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Nitrogen Use Efficiency of Paddy Husk Biochar-Based Organic Fertilizers Applied to Capsicum Plants Grown in an Ultisol

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ABSTRACT

Purpose: *Low Nitrogen Use Efficiency (NUE) of urea (U) in vegetable cultivations leads to environmental pollution. This study aimed to develop N-enriched paddy husk biochar-based organic fertilizers (BOF) using liquid organic fertilizers such as fish tonic (FT) and cattle slurry (CS) as a potential solution for the low NUE.*

Research Method: *Paddy husk biochar (BC) was enriched with N using FT, CS, and U and pelletized to produce BOF_{FT} and BOF_{CS}, and SRF_U respectively. A pot experiment was conducted using Capsicum annum with 100% N from four fertilizer treatments and 0% N control. Growth, N nutrition and NUE of plants were measured.*

Findings: *Nitrogen content in BC (0.59%) was increased to 2.0% and 1.1% by incorporating FT and CS, respectively, while 23.0% in the SRF_U. The BOF_{FT} was comparable to urea (U), only treatment on growth and NUE of Capsicum plants. As unutilized N in BOF_{FT} is in organic forms, their losses to the environment should be low. BOF_{CS} could not provide the required N for the growth of Capsicum plants. Intercalation of U into BC provided the highest growth (5.1 g/plant) and NUE (16.7 kg /kg N) among all treatments, suggesting the requirement for further improvements to BOF_{FT}.*

Research Limitations: *Produced fertilizers should be tested under different eco-physiological situations to obtain a solid overview of their performance.*

Originality / Value: *This is the first attempt to produce paddy husk biochar-based organic fertilizers by enriching biochar with N using cattle slurry and fish tonic.*

Keywords: *Cattle slurry, Fish tonic, Nitrogen use efficiency, Organic fertilizer, Rice husk biochar, , Urea.*

INTRODUCTION

Globally about 85% of added N in vegetable cultivations is lost to the environment (Zhang *et al.*, 2015) contributing to several environmental and health issues. The low use efficiency of N fertilizers (NUE) is due to the loss of reactive N through ammonia volatilization, denitrification, and leaching. Loss of N from agricultural fields cannot be alleviated, albeit minimized by management practices. Attempts have been made to reduce fertilizer N losses with the help of biochar (BC), because of its large specific surface area, porosity, and presence of several functional groups that can adsorb ammonia (Marcińczyk and Oleszczuk, 2022). Commonly used efficiency-enhancing biochar-based technologies are the co-applications of BC with urea (U) and producing slow-release fertilizers (SRFs) by intercalating or coating N fertilizers with BC.

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According to Bai *et al*. (2022), biochar co-applied with fertilizers led to an additional 12.1% increase in yield, and the highest yield increments were observed when biochar was co-applied with both inorganic and organic fertilizers. Jayarathna *et al*. (2021) developed an effective SRF using U and rice husk BC, and their product had the potential to reduce U application to paddy fields by 25% while obtaining comparable yields. Manikandan & Subramanian (2013) also have attempted to produce a slow-release fertilizer by intercalating U into BC. In addition, BC is well known as a material for improving soil quality and plant growth and reducing greenhouse gas emissions from soil (Gaudutis *et al*., 2023).

Rather than using synthetic fertilizers, organic nutrient sources have drawn attention in the recent past since there is a considerably high demand for organically grown vegetables. Therefore, organic vegetable production is expanding rapidly while having a problem in N nutrition management (Hartz and Johnstone, 2006). Particularly in vegetable cultivation, N is the most limiting nutrient to make a profitable and efficient vegetable production. Organic growers are limited to the use of organic N sources which are derived from natural processes (Gaskell and Smith, 2007).

Most economical way to provide plant available N in organic farming systems is growing leguminous cover crops. Although cover crops have high potential to provide most of the plant required N, actual N contribution by cover crops can be vary depend on the field specific conditions (Hartz and Johnstone, 2006). In addition compost, plant by-products, animal manure and other biological materials are often applied to organic fields to maintain the soil fertility (Shaikh and Patil, 2013). But the low N content in organic N sources is a major constraint for organic agriculture as farmers have to apply large quantities. Compost like commonly used organic amendments typically contains only about 1% to 2% N on a dry weight basis (Gaskell and Smith, 2007).

