Ecofriendly utilization of nutrient enriched biochar from sugar industry wastes and its effect on nutrient use efficiency and yield of rice

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DOI: https://doi.org/10.22271/chemi.2020.v8.i1i.8324

Abstract
An experiment was conducted to study the nutrient use efficiency of nutrient enriched biochar (NEB) from sugar industry wastes with seven treatments comprising T1 (absolute control), T2 (50% RD of PK through NEB), T3 (75% RD of PK through NEB), T4 (100% RD of PK through NEB), T5 (125% RD of PK through NEB), T6 (50% through NEB + 50% through inorganic fertilizer) and T7 (100% RD of PK through inorganic fertilizer) in RBD using the rice variety TRY 3 at Anbil Dharmalingam Agricultural College and Research Institute, Trichy District, Tamil Nadu. In all treatments, nitrogen was supplied based on LCC reading. The result of the field experiment revealed that application of NPK through NEB favourably influenced the yield contributing parameters viz., number of tillers per hill, productive tillers per hill, length of panicle, number of filled grains per panicle which will release the nutrients slowly and steadily to maintain the availability of nutrients throughout the crop period thereby increasing the nutrient use efficiency and crop yield. Since the yield of T3 treatment (6103 kg/ha) was on par with T4 (6165 kg/ha) and T5 (6269 kg/ha) treatments, which indicated that the plants received the essential nutrients in required quantities at 75% RD of PK through NEB itself. On optimization of graded levels of NEB, the application of 75% RD of Pk through NEB was found to be the best treatment with respect to nutrient use efficiency and grain yield in response to the quantity of nutrient applied.

Keywords: Nutrient use efficiency, biochar, sugar industry waste, rice, vertic ustopept, sodic soil

Introduction
Biochar is a carbonaceous material produced by thermo – chemical conversion of organic materials under reduced oxygen condition (Shackley and Sohi, 2010)[13]. It is mostly used for carbon sequestration, but now, it is used as amendment and also as a carrier for slow release of fertilizer to enhance the soil fertility and improve the crop productivity by increasing the nutrient use efficiency (Sarkhot et al., 2012)[11]. India is the largest producer of sugarcane and the second largest consumer of sugar in the world. The potential of biochar prepared from various crop residues are being studied as soil input to enhance SOC, increase nutrient use efficiency, improve physical and chemical health and thereby crop productivity. However, the biochar produced from sugar industry wastes like press mud, bagasse and spent wash are rich in nutrients, it reduces the nutrient losses by adsorption of nutrients in its matrix which will be slowly released for plant requirement (Sohi et al., 2010)[13]. Hence, the present investigation was undertaken to study the eco – friendly utilization of nutrient enriched biochar from sugar industry wastes and its effect on nitrogen use efficiency.

Materials and Methods
A field experiment was conducted at ADAC & RI, Trichy in a Randomized Block Design (RBD) with seven treatments comprising T1 (absolute control), T2 (50% RD of PK through NEB), T3 (75% RD of PK through biochar), T4 (100% RD of PK through biochar), T5 (125% RD of PK through biochar), T6 (50% RD of PK through biochar + 50% RD of PK through inorganic fertilizer) and T7 (100% RD of PK through inorganic fertilizer) using rice (TRY 3) as the test crop. In all treatments, the nitrogen was supplied based on LCC reading. The nutrient enriched biochar (NEB) from sugar industry wastes used for the experiment was collected from EID Parry (I) Ltd, Nellikuppam, Cuddalore district having N, P2O5, K2O content of 7: 7: 7.
The experimental soil was *Vertic Ustropept* having low in KMnO₄- N, medium in NaHCO₃-P and medium in NH₄OAc-K status (197 kg ha⁻¹, 12.8 kg ha⁻¹, 136 kg ha⁻¹, respectively). The plant samples collected at active tillering (AT), panicle initiation (PI), and post harvest stage (straw) and grain were analyzed for N, P and K uptake (Jackson, 1973) [8] and the nutrient use efficiency was calculated following Cassman et al. (1996) [3]. LCC was used to correlate the nitrogen requirement of plants. LCC was used to correlate the nitrogen requirement of plants. LCC readings were recorded at 7 – 10 days interval from 14 DAT. The critical value for the LCC reading is 4. The soil samples were collected from each experimental plot at active tillering (AT), panicle initiation (PI) and post harvest (PH) stage were analyzed for NH₄-N, NO₃-N, available nitrogen (N), available phosphorus (P) and available potassium (K).

