunch biochar	7.90 ± 0.82 ^{a}	2.30 ± 0.36 ^{a}
Rice hull	0.00 ± 0.00 ^{d}	0.00 ± 0.00 ^{d}
Rubber sawdust	0.00 ± 0.00 ^{d}	0.00 ± 0.00 ^{d}
Oil palm bunch	4.50 ± 0.56 ^{b}	1.30 ± 0.22 ^{b}
C.V. (%)	39.92	33.01
F-test	**	**

Note. Numbers followed by the same letter in the same column are not significantly different at the 99% level (DMRT). F-test: ** = significant at $p < 0.01$

al., 2020). It has been demonstrated that biochar offers agricultural ecosystems a number of advantages, including increased yields (Katterer et al., 2016).

Soil Fertility

The initial soil values are listed in Table 3. The pH of the soil ranged from 5.0 to 5.9 among different biochars. pH of all treatments was in a range of 5.0-6.8 for tropical soil (Udo & Ogunwale, 1977). The resulting electrical conductivity content in the soil was in the range of 0.02-0.04 $mScm^{-1}$ and remained below the limit of the EC value for agricultural soil, 4 dSm^{-1} (Christiansen, 1977). Organic matter content ranged from 2.11 to 2.65%, showing that it was optimum at the critical level between 1.5 and 3.5% for soils in the tropics. The control group had the lowest score (1.16%). Total N varied between 0.08-0.16%, showing that it was lower than the critical level between 0.3 and 0.6% for soils in the tropics (Bremner & Mulvancy, 1982). Available P content extended between 22.0 and 138.0 mg kg^{-1}, showing that it was greater than the critical level between 10 and 15 mg/kg (Adeoye & Agboola, 1985). The available K content ranged from 7.0 to 30.0% and was lower than the critical level of 60-90 mg kg-1 (Adeoye, 1986).

Application of biochar increased soil pH, OM, N, and P values compared to the other treatments. This indicates that OM and P are not required for optimal crop production. However, soil requires the addition of nitrogen for optimal crop production. Direct fertilisation impacts and an increase in soil nutrient stocks, particularly phosphorus (P), have been demonstrated for biochar (Biederman & Harpole, 2013; Gul & Whalen, 2016; Shepherd et al., 2017; Zhang et al., 2017).

Table 3
Soil analysis before planting

Treatment	pH	EC ($mScm^{-1}$)	OM (%)	Total N (%)	Avail. P (mg kg^{-1})	Avail. K (mg kg^{-1})
Control	5.1^{d}	0.03	1.67^{d}	0.08^{c}	22.00^{f}	17.00^{b}
Rice hull biochar	5.4^{c}	0.03	2.11^{c}	0.11^{abc}	91.00^{d}	30.00^{a}
Rubber sawdust biochar	5.1^{d}	0.02	2.11^{c}	0.11^{abc}	29.00^{e}	8.00^{de}
Oil palm bunch biochar	6.4^{a}	0.04	3.36^{a}	0.17^{a}	$138.00^{.b}$	9.00^{d}
Rice hull	5.5^{b}	0.03	2.06^{c}	0.10^{abc}	99.00^{c}	7.00^{e}
Rubber sawdust	5.3^{c}	0.02	3.29^{a}	0.16^{ab}	22.00^{f}	$9.00^{.d}$
Oil palm bunch	6.3^{a}	0.04	2.33^{b}	0.12^{abc}	183.00^{a}	15.00^{c}
C.V. (%)	14.77	2.23	12.37	11.71	1.32	1.46
F-test	**	ns	**	*	**	**

Note. Numbers followed by the same letter in the same column are not significantly different from the DMRT test at the 99% level