There are a number of N-rich organic wastes that are commonly available but underutilized. They can be used to produce N-enriched organic fertilizers. Seaweed extracts (9% N), Fish emulsions (5% N) and dairy manure (0.6-2.1% N) are some of them (Shaikh and Patil, 2013). BC can be fortified with N-rich organic fertilizers and pelletized for ease of application. Improperly produced liquid organic fertilizers using locally available wastes have created many difficulties during storage and field application. However, no study has been reported on the production or use of organic fertilizer incorporated BC in agricultural fields.

A farmer-friendly, biochar-based organic N fertilizer has been developed by enriching partially burnt paddy husk (PBPH) using N-rich liquid fertilizers (Jayarathna *et al*., 2023). Also, in their study, cow urine and fish tonic have been used in addition to urea to enrich PBPH. PBPH enriched with urea and fish tonic has resulted in the highest N uptakes. But no attempt has been made yet to enrich paddy husk BC with fish tonic or cattle slurry to produce organic fertilizers. Therefore, the objectives of this study were to develop N-enriched organic fertilizers using paddy husk BC and locally available liquid organic fertilizers such as fish tonic and cattle slurry. The NUE of the developed fertilizers was assessed in capsicum grown in an Ultisol under plant house conditions.

MATERIALS AND METHODS

Soil Sampling and Processing

Topsoil (0-15 cm) of a Reddish Brown Latosol (a Rhodudult) was collected from a vegetable cultivating research plot at the Horticulture Research and Development Institute at Gannoruwa, Sri Lanka (7°16' 47" N, 80°35' 52" E). This field belongs to the WM2 agroecological zone. At the time of sampling, the field had been cultivated with different types of vegetables for more than 20 years. Soil was collected from randomly selected locations in the field, and composited. A sub-sample from the composite sample was air-dried, sieved using a 2-mm sieve, and used for soil characterization. The rest of the field fresh soil was used for the pot experiment (see below) after removing the visible organic residues and gravels.

Characterization of Soil

Collected soil was analyzed for texture by pipette method (Igaz *et al*., 2020), organic carbon content (OC) by the Walkley and Black method (Meersmans *et al*., 2009), electrical conductivity (EC) of a 1:5 soil:water mixture by EC meter (Eutech manufacturer, Singapore) and pH by pH meter (Eutech manufacturer, Singapore) using a 1:2.5 soil:water suspension (Al-Wabel *et al*., 2013). Available N was determined using 1M KCl (Unger *et al*., 2009), total N by Kjeldahl digestion (Bremner, 1960) followed by distillation and titration, available P by Olsen method using UV-visible spectrophotometer (Shimadzu UV-1601) (Al-Wabel *et al*., 2013), and exchangeable K using 1M CH_3COONH_4 and flame photometer (Jenvay manufacturer) (Al-Wabel *et al*., 2013).

Production and Characterization of N-Enriched Paddy Husk Biochar-Based Fertilizers

Biochar was produced from paddy husk by employing a slow pyrolysis process at 550^0C for about 120 minutes (Alahakoon *et al*., 2022). Fresh cattle slurry was collected from the animal farm of the Faculty of Veterinary Medicine and Animal Science, University of Peradeniya, Sri Lanka, and fish tonic was collected from the Agriculture Research Station, Department of Agriculture, Makandura, Sri Lanka. They were used in liquid form for the characterization of basic chemical properties, but the values were expressed on a dry weight basis after determining their dry matter content by drying to a constant weight at 60°C. Both organic fertilizers were characterized for basic chemical properties such as pH and EC (Al-Wabel *et al*., 2013) and total N was determined by the Kjeldahl method (Bremner, 1960).

Biochar samples were first dried under sunlight and kept in the oven at 105 °C for about 2 hours to remove the adsorbed water. K-humate was mixed with BC at a rate of 0.5% (w/w) as a growth promoter aiming to increase N uptake by plants. K-humate and biochar mixture was mixed at a ratio of 1:1 on a volume basis with fish tonic and a weight basis with cattle slurry. Then those two mixtures were dried under sunlight and the biochar-based organic fertilizer composite was pelletized by using the pelletizer (Gemco energy) available at the Research Station at Makandura. It produced cylindrical pellets with a diameter of 1 cm and a length of about 2–3 cm. The cattle slurry and fish tonic enriched biochar pellets were denoted asBOF_{CS} and BOF_{FT} respectively. In addition to the two new organic fertilizers, a slow-release fertilizer (SRF_U) with 23% N made using rice husk BC and U (Jayarathna, 2021) was also used in the pot experiment as a positive control.