### Results and Discussions

#### LCC Reading
LCC readings were recorded above the threshold value without addition of N fertilizer up to 21 days in all treatments (Table 2). Since the most of the nitrogen supplied by NEB in 125% RD of PK (62.5 kg ha⁻¹) it has been released in a phased manner and matched the N demand of the rice crop up to 42 days. In general, all NEB applied treatments recorded below the critical level at 2 stages only (21 and 63 DAT). In case of inorganic fertilizer applied treatment, it recorded below the critical level at 3 stages (21, 42 and 63 DAT). This might be due to the losses by leaching and volatilization. The slight decrease in the LCC reading after the PI stage might be due to transfer of N from leaf to reproductive parts.

#### Soil available nitrogen
Nitrogen (N) is often the most limiting factor in crop production (Vitousek and Howarth, 1991) [15]. Increase in the rate of NEB application increased the available N content of the soil (Table 3). During active tillering stage, an increase of 21, 42, 57, 69, 39 and 38 kg ha⁻¹ were observed in T₁, T₂, T₃, T₄, T₅ and T₆ respectively over control. The same trend of available N was observed at both panicle initiation and post harvest stage. This is in line with the findings of Angst and Sohi (2013) [10]. Biochar has been shown to have promise in reducing inorganic-N leaching (Singh et al., 2010) [12]. According to Lehmann et al. (2003) [9], the application of biochar to the soil caused a decrease in N leaching by 60%, and increased crop productivity by 38-45%.

#### Soil ammoniacal and nitrate nitrogen
The results of field experiment showed that the transformation and the availability of N in soil were greatly influenced by NEB application. At tillering stage, NH₄-N and NO₂-N content increased with increase in dose of NEB, which indicated that the application of NEB added certain amount of N and increased the ammonification and nitrification (Table 4). Similar result was observed by Castaldi et al. (2012) [8], Ball et al. (2010) [2] and De Luca et al. (2006) [6]. The increase in NO₃-N content of the soil from panicle initiation to post harvest stage might be due to microbial oxidation of NH₄-N to NO₃-N (Liang et al., 2006) [10].

#### Soil available phosphorus
Among the treatments, the highest available P content was obtained in 125% RD of PK through NEB in all three stages but there was a little decrease in available P with growth stages due to uptake by plants (Table 3). A steady supply of available P might be due to the formation of chelates (Topoliantz and Ponge, 2005) [14]. They also stated that, biochar indirectly influenced the P availability by interfere with the interaction of Al³⁺, Fe³⁺, Fe²⁺, and Ca²⁺ by sorbing organic molecules that act as chelates. In 100% RD of PK through inorganic fertilizer, a tremendous decrease was observed with growth stages. This might be due to conversion of labile P to the insoluble phosphates (Tricalcium phosphate).

#### Soil available potassium
The available K status was increased with the increased level of NEB application but there was a decreased trend was occurred between the stages. Tremendous decrease in K content was observed in 100% RD of PK through inorganic fertilizer (Table 3) which might be due to uptake of K by plants and also by leaching loss. A steady rate of decrease was observed in NEB applied plots occurred only due to uptake by plants because biochar lower the leaching loss. Similar work was done by Widowati et al. (2014) [17] and reported that the higher rate of biochar application would lower the leaching of potassium although the amounts of K in the soil increased and he also observed that potassium retention was also high with biochar.

#### Nutrient use efficiency parameters
The N use efficiency parameters such as agronomic efficiency (AE), recovery efficiency (RE) and utilization efficiency (UE) were highest in 125% RD of PK through NEB. The quantity of N supplied through NEB was more in this treatment (62.5 kg ha⁻¹). Hence, it require nitrogen at only one time during the crop period as evidenced in LCC and SPAD readings. Due to the slow release of N the requirement will be less which inturn increases the efficiency. In case of physiological efficiency (PE) and factor productivity (FP), 50% RD of PK through NEB recorded the highest value. The similar trend was followed in P and K use efficiency in physiological efficiency and factor productivity parameters except in agronomic efficiency (AE), recovery efficiency (RE) and utilization efficiency (UE) where the highest value was registered in 75% RD of PK through NEB (Table 6). Wang et al. (2012) [12] also reported that, the biochar enriched with P are the potential P sources with high agronomic efficiency. Cassman and Pingali (1995) [4] reported that timing and formulation of applied N improved the agronomic efficiency from 24 to 33 in rice. Glaser et al. (2002) [7] observed that the addition of biochar enhanced the nutrient retention and nutrient availability due to their high surface area. Higher nutrient retention ability, in turn improved the fertilizer use efficiency and reduces leaching.