Table 4
Soil analysis after planting

Treatment	pH	EC ($mScm^{-1}$)	OM (%)	Total N (%)	Avail. P ($mg\ kg^{-1}$)	Avail. K ($mg\ kg^{-1}$)
control	5.0^{a}	0.03^{c}	1.16^{d}	0.06	12.00^{e}	4.00^{g}
Rice hull biochar	5.7^{b}	0.06^{b}	1.84^{c}	0.09	68.00^{b}	434.00^{a}
Rubber sawdust biochar	5.2^{a}	0.03^{c}	1.91^{c}	0.10	12.00^{e}	33.00^{f}
Oil palm bunch biochar	5.7^{b}	0.15^{a}	2.65^{a}	0.13	85.00^{a}	90.00^{c}
Rice hull	5.9^{b}	0.05^{bc}	1.85^{c}	0.09	51.00^{d}	123.00^{b}
Rubber sawdust	5.2^{a}	0.05^{bc}	2.30^{b}	0.12	14.00^{e}	68.00^{e}
Oil palm bunch	5.7^{b}	0.06^{b}	1.91^{c}	0.10	56.00^{c}	83.00^{d}
C.V. (%)	17.00	18.5	17.46	11.7	2.70	5.78
F-test	**	**	**	ns	**	**

Note. Numbers followed by the same letter in the same column are not significantly different from the DMRT test at the 99% level

Table 4 shows the soil analysis after baby corn was harvested; the pH of the soil ranged from 5.0 to 5.7 among different biochars. pH of all treatments was in a range of 5.0-6.8 for tropical soil (Udo & Ogunwale, 1977). The resulting electrical conductivity content in the soil was in a range of 0.03-0.15 $mScm^{-1}$ and remained below the limit of the EC value for agricultural soil, 4 dS/m^{-1} (Christiansen, 1977). Total N varied between 0.06-0.13%, showing that it was lower than the critical level between 0.3 and 0.6% for soils in the tropics (Bremner & Mulvancy, 1982). Available P content extended between 12.0 and 85.0 $mg\ kg^{-1}$, showing that it was greater than the critical level between 10 and 15 $mg\ kg^{-1}$ (Adeoye & Agboola, 1985). The available K content ranged from 4.0 to 434% and was greater than the critical level of 60-90 $mg\ kg^{-1}$ (Adeoye, 1986).

The soil was analysed before and after the baby corn was harvested. Soil increased the availability of OM, N, and P after biochar application. Moreover, increased soil organic matter content (Van Zwieten et al., 2007; Bera et al., 2016; Lashari et al., 2013; Van Zwieten et al., 2010). The application of biochar to tropical soils makes the soil more fertile. However, K decreased because much of the K in the biochar plots could have been lost for plant uptake.

The Adoption and Barriers of using Biochar by Farmers

According to farmer field surveys in the sandy soil of Narathiwat Province, most farmers were interested in using biochar (43.33%), followed by farmers who decided to adopt the practice of applying biochar in their fields (30.00%). However, 26.67% of farmers hesitated to use biochar in croplands (Table 5). Most farmers in this area are small-scale farmers and have experience in crop cultivation for a long time. Similar to Latawiec et al. (2017), farmers who had operated agricultural enterprises for 10-20 years were the most familiar with biochar (40%), while people who had operated agricultural businesses for 5-10 years were the least familiar (17%). Small-scale farmers in Brazil are more likely to embrace innovation because their operations yield greater profits than those of larger farmers (Table 5).

Table 5
Interest in the adoption of using biochar by farmers in Narathiwat Province

Interest adoption	Frequency	Percent
Interest	13	43.33
Practice (adopted)	9	30.00
Hesitate	8	26.67
Total	30	100

Table 6 presents Pearson correlation coefficients (r) between the biochar adoption and economic, social, environmental, and barrier factors with interest in biochar adoption in farmer fields at $p < 0.05$. can be classified into three groups of farmers with various reasons to use biochar.

Table 6
The correlation of economic, social, environmental, and barrier factors with interest in biochar adoption in farmer fields

Factors	Interest in adopting		
	Interest	Adopted	Hesitate
Economic value			
Creating a value-added agricultural waste product	0.107	0.347	-0.480*
Save chemical fertiliser cost	0.404*	0.400**	-0.867**
Increase income, yield	0.389**	0.342	-0.789**
Purchase of agricultural waste materials and processing them to make money	0.007	0.376*	-0.398**
Social value			
Biochar creates local jobs	0.121	-0.064	-0.070
Enhance food security	0.112	0.492**	-0.635**
Improve livelihoods and reduce poverty for farmers	0.260	-0.050	-0.240
Environmental value			
Biochar improves soil health in terms of enhancing the physical, chemical, and biological properties of the soil	0.586**	0.040	-0.699**
Utilising available agricultural waste biomass	0.340	0.173	-0.561
Carbon sequestration	0.569**	-0.277	-0.350
Barriers to adoption			
Insufficient practical knowledge about biochar application	0.086	-0.308	0.223
Production methods are complicated	-0.538**	-0.065	0.67**
Limited access to necessary equipment	-0.339	-0.011	0.391*