The total N content in each of the two developed fertilizers were determined by using Kjeldahl method (Enders *et al*., 2012). The pH of the two developed fertilizers was measured in the ratio of 1:20 biochar organic fertilizer: water (Quan *et al*., 2020).

Plant House Experiment

A pot experiment was conducted using the soil collected from a vegetable cultivating experimental agricultural field at Horticultural crop Research and Development Institute, Gannoruwa (716’47" N; 8035’52" E). Five kilograms of field fresh soil (4.6 kg of dry soil) was filled into pots little by little and compacted so that it maintained the bulk density of each layer at 1.3 g/cm^3. One vigorously growing Capsicum seedling was transplanted in each pot. Five fertilizer treatments, namely: No-N control (0N), (2) 100% of the recommended N as urea (U), (3) 100% of recommended N as a slow released fertilizer developed from urea and biochar (SRF_U), (4) 100% of recommended N as organic fertilizer developed from cattle slurry and biochar (BOF_{CS}), and (5) 100% of recommended N as organic fertilizer developed from fish tonic and biochar (BOF_{FT}) were imposed into pots growing with Capsicum (*Capsicum annum*, variety CA-8) plants. In calculating the equivalent BOF_{CS} and BOF_{FT} contents, we assumed all N in them would be available to the plant during the growing period. The basal application was followed by one split application at 4 weeks after transplanting (WAT). Except for the 0N treatment, all the other treatments received 23 mg of N kg^{-1} soil, equivalent to the recommended N rates for Chilli (100 kg/ha per application), in each fertilizer application. Irrigation was practiced throughout the experimental period ensuring no leaching losses of nutrients. All management practices, including P and K applications, were the same across all treatments as recommended by the Department of Agriculture. TSP and MOP were applied at a rate of 108 mg/kg of dry soil and 33 mg/kg of dry soil, respectively, as the basal dressing with the N application. In the next split application, only MOP was applied at the rate of 33 mg/kg of dry soil with the N application. Treatments were arranged in a Randomized Complete Block Design (RCBD) under net house conditions with 5 replicates.

Measurements and Calculations

The nitrogen nutritional status of the plants was assessed by measuring the greenness of the plants through a SPAD meter (Konika 505) at weekly intervals after three weeks from transplanting. Plants were uprooted carefully 6 weeks after transplanting (WAT) without damaging the roots. Plants were washed with distilled water to remove contaminants. To measure the leaf area, representative leaves were collected, one leaf from each leaf whirl of a plant. Circles with a known diameter were cut from each of those leaves, and dry weight after oven drying for 48 hours at 65 °C of those circular leaf parts (W) as well as the remaining leaf parts were obtained (W'). The area of the circular parts (A) was calculated by summing the area of all circles collected from the plant. The area of remaining leaf parts (A') was calculated using the following equation:

$$A' = \left(\frac{A}{W}\right) \times W'$$

Using the sum of the area of the remaining leaf parts and the area of the circular parts, the total leaf area of the plant was determined.

Roots and shoots were separated and oven-dried at 65 °C until a constant weight was obtained. After measuring the dry weights, roots and shoots were ground to pass through a 1 mm sieve. The nitrogen concentration of the plant samples was determined by the Kjeldahl method (Bremner, 1960). To calculate the use efficiency of applied N fertilizer in the experiment, the apparent recovery of N (ARN) and agronomic efficiency (AE) in different treatments were calculated as a fraction of increased N uptake due to fertilizer application (Fageria and Baligar, 2005) as follows:

$$\text{ARN}(\%) = \frac{(N_f - N_u) \times 100}{N_a}$$

where N_f and N_u are the N accumulation in above-ground biomass (g) in the fertilized and unfertilized pots, respectively, and N_a is the quantity of N applied (g).

$$\text{AE(g/g)} = \frac{\text{DM}_f - \text{DM}_u}{N_a}$$

where DM_f is the total plant dry matter of the fertilized pots (g), DM_u is the total plant dry matter of the unfertilized pots (g), and N_a is the quantity of N applied (g).

Statistical Analysis

After an exploratory data analysis to identify the outliers, normality, and uniform variance of the data, repeated measures analysis was done for SPAD meter readings. One-way ANOVA was performed for all other parameters. Duncan's multiple range test was used to compare and assess the significance of the mean values at $p < 0.05$. Statistical analysis was carried out using IBM SPSS® Statistics (version 21).