#### Grain and Straw yield
An increase in grain yield of 74.9, 113.0, 115.2, 118.8, 108.7 and 104.7% and straw yield of 78.1, 118.7, 122.8, 128.6, 114.3 and 110.2% were recorded in T₂, T₃, T₄, T₅, T₆ and T₇ respectively over control (Table 5). The results of the field experiment revealed that the application of NEB, had increased the yield significantly. Though, the treatment T₃ registered the highest grain yield, it was found to be on par with T₅ and T₆. Hence, it is concluded that only the yield increase was significant up to 75% RD of P and K applied through NEB, which indicated that the plants received the essential nutrients in required quantities at 75% RD of P and K through NEB itself.
Table 1: Total quantity of nutrients (kg ha\(^{-1}\)) applied in field experiment

| Treatments                                                                 | Basal | 21 DAT | 42 DAT | 63 DAT | Total N | Total P & K |
|---------------------------------------------------------------------------|-------|--------|--------|--------|---------|-------------|
| T\(_1\), Absolute control                                                | -     | -      | -      | -      | -       | -           |
| T\(_2\), 50% RD of PK through NEB                                        | 25    | 30     | -      | -      | 85      | 25          |
| T\(_3\), 75% RD of PK through NEB                                        | 37.5  | 30     | -      | -      | 97.5    | 37.5        |
| T\(_4\), 100% RD of PK through NEB                                       | 50    | 30     | -      | -      | 110     | 50          |
| T\(_5\), 125% RD of PK through NEB                                       | 62.5  | -      | 30     | -      | 92.5    | 62.5        |
| T\(_6\), 50% RD of PK through NEB + 50% RD of PK through inorganic fertilizer | 37.5  | 30     | -      | -      | 97.5    | 50          |
| T\(_7\), 100% RD of PK through inorganic fertilizer                     | 37.5  | 30     | 30     | -      | 127.5   | 50          |

Table 2: LCC reading during field experiment (at 7 days interval)

| Treatment | Days | AT   | PH | PI   | PH | AT   | PI   | PH | AT   | PI   | PH | AT   | PI   | PH | AT   | PI   | PH |
|-----------|------|------|----|------|----|------|------|----|------|------|----|------|------|----|------|------|----|
| T\(_1\)   | 14   | 2.5  | 3.0 | 3.0  | 3.0| 3.0  | 3.0  | 3.0| 3.0  | 3.0  | 3.0| 3.0  | 3.0  | 3.0| 3.0  | 3.0  | 3.0|
| T\(_2\)   | 21   | 4.0  | 3.5 | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0|
| T\(_3\)   | 28   | 4.0  | 3.5 | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0|
| T\(_4\)   | 35   | 4.0  | 4.0 | 4.0  | 3.5| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0|
| T\(_5\)   | 42   | 4.0  | 3.5 | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0|
| T\(_6\)   | 49   | 4.0  | 4.0 | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0|
| T\(_7\)   | 56   | 4.0  | 3.0 | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 4.0| 4.0  | 4.0  | 3.5|

Table 3: Effect of NEB on available N content (kg ha\(^{-1}\)) of soil at different growth stages of rice

| Treatments | Available N (kg ha\(^{-1}\)) | Available P (kg ha\(^{-1}\)) | Available K (kg ha\(^{-1}\)) |
|------------|-----------------------------|-----------------------------|-----------------------------|
| T\(_1\)    | AT                          | PH                          | AT                          |
| T\(_2\)    | 199                         | 13.7                        | 13.3                        |
| T\(_3\)    | 220                         | 15.9                        | 15.4                        |
| T\(_4\)    | 241                         | 17.5                        | 17.1                        |
| T\(_5\)    | 256                         | 18.0                        | 17.4                        |
| T\(_6\)    | 268                         | 18.9                        | 17.7                        |
| T\(_7\)    | 238                         | 16.8                        | 16.4                        |
| SEd        | 5                           | 0.4                         | 0.3                         |
| CD (0.05)  | 10                          | 0.9                         | 1.3                         |