Note. *Significant at five levels of probability ($p < 0.05$)

First group: Farmers who were interested in using biochar showed that economic value was positively correlated with saving chemical costs (0.404*) and increasing income and yield (0.389**). Environmental values were positively correlated with biochar, which improved soil health by enhancing the physical, chemical, and biological properties of the soil (0.586**) and carbon sequestration (0.569**). However, barriers to adoption were negatively correlated with complicated production methods (-0.538**). Biochar must be profitable for farmers to be used extensively as a soil amendment. One of the primary elements encouraging farmers to adopt new techniques is yield gains, as they directly improve financial performance (Azzi et al., 2019). Moreover, selling biochar as a product or using or selling the heat and other energy generated during pyrolysis are two other ways for farmers to make money using a biochar system (Azzi et al., 2022).

In the second group, farmers willing to accept biochar and apply it in practice showed that economic value was positively correlated with saving chemical costs (0.400**), and farmers could purchase agricultural waste materials and process them to make money (0.376*). Regarding social value, being positively correlated with biochar can enhance food security.

The last group, farmers, was hesitant to use biochar in their field; it showed that economic value was negatively correlated with creating a value-added agricultural waste product (-0.480*), saving chemical costs (-0.867**), increasing income and yield (-0.789**), and purchasing agricultural waste materials and processing them to make money (-0.398**). Social value was negatively correlated with enhanced food security (-0.635**). Barriers to adoption were positively correlated with complicated production methods (0.67**) and limited access to necessary equipment (0.391*).

Guideline for the Utilisation of Biochar in Sandy Soil

Guideline for Interest Group

The farmers in this group considered the economic and environmental values, including saving costs of commercial fertiliser and biochar, which can increase income and yield, as well as carbon storage in soil. However, farmers are concerned that the biochar method is complicated. Therefore, the government should support farmers with training methods or transfer new technologies for biochar production in an easy way. However, an alternative way to improve sandy soil for farmers in this group in the first way is to use oil palm bunches to improve soil; however, in treatment 7, the application of oil palm bunches increased plant height not significantly with the biochar of rice hull and oil palm bunches. Then, they exchange experiences with farmers who adopt biochar in their fields. Next, we show the advantages or compare the growth and yield of biochar and raw oil palm bunches and assess the interest in adopting biochar again. Compared to conventional crops, biochar was shown to be more beneficial when applied to sandy soils and intensive crop production systems (such as those that produce fruits and vegetables). In some regions, it has been demonstrated that using biochar increases yields, giving farmers an extra revenue stream (Jansen, 2023).

Guideline for Adopted Group

The farmers in this group are ready to practice applying biochar in their field because they accept the economic and social value, including saving on chemical fertiliser costs and purchasing agricultural waste materials and processing them to make money. This encourages them to utilise para-sawdust biochar, followed by oil palm bunches and rice hulls, because para-rubber is the main economic crop in Narathiwat Province, followed by oil palm and rice. Therefore, every year, this agricultural waste is easily found in this area, and the price for transporting it is low.

Guideline for Hesitant Group

Farmers in this group are most concerned about economic value, including creating value-added agricultural waste products, saving chemical costs, increasing income and yield, and purchasing agricultural waste materials and processing them to make money. Social value farmers were negatively correlated with enhanced food security. Barriers to the adoption of this group were production methods that were complicated and had limited access to the necessary equipment. To overcome barriers to the adoption of biochar, the same interest group was the government, which should support farmers with training methods or transfer new technology for the production of biochar in an easy way and also support equipment or credit access to them. Typically, in the local context of Narathiwat Province, a great number of the farmers applied more chemical fertilisers in the long term, and most of the farmers prefer to use chemical fertilisers rather than organic fertilisers to preserve crop yield because they think the use of biochar requires more labor time and machine cost compared with the use of chemical fertilisers, which have high nutrient content and faster growth; however, biochar increases crop yield slowly in the short term. Therefore, organisations should provide financial incentives to adopt biochar to address these challenges. Shackley et al. (2016) discussed the societal effects of biochar attractiveness in relation to food security, economics, health, and energy efficiency. According to their findings, social and cultural factors are the primary obstacles to using biochar in agriculture. The socio-cultural challenges identified included farmers' mistrust, a lack of biochar, a lack of equipment for producing biochar, people's opposition to new development ideas, and a lack of knowledge about the qualities of biochar. According to several studies, biochar is more likely to be cost-effective in underdeveloped nations because of lower production costs (kilns and stoves) and the possibility of higher yield increases in tropical and sandy soils (Dickinson et al., 2015; Pratt & Moran, 2010).