RESULTS AND DISCUSSION

Characterization of RBL Soil

The soil texture of Reddish Brown Latosols (RBL) soil used for this experiment was sandy clay loam. Soil pH is slightly acidic, non-saline soil, and non-sodic as the pH < 8.5 and EC < 4 dS/m (Table 1). Organic carbon content was low (0.77%), resulting in the total N content of the soil also being low (0.05%). Low OC content could be attributed to the complete removal of the harvest and residues and continuous tillage operations in each season as observed by Hartati and Sudarmadji (1970). The available P and K levels are very low and attributed to the intensive cultivation, imbalance fertilizer application, and/or adsorption to the inorganic and organic colloids.

Characterization of Biochar, Cattle Slurry, Fish Tonic, BOF_{CS}, and BOF_{FT}

The paddy husk biochar, cattle slurry, fish tonic, cattle slurry-biochar fertilizer (BOFCS), fish tonic-biochar (BOF_{FT}), and urea-biochar fertilizer (SRF_U) showed alkaline pH values (Table 2). All raw materials and fertilizers showed low EC values. These values are in close agreement with properties observed by others. For example, Thygesen *et al*. (2012) observed a pH of 7.35 and an EC of 0.15 dS/m for cattle slurry, while Arani *et al*., (2023) observed a pH of 4.34–7.41 and EC of 1.69–39.3 dS/m. Due to the high solid contents, the density of cattle slurry was 1.10 g/cm^3 and in fish tonic 1.03 g/cm^3.

Effect on Soil pH

The pH of the soil used for this experiment was 6.48, but by the end of the experimental period (i.e., 6 WAT) soil pH had significantly ($p < 0.001$) decreased in all treatments (Figure 1). The lowest soil pH (5.59 to 5.65) was observed in the control, 100% N as Urea, and 100% N as SRF_U treatments, which were not statistically different ($p > 0.05$) from each other. Compared to those three treatments, the pH in BOF_{FT} treated soils (6.06) was significantly higher.

Nitrogen fertilizers may acidify the soil mainly after nitrification as each mole of urea-N oxidized to NO_3^- produces one mole of H^+ (Bouman *et al.*, 1995). Cattle slurry mostly contains NH_4^+ (Bernardi *et al.*, 2012), which is ultimately converted into NO_3^- by acidifying the soil. Anyhow, even though no N fertilizer was added to the control treatment, it also had significantly lowered the soil pH with time, probably due to the uptake of basic cations by plant roots releasing H^+. Since BOF_{FT} andBOF_{CS} have added a higher BC amount to the soil compared to SRF_U, less acidifying effect could be possible with those two organic fertilizers. Basic cations in the ash component of biochar are mainly responsible for the higher pH (Li *et al.*, 2018) in BOF_{FT}- and BOF_{CS}-applied soils. Biochar increases CEC in amended soils with low Ca content, like the soils in this study (Hailegnaw *et al.*, 2019), suggesting a higher retention of cations without them being leached.

However, since biochar contains a high concentration of leachable cations, the reduction of leaching losses due to increased CEC cannot apply to our observations. On the other hand, we managed soil water content to ensure no leaching of nutrients occurred from pots. Other possible mechanisms for higher pH in biochar-amended soils include the presence of

Table 1: Physiochemical characteristics of Reddish Brown Latosols (RBL) soil.

Property	Units	Values ± SD†
pH (1:2.5, water)	-	6.48 ± 0.2
EC (1:5, water)	dS/m	0.02 ± 0.01
Organic C (dichromate oxidation method)	%	0.77 ± 0.07
Total N (Kjeldahl method)	%	0.05 ± 0.02
Available N (1M KCl)	%	0.02 ± 0.01
Available P (Olsen method)	mg/kg	3.36 ± 0.02
Exchangeable K (1M CH_3COONH_4)	mg/kg	52.6 ± 2.46
Sand	%	60.7
Silt	%	10.8
Clay	%	28.5
Texture	-	Sandy clay loam

† SD is the standard deviation.

Table 2: Basic characteristics of raw materials used and organic N fertilizers produced.

