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Peat-Based Organo-Mineral Fertilizer Improves Nitrogen Use Efficiency, Soil Quality, and Yield of Baby Corn (*Zea mays* L.)

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Abstract: The application of organo-mineral fertilizers (OMFs) is gaining popularity day by day because of their potential effect on crop productivity and soil fertility enhancement. Therefore, this research was conducted to observe the effect of a peat soil–urea (PSU) fertilizer on baby corn yield, quality, nitrogen (N) use efficiency, and soil quality compared with commercial urea. A completely randomized design (CRD) with four replicates was used to set up the experiment. In this trial, N was applied from three sources, viz., urea, PSU-L (low N = 15%), and PSU-H (high N = 25%) at a rate of 50, 75, and 100% of the recommended N application dose. The growth, yield, quality, and N use efficiency of baby corn were significantly impacted by the application of PSU fertilizer to the soil. Substantially higher leaf chlorophyll, cob vitamin C, and protein content were found in PSU-treated plants compared with commercial urea. The application of PSU produced about 21% higher cob and a 14% fodder yield over commercial urea. On average, the N uptake by baby corn was 22% higher in PSU-treated plants than urea-treated plants, resulting in 24 and 33% higher N use efficiency and fertilizer N use efficiency, respectively, in PSU than commercial urea. Therefore, the N application rate could be reduced by around 30% using PSU as an alternate N source compared with using commercial urea. In addition, the application of PSU to soil substantially increased the soil organic carbon (SOC) content, whereas SOC decreased in urea-treated soil.

Keywords: organo-mineral fertilizer; baby corn; peat soil–urea; urea; yield; nitrogen use efficiency; soil organic carbon

Citation: Uddin, M.K.; Yeasmin, S.; Mohiuddin, K.M.; Chowdhury, M.A.H.; Saha, B.K. Peat-Based Organo-