CONCLUSION

From the overall results, treatment with raw material and biochar (Treatment 2-7) as an amendment resulted in the highest plant height, number of leaves, stem diameter, stem fresh and dry weight, and root length when compared with the control. In contrast, the treatment control showed the lowest overall growth response and yield performance in plants. Thus, it can be concluded that the application of biochar has a significant effect on plant growth, yield, and soil quality. The probability of using biochar in terms of adoption is 30% of farmers will use biochar in their fields because they believe that biochar has economic and environmental value in terms of saving chemical fertiliser costs, purchasing agricultural waste materials and processing them to make money, and enhancing food security. Moreover, 43% of farmers are interested in applying biochar in their fields, but they are concerned about production methods being complicated and having limited access to necessary equipment. This means that if the solution for the method and equipment of biochar is 73% probable, farmers will use biochar in sandy soils. This is the first study in Narathiwat Province and one of the first in sandy soil, showing a relationship between applying biochar to soil on plant growth and yield and farmers' interest in adopting it. This is a possible choice for sustainable agricultural management of their farms. This information will help small grower groups in Narathiwat Province.

LIMITATION

A limitation of this study was the lack of data on the number of baby corn ears per plant, which is an important yield trait. Future research should include this measurement to fully assess crop performance under different biochar treatments.

ACKNOWLEDGEMENT

The authors are thankful to the Princess of Naradhiwas University and farmers for contributing to the success of this research.

REFERENCES

Abiven, S., Hund, A., Martinsen, V., & Cornelissen, G. (2015). Biochar amendment increases maize root surface areas and branching: A shovelomics study in Zambia. *Plant and Soil*, *395*(1-2), 45-55. https://doi.org/10.1007/s11104-015-2533-2

Adeoye, G. O. (1986). *Comparative studies of some extractants for sedimentary soil of South Western Nigeria* [Unpublished doctoral dissertation]. University of Ibadan.

Adeoye, G. O., & Agboola, A. A. (1984). Relationship between soil physical and chemical characteristics and ear-leaf concentration of P, K, Mg, Zn, Fe, Cu, Mn and relative yield of maize in soils derived from sedimentary rocks of South-Western Nigeria. *Fertiliser Research*, *5*(2), 109-119. https://doi.org/10.1007/BF01049495

Agegnehu, G., Bass, A. M., Nelson, P. N., & Bird, M. I. (2016). Benefits of biochar, compost and biochar-compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment*, *543,* 295-306. https://doi.org/10.1016/j.scitotenv.2015.11.054

Ali, S., Rizwan, M., Qayyum, M. F., Ok, Y. S., Ibrahim, M., Riaz, M., Arif, M. S., Hafeez, F., Al-Wabel, M. I., & Shahzad, A. N. (2020). Biochar soil amendment on alleviation of drought and salt stress in plants: A critical review. *Environmental Science and Pollution Research*, *24*, 12700-12712. https://doi.org/10.1007/s11356-017-8904-x

Azzi, E. S., Jungefeldt, L., Karan, S., & Sundberg, C. (2022). *Biochar in Swedish agriculture – Straw pyrolysis as a first step towards net-zero*. Mistra Food Futures Report.