Property	Units	Raw materials †			Products †		
		BC	CS	FT	BOFCS	BOF_{FT}	SRF_U
pH (1:20, water)	-	8.85 ± 0.02	9.74 ± 0.03	7.38 ± 0.01	8.69 ± 0.01	8.30 ± 0.01	8.42 ± 0.02
Total N	% (w/w)	0.59 ± 0.01	2.8 ± 0.3	-	1.1 ± 0.1	2.0 ± 0.1	23.0 ± 0.5
	% (w/v)	-	1.2 ± 0.2	1.3 ± 0.1	-	-	-

† BC – rice husk biochar; CS – cattle slurry; FT – Fish Tonic; BOF_{CS} = Cattle slurry mixed BC pellets; BOF_{FT} = Fish tonic mixed BC pellets; SRF_U = Urea intercalated BC pellets.

negatively charged functional groups binding surplus H^+, decarboxylation of organic anions by consuming surplus H^+, and increased pH buffering capacity due to increased CEC (Hailegnaw *et al.*, 2019).

Effect on Nitrogen Nutritional Status

The SPAD meter readings are closely related to leaf N concentrations (Uddling *et al.*, 2007), and therefore it can be used to monitor the N status of *Capsicum*. The interaction effect between time × treatment significantly ($p < 0.01$) affected the SPAD reading. The SPAD readings increased with time from 35.0–38.8 at 3 WAP to 45.2–52.4 at 6 WAP in different treatments (Figure 2). At the 3rd WAT, no significant difference in SPAD readings was observed among treatments. Thereafter, the SRF_U showed significantly ($p < 0.05$) higher SPAD readings than the control, BOF_{CS}, and BOF_{FT}.

At the time of uprooting (6 WAT), the SPAD reading of SRF_U was significantly ($p < 0.001$) higher than the control, while other treatments were comparable to SRF_U. SPAD readings increased with time until the 5th WAT in all treatments, but it kept increasing until the 6th WAT only in SRF_U. It was clear from the data that, at the same N application rate, SRF_U was able to supply more N to plants than any other product tested, including the U treatment. A critical SPAD reading of 56–59 at the flowering stage has been reported

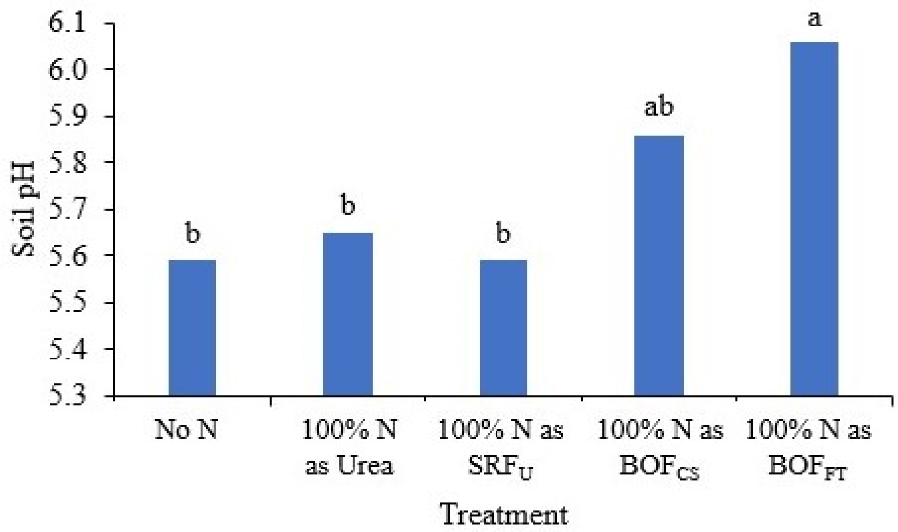

Figure 1: pH of the soil treated with different N fertilizers at 6 weeks after transplanting. Note: SRF_U is slow released fertilizer developed from urea and biochar,BOF_{CS} is 100% of recommended N as organic fertilizer developed from cattle slurry and biochar, and BOF_{FT} is 100% of recommended N as organic fertilizer developed from fish tonic and biochar. Bars with same letters are not significantly different at P<0.05.