Table 4: Effect of NEB on NH\(_4\) – N and NO\(_3\) - N content (kg ha\(^{-1}\)) of soil at different growth stages of rice

| Treatments | NH\(_4\) - N content (kg ha\(^{-1}\)) | NO\(_3\) - N content (kg ha\(^{-1}\)) |
|------------|--------------------------------------|--------------------------------------|
| T\(_1\)    | AT                                   | AT                                   |
| T\(_2\)    | 110                                  | 109                                  |
| T\(_3\)    | 123                                  | 110                                  |
| T\(_4\)    | 152                                  | 141                                  |
| T\(_5\)    | 173                                  | 155                                  |
| T\(_6\)    | 183                                  | 120                                  |
| T\(_7\)    | 150                                  | 97                                   |
| SEd        | 3                                    | 2                                    |
| CD (0.05)  | 7                                    | 4                                    |

Table 5: Effect of NEB on Drymatter production (kg ha\(^{-1}\)) at different stages of rice and yield of rice

| Treatments | Drymatter production (kg ha\(^{-1}\)) | Active Tillering | Panicle Initiation | Straw yield (kg ha\(^{-1}\)) | Grain yield (kg ha\(^{-1}\)) |
|------------|--------------------------------------|------------------|--------------------|------------------------------|-----------------------------|
| T\(_1\)    | 1565                                 | 3085             | 3209               | 2865                         |
| T\(_2\)    | 2198                                 | 5547             | 5714               | 5012                         |
| T\(_3\)    | 2390                                 | 6812             | 7019               | 6103                         |
| T\(_4\)    | 2399                                 | 7008             | 7151               | 6165                         |
| T\(_5\)    | 2447                                 | 7190             | 7335               | 6269                         |
| T\(_6\)    | 2324                                 | 6739             | 6876               | 5979                         |
| T\(_7\)    | 2279                                 | 6612             | 6745               | 5865                         |
| SEd        | 45                                   | 130               | 126                | 109                          |
| CD (0.05)  | 98                                   | 284               | 277                | 239                          |
Table 6: Effect of NEB on nutrient use efficiency parameters

| Treatments | Nitrogen use efficiency | Phosphorus use efficiency | Potassium use efficiency |
|------------|-------------------------|---------------------------|--------------------------|
|            | ANR | AE | RE | FP | UE | ANR | AE | RE | FP | UE | ANR | AE | RE | FP | UE |
| T1         | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| T2         | 27.3 | 25.3 | 0.4 | 33.7 | 54.7 | 430.7 | 85.9 | 0.4 | 114.6 | 186.1 | 97.1 | 85.9 | 1.9 | 114.6 | 186.1 |
| T3         | 37.0 | 33.2 | 0.6 | 29.4 | 72.3 | 400.5 | 86.3 | 0.5 | 76.4 | 187.9 | 93.5 | 86.3 | 2.0 | 76.4 | 187.9 |
| T4         | 33.5 | 30.0 | 0.5 | 26.0 | 65.8 | 389.4 | 66.0 | 0.4 | 57.3 | 144.8 | 87.3 | 66.0 | 1.7 | 57.3 | 144.8 |
| T5         | 43.0 | 36.8 | 0.7 | 31.0 | 81.4 | 321.8 | 50.4 | 0.3 | 42.4 | 111.6 | 84.6 | 50.4 | 1.3 | 42.4 | 111.6 |
| T6         | 35.6 | 31.9 | 0.6 | 29.4 | 69.5 | 355.0 | 62.3 | 0.4 | 57.3 | 135.6 | 91.3 | 62.3 | 1.5 | 57.3 | 135.6 |
| T7         | 25.5 | 23.5 | 0.4 | 22.5 | 51.3 | 413.7 | 60.0 | 0.3 | 57.3 | 130.7 | 917.0 | 60.0 | 1.4 | 57.3 | 130.7 |

Conclusions
The study on the effect of NEB on nutrient use efficiency and yield of rice was carried out in field experiment. On optimization of graded levels of NEB, the application of 75% RD of P and K through NEB along with LCC based N application was found to be the best treatment with respect to nitrogen use efficiency and grain yield in response to the quantity of nitrogen applied.

Acknowledgement
Author thankful to Department of Soil Science and Agricultural Chemistry, Anbil Dharmalingam Agricultural College and Research Institute (ADAC&RI), Tamil Nadu Agricultural University, Tiruchirapalli - 620 009, Tamil Nadu

Funding Source: M/s. EID Parry (I) Ltd., Nellikuppam, Cuddalore district, Tamil Nadu, India

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