Azzi, E. S., Karltun, E., & Sundberg, C. (2019). Prospective life cycle assessment of large-scale biochar production and use for negative emissions in Stockholm. *Environmental Science & Technology*, *53*(14), 8466-8476. https://doi.org/10.1021/acs.est.9b01615

Bai, Y., Gu, C., Tao, T., Chen, G., & Shan, Y. (2019). Straw incorporation promotes microbial biomass and carbon cycling in soil: Evidence from a meta-analysis. *Soil Use and Management*, *35*(2), 366-376. https://doi.org/10.1111/sum.12481

Boluda-Verdú, I., Molina-Sánchez, L., Parres-García, F., & Carbonell-Verdú, A. (2022). Lignocellulosic waste from agriculture: A potential source for carbon sequestration. *Agronomy*, *12*(8), 1778. https://doi.org/10.3390/agronomy12081778

Burrell, L. D., Zehetner, F., Rampazzo, N., Wimmer, B., & Soja, G. (2016). Long-term effects of biochar on soil physical properties. *Geoderma*, *282*, 96-102. https://doi.org/10.1016/j.geoderma.2016.07.019

Dai, Y., Wang, W., Lu, L., Yan, L., & Yu, D. (2016). Utilisation of biochar for the removal of nitrogen and phosphorus. *Journal of Cleaner Production*, *257*, 120573. https://doi.org/10.1016/j.jclepro.2020.120573

Dai, Y., Zheng, H., Jiang, Z., & Xing, B. (2020). Combined effects of biochar properties and soil conditions on plant growth: A meta-analysis. *Science of the Total Environment*, *713*, 136635. https://doi.org/10.1016/j.scitotenv.2020.136635

Das, S. K., Ghosh, G. K., Avasthe, R., & Sinha, K. (2020). Compositional heterogeneity of different biochar: Effect of pyrolysis temperature and feedstocks. *Journal of Environmental Management*, *278*, 111501. https://doi.org/10.1016/j.jenvman.2020.111501

Dong, D., Wang, C., van Zwieten, L., Wang, H., Jiang, P., Zhou, M., & Wu, W. (2020). An effective biochar-based slow-release fertiliser for reducing nitrogen loss in paddy fields. *Journal of Soils and Sediments*, *20*(10), 3027-3040. https://doi.org/10.1007/s11368-019-02401-8

Doran, J. W., Elliott, E. T., & Paustian, K. (1998). Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. *Soil and Tillage Research*, *49*(1-2), 3-18. https://doi.org/10.1016/S0167-1987(98)00150-0

Hien, T. T. T., Toan, V. D., & Toan, P. V. (2021). Biochar production from agricultural wastes and its application for soil improvement. *IOP Conference Series: Earth and Environmental Science*, *947*, 012025. https://doi.org/10.1088/1755-1315/947/1/012025

Hossain, M. Z., Bahar, M. M., Sarkar, B., Donne, S. W., Ok, Y. S., Palansooriya, K. N., Kirkham, M. B., Chowdhury, S., & Bolan, N. (2020). Biochar and its importance on nutrient dynamics in soil and plant. *Biochar*, *2*, 379-420. https://doi.org/10.1007/s42773-020-00065-z

Hussain, R., Ghosh, K. K., & Ravi, K. (2017). Impact of biochar produced from hardwood of mesquite on the hydraulic and physical properties of compacted soils for potential application in engineered structures. *Geoderma*, *385*, 114836. https://doi.org/10.1016/j.geoderma.2020.114836

Ibrahim, A., Usman, A. R., Al-Wabel, M. I., Nadeem, M., Ok, Y. S., & Al-Omran, A. (2013). Effects of conocarpus biochar on hydraulic properties of calcareous sandy soil. *Proceedings of the 4th International Conference on Sustainable Development*. http://hdl.handle.net/123456789/173

Islam, M., Gerzabek, M. H., Rahman, A., & Rahman, T. (2017). The influence of biochar on the uptake of heavy metals by rice in a soil contaminated with arsenic, antimony, and chromium. *Journal of Environmental Engineering and Landscape Management*, *25*(2), 114-126.

Jeffery, S., Abalos, D., Prodana, M., Bastos, A. C., van Groenigen, J. W., Hungate, B. A., & Verheijen, F. (2017). Biochar boosts tropical but not temperate crop yields. *Environmental Research Letters*, *12*(5), 053001. https://doi.org/10.1088/1748-9326/aa67bd

Jiang, J., Wang, S., Zhu, Q., Guo, K., & Wu, S. (2021). Characteristics of biochar derived from livestock manure and its potential for carbon sequestration and soil amendment. *Journal of Cleaner Production*, *323*, 129162. https://doi.org/10.1016/j.jclepro.2021.129162