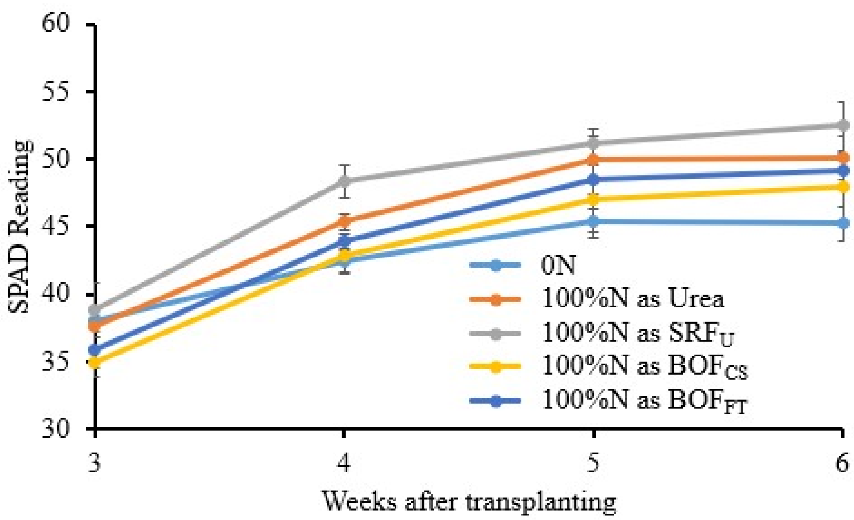

Figure 2: Change in SPAD reading from 3 to 6 WAT in Capsicum plants treated with different N fertilizer products. Vertical bars at each data point indicate ±SE (n=5). Note: SRF_U is slow released fertilizer developed from urea and biochar, BOF_{CS} is 100% of recommended N as organic fertilizer developed from cattle slurry and biochar, and BOF_{FT} is 100% of recommended N as organic fertilizer developed from fish tonic and biochar.

to obtain maximum yield (Carvalho *et al.*, 2013; Costa *et al.*, 2018). We observed smaller SPAD values than theirs, but it was during the vegetative period. Grainfenberg *et al.* (1985) reported that the nutritional requirements of pepper are small during the vegetative stage, but increase significantly when the flowering stage is reached. It was only the SRF_U-treated plants that indicated an increasing trend in SPAD; the reading at 6 WAP suggests a positive impact on yield compared to other treatments (Figure 2). Fertilizer application has made a significant difference in shoot, root, and total N concentrations at 6 WAT. Control treatment has shown the lowest N concentrations in all cases (Table 3). The highest N concentrations in shoots (4.4% and 4.3%) and whole plant (41 g/g) were shown by SRF_U and BOF_{FT}, and they were comparable to the Urea treatment (3.9% and 3.6). BOF_{CS} has shown comparable shoot and total N concentrations for the control and the Urea treatment, but SRF_U and BOF_{FT} were significantly lower than that. Vadillo *et al.* (2024) observed that the critical N concentration in shoots of chili decreases with an increase in dry matter content. Even with the highest dry matter content (Table 4), shoot N concentration in plants treated with SRF_U

Table 3: Mean N concentrations in the shoot, root, and total dry matter contents at 6 WAT in Capsicum plants treated with different N fertilizers.

Treatment	N concentration (%)		
	Shoot	**Root**	**Total**
0N	2.4^{c}	1.8^{b}	2.3^{c}
Urea	3.9^{ab}	2.4^{a}	3.6^{ab}
SRF_U	4.3^{a}	2.5^{a}	4.1^{a}
BOF_{CS}	2.9^{bc}	2.4^{a}	2.8^{bc}
BOF_{FT}	4.4^{a}	2.4^{a}	4.1^{a}

† Different letters in the same column are significantly different by Duncan's multiple range test at $p < 0.05$.

was significantly high. Plants treated with BOF_{FT} also reported similar shoot N concentration, but this could be due to lower dry matter content rather than the higher availability of N.

Effect on Plant Growth

Leaf area and dry matter contents in different plant parts reflect the growth of the *Capsicum* plants. As shown in Table 4, the application of N has made a significant ($p < 0.001$) impact on plant growth parameters except in the BOF_{CS} treatment, where growth of the plants in that treatment was not significantly different from the no-N-added control treatment. Among the other N-added treatments, 100% N as SRF_U treatment had significantly higher plant growth than the others. When compared to the 100% N as Urea treatment, total dry matter accumulation in the 100% N as SRF_U treatment was 60% higher. Growth of the plants in 100% N as BOF_{FT} treatment was comparable with plants in the 100% N as Urea treatment. A similar trend could be observed for the shoot: root ratio of the plants in different treatments (Table 4).