Laghari, M., Mirjat, M. S., Hu, Z., Fazal, S., Xiao, B., Hu, M., Chen, Z., & Guo, D. (2015). Effects of biochar application rate on sandy desert soil properties and sorghum growth. *Catena*, *135*, 313-320. https://doi.org/10.1016/j.catena.2015.08.013

Li, H., Dong, X., da Silva, E. B., de Oliveira, L. M., Chen, Y., & Ma, L. Q. (2017). Mechanisms of metal sorption by biochars: Biochar characteristics and modifications. *Chemosphere*, *178*, 466-478. https://doi.org/10.1016/j.chemosphere.2017.03.072

Liu, Z., Chen, X., Jing, Y., Li, Q., Zhang, J., & Huang, Q. (2019). Effects of biochar amendment on nitrogen transformation and heavy metals in an acidic soil. *Environmental Science and Pollution Research*, *26*, 7808-7818.

Major, J., Rondon, M., Molina, D., Riha, S. J., & Lehmann, J. (2010). Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil*, *333*, 117-128. https://doi.org/10.1007/s11104-010-0327-0

Majumder, S., Neogi, S., Dutta, T., Powel, M. A., & Banik, P. (2019). The impact of biochar on soil carbon sequestration: Meta-analytical approach to evaluating environmental and economic advantages. *Journal of Environmental Management*, *250*, 109466. https://doi.org/10.1016/j.jenvman.2019.109466

Maroušek, J., & Trakal, L. (2022). Techno-economic analysis reveals the untapped potential of wood biochar. *Chemosphere*, *291*, 133000. https://doi.org/10.1016/j.chemosphere.2021.133000

Mohammadi, A., Cowie, A. L., Anh Mai, T. L., Brandão, M., Anaya de la Rosa, R., Kristiansen, P., & Joseph, S. (2017). Climate-change and health effects of using rice husk for biochar-compost: Comparing three pyrolysis systems. *Journal of Cleaner Production*, *162*, 260-272. https://doi.org/10.1016/j.jclepro.2017.06.026

Mylavarapu, R. S., Sanchez, J. F., Nguyen, J. H., & Bartos, J. M. (2013). Evaluation of pre-plant incorporated controlled release nitrogen fertilisers for vegetable production in Florida. *Proceedings of the Florida State Horticultural Society*, *126*, 248-251.

Neogi, S., Sharma, V., Khan, N., Chaurasia, D., Ahmad, A., Chauhan, S., Singh, A., & You, S. (2022). Sustainable biochar: A facile strategy for soil and environmental restoration, energy generation, mitigation of global climate change and circular bioeconomy. *Chemosphere*, *293*, 133474. https://doi.org/10.1016/j.chemosphere.2021.133474

Norman, J. M., Garcia, R., & Verma, S. B. (1992). Soil surface CO2 fluxes and the carbon budget of a grassland. *Journal of Geophysical Research*, *97*(D17), 18845-18853. https://doi.org/10.1029/92JD01348

Piash, M. I., Kamruzzaman, M., Rahman, M. M., Hossain, M. M., & Hasan, A. K. (2023). Biochar application improved soil properties and increased yield of summer tomato in the subtropical region. *Scientific Reports*, *13*, 3457.

Prendergast-Miller, M. T., Duvall, M., & Sohi, S. P. (2014). Biochar–root interactions are mediated by biochar nutrient content and impacts on soil nutrient availability. *European Journal of Soil Science*, *65*, 173-185. https://doi.org/10.1111/ejss.12079

Qian, L., Chen, L., Joseph, S., Pan, G., Li, L., Zheng, J., Zhang, X., Zheng, J., Yu, X., & Wang, J. (2020). Biochar compound fertiliser as an option to reach high productivity but low carbon intensity in rice agriculture of China. *Carbon Management*, *5*(2), 145-154. https://doi.org/10.1080/17583004.2014.912868

Rathod, P. H., Sharma, S., & Patel, A. (2023). Conversion of agricultural waste into biochar: A sustainable approach for soil enhancement. *Journal of Soil Science and Plant Nutrition*, *23*, 3347-3359.