Effect on Nitrogen Uptake and Use Efficiency

Application of N has made a significant ($p < 0.001$) impact on N uptake by *Capsicum* plants. All the N-added treatments except 100% N as BOF_{CS} have resulted in significantly ($p < 0.001$) higher results than the control treatment. The significantly ($p < 0.001$) highest shoot and total N uptake were in 100% N as SRF_U. Control and the 100% N as BOF_{CS} treatments are not significantly ($P > 0.05$) different and had the least N uptake. 100% N as Urea and 100% N as BOF_{FT} treatments have resulted in statistically similar ($p > 0.05$) N uptake by *Capsicum* plants. They were significantly ($p < 0.001$) higher than the results of control and 100% N as BOF_{CS} treatments and significantly ($p < 0.001$) lower than the results of 100% N as SRF_U.N uptake in roots was increased significantly ($p < 0.01$) by N application, but N content in roots were significantly lower in 100% N as BOF_{CS} treatment when compared to 100% N as SRF_U (Table 5). Since the amount of N applied as different fertilizers were the same across N added treatments, both apparent recovery efficiency (ARE) and agronomic efficiency (AE) have shown the same trend as total N uptake by plants (Table 3 and 4). While ARE in 100% N as SRF_U was about 79%, AE was 16.2 (kg/kg of N).

The lowest ARE (8.9%) and AE (2.1 kg/kg of N) was observed in the 100% N as BOF_{CS} treatment. SRF_U is slowly releasing urea to soil solution because of the BC matrix. This allows better synchronization of N supply with plant uptake of N and reduces losses through ammonia volatilization while allowing plants to uptake more of the applied N. Consequently, the largest NRE and AE were observed in the SRF_U treatment. After an extensive review of literature, Hegde *et al.* (2007) concluded that better synchronization of fertilizer N supply with crop N demand can result in high yields, reduce losses of N, and efficient utilization of applied N. The lowest N use efficiencies were shown by BOF_{CS} treatment.

This could be due to the slow mineralization of organic N in BOF_{CS} and adverse effects of volatile NH_3 on the growth of seedlings resulting from the high amount of BC that has an alkaline pH. Urea and BOF_{FT} have shown similar ($p > 0.05$) efficiencies, which were significantly ($p < 0.05$) higher than that of BOF_{CS} and lower than that of SRF_U. Urea has readily available N, and BOF_{FT} has a formula of it, which resulted in higher efficiencies than BOF_{CS}. But urea is prone

Table 4: Mean leaf area, shoot, root, total dry matter (DM) and shoot: root ratio (S/R) at 6 WAT in Capsicum plants treated with different N fertilizers.

Treatment	Leaf area † (cm^2/plant)	Shoot DM † (g/plant)	Root DM † (g/plant)	Total DM † (g/plant)	S/R †
0N	179.71^{c}	1.28^{c}	0.37^{b}	1.65^{c}	3.60^{bc}
Urea	320.50^{b}	2.57^{b}	0.61^{a}	3.18^{b}	4.18^{bc}
SRF_U	507.94^{a}	4.33^{a}	0.76^{a}	5.09^{a}	5.72^{a}
BOF_{CS}	210.46^{c}	1.57^{c}	0.51^{ab}	2.09^{bc}	3.10^{c}
BOF_{FT}	323.71^{b}	2.62^{b}	0.62^{a}	3.24^{b}	4.42^{b}

† Different letters in the same column are significantly different by Duncan's multiple range test at $p<0.05$.

Table 5: Mean N uptake in different plant parts, apparent recovery efficiency of N (ARE), and agronomic efficiency (AE) of Capsicum plants at 6 WAT treated with different N fertilizers.

Treatment	N uptake (g/plant)			ARE (%)	AE (kg/kg)
	Shoot	Root	Total		
0N	0.031^{c}	0.006^{c}	0.038^{c}	-	-
Urea	0.106^{b}	0.015^{ab}	0.120^{b}	38.74^{b}	7.16^{bc}
SRF_U	0.186^{a}	0.019^{a}	0.206^{a}	79.33^{a}	16.25^{a}
BOF_{CS}	0.044^{c}	0.012^{b}	0.058^{c}	8.86^{c}	2.10^{c}
BOF_{FT}	0.104^{b}	0.015^{ab}	0.126^{b}	42.14^{b}	8.48^{b}

† Different letters in the same column are significantly different by Duncan's multiple range test at $p < 0.05$.

to losses through ammonia volatilization (Bremner, 1995), which causes lower efficiency than SRF_U.

Maximising the efficiencies (ARE and AE) of applied N fertilizers is important to ensure optimum plant growth, fewer environmental consequences due to reactive N, and high economic benefits. Iqbal *et al.* (2019) observed that substitution of N fertilizers by 60% with poultry or cattle manure significantly decreases yields and NUE in rice cultivation in China but not at 30% substitution. In our study, 100% of N fertilizers were substituted with BOF and recorded lower dry matter contents and NUE. Manure decomposition at early growth could not have provided sufficient nutrients for plant growth as compared to inorganic fertilizer.

When liquid cattle manure, i.e., excrements plus urine that occasionally contains bedding materials, which resembles cattle slurry used in this study, was used alone, it can improve growth, yield, and macronutrient uptake by maize (Bernardi *et al.*, 2012) and fertility of forage cultivating soil (Lithourgidis *et al.*, 2007). Nitrogen in BOF_{CS} is mostly in organic forms and becomes plant-available only after mineralization (Müller *et al.*, 2011). Therefore, one possibility for the poor growth of *Capsicum* plants in the BOF_{CS} treatment could be the low rate of N mineralization, which resulted in poor synchronization of the demand and supply of N. On the other hand, the N content in BOF_{CS} is only 1.1%. Therefore, the rate of BC received by the 100% N as BOF_{CS} treatment (2.1 g/kg soil) was much higher than the quantity of BC received by the BOF_{FT} (1.2 g/kg soil) or SRF_U (0.09 g/kg) treatments. Adding a high amount of BC to soil can be harmful to plant growth as a result of increased soil pH and soil salinity (Brtnicky *et al.*, 2021). Although the pH in BOF treatments is significantly higher than that of other treatments (Fig. 3), the rate of BC application was only a mere 4 t/ha. Therefore, the possibility of adverse effects due to higher BC application on plant growth in BOF_{CS} treatment cannot be justified. Cattle slurry contains a high amount of NH_4^+-N, and a large percentage of this N can be lost through ammonia volatilization (Bernardi *et al.*, 2012) due to the high pH of the BC, although some others have observed a reduction in NH_3 loss when BC is mixed with manure (Sha *et al.*, 2019). The alkaline condition in soil created due to urea hydrolysis soon after the application of 100% N as urea can also promote NH_3 volatilization. Previous studies have proven that there is a significant correlation between ammonia volatilization and soil pH: the higher the soil pH, the higher the ammonia volatilization (Zhenghu and Honglang, 2000). Ammonia gas can be toxic to early plant growth (Bremner, 1990) and could be another reason for poor growth of plants in the BOF_{CS} treatment

One hundred percent (100%) N as Urea or BOF_{FT} has resulted in statistically similar ($p > 0.05$) leaf area, shoot dry matter, total dry matter, and N uptake of *Capsicum* plants. They were significantly ($p < 0.001$) higher than the results of the control and 100% N as BOF_{CS} treatments and significantly ($p < 0.001$) lower than the results of 100% N as SRF_U. Urea is the conventional source of inorganic N supply in *Capsicum* cultivations, which is subjected to rapid hydrolysis and supplies readily available N to plants. Therefore, it probably supplies sufficient N for plant growth. But using urea could lead to higher losses (Bremner, 1990) than slow-release fertilizers comprised with BC. Since there is a quick release of NH_4^+ in urea, it probably has less synchronization with plant uptake than SRF_U since at the latter part of the plant growth, N supply from urea has already declined because of losses. Fish tonic enriched BC has resulted in similar growth and N uptake as urea. That could be because of its slow release rates of N, supply of micronutrients, and organic and inorganic forms of N that are in fish tonic. This observation is consistent with a study conducted using urea and fish tonic (without BC) for tomato (*Solanum lycopersicon*). In that study also, the 100% fish tonic treatment had the best plant growth and yield (Jegatheeswaran *et al.*, 2021).

CONCLUSION

Organic N fertilizers were developed by mixing cattle manure or fish tonic with paddy husk biochar and by pelletizing the mixture. The two products, BOF_{CS} and BOF_{FT}, had 1.1% and 2.0% total N contents, respectively. When the recommended rate of urea for *Capsicum* was completely replaced by BOF_{CS}, the plant growth, plant nutrition status, and N use efficiencies were significantly reduced, but plants receiving BOF_{FT} gave comparable results. The soil pH was also significantly higher in BOF-applied soil when compared to the urea-applied soil, probably because of the high rates of biochar application. While SRF_U is the most efficient and productive N fertilizer among those tested, cattle slurry and fish tonic incorporated into biochar pellets cannot 100% substitute the urea N required for the growth of *Capsicum* plants in the studied Ultisol. Future experiments with different rates of urea substitution by BOF would shed more light on the feasibility of the two new organic products, made using rice husk biochar and cattle slurry or fish tonic, for their effectiveness in supporting *Capsicum* growth in different soils and agro-climatic conditions.

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