Rathore, S. S., Babu, S., Singh, R., Kumar, S., Yadav, D., Yadav, S. K., Yadav, V., Ansari, M. A., Das, A., Rajanna, G. A., Wani, O. A., Raj, R., Yadav, D. K., & Singh, V. K. (2023). Biochar implications in cleaner agricultural production and environmental sustainability. *Environmental Science: Advances*, *2*, 1042-1059. https://doi.org/10.1039/D2VA00324D

Ren, L., Kong, X., Su, J., Zhao, D., Dong, W., Liu, C., Liu, C., Luo, L., & Yan, B. (2022). Oriented conversion of agricultural bio-waste to value-added products - A schematic review towards key nutrient circulation. *Bioresource Technology*, *346*, 126578. https://doi.org/10.1016/j.biortech.2021.126578

Samoraj, M., Mironiuk, M., Witek-Krowiak, A., Izydorczyk, G., Skrzypczak, D., Mikula, K., Baśladyńska, S., Moustakas, K., & Chojnacka, K. (2022). Biochar in environmentally friendly fertilisers - Prospects of developing products and technologies. *Chemosphere*, *296,* 133975. https://doi.org/10.1016/j.chemosphere.2022.133975

Siedt, M., Schäffer, A., Smith, K. E. C., Nabel, M., Roß-Nickoll, M., & van Dongen, J. T. (2021). Comparing straw, compost, and biochar regarding their suitability as agricultural soil amendments to affect soil structure, nutrient leaching, microbial communities, and the fate of pesticides. *Science of the Total Environment*, *751*, 141607. https://doi.org/10.1016/j.scitotenv.2020.141607

Steinbeiss, S., Gleixner, G., & Antonietti, M. (2009). Effect of biochar amendment on soil carbon balance and soil microbial activity. *Soil Biology and Biochemistry*, *41*(6), 1301-1310. https://doi.org/10.1016/j.soilbio.2009.03.016

Sun, Y., Gao, B., Yao, Y., Fang, J., Zhang, M., Zhou, Y., & Chen, H. (2014). Effects of feedstock type, production method, and pyrolysis temperature on biochar and hydrochar properties. *Chemical Engineering Journal*, *240*, 574-578. https://doi.org/10.1016/j.cej.2013.10.081

Tian, J., Wang, J., Dippold, M. A., Gao, Y., Blagodatskaya, E., Kuzyakov, Y., & Gao, Y. (2020). Biochar affects soil microbial community composition and enzyme activities in a 4-year field experiment. *Soil Biology and Biochemistry*, *141*, 107678. https://doi.org/10.1016/j.soilbio.2019.107678

Van Nguyen, V., Kumar Chaudhary, D., Dayal, R. K., Garg, V., Sharma, R., Kumar, N., & Kumar Yadav, B. (2022). Biochar application for the remediation of heavy metal polluted soil: A review on the mechanism, kinetics, functional surface chemistry and factor affecting the remediation. *Renewable and Sustainable Energy Reviews*, *154*, 111810. https://doi.org/10.1016/j.rser.2021.111810

Verheijen, F., Jeffery, S., van der Velde, M., Penizek, V., Beland, M., Bastos, A. C., & Botula, Y. D. (2019). Reductions in soil surface albedo as a function of biochar application rate: Implications for global radiative forcing. *Environmental Research Letters*, *14*(8), 084008. https://doi.org/10.1088/1748-9326/8/4/044008

Wang, B., Lehmann, J., Hanley, K., Hestrin, R., & Enders, A. (2022). Adsorption and desorption of ammonium by maple wood biochar as a function of oxidation and pH. *Chemosphere*, *287*, 132255. https://doi.org/10.1016/j.chemosphere.2021.132255

Wang, C., Lu, H., Dong, D., Deng, H., Strong, P.J., & Wu, W. (2013). Insight into the effects of biochar on manure composting: Evidence supporting the relationship between N2O emission and denitrifying community. *Bioresource Technology, 138,* 394-400. https://doi.org/10.1016/j.biortech.2013.03.014

Wang, J., & Wang, S. (2019). Preparation, modification and environmental application of biochar: A review. *Journal of Cleaner Production*, *227*, 1002-1022. https://doi.org/10.1016/j.jclepro.2019.04.282

Zhang, A., Liu, Y., Pan, G., Hussain, Q., Li, L., Zheng, J., & Zhang, X. (2019). Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China Plain. *Plant and Soil*, *351*, 263-275. https://doi.org/10.1007/s11104-011-0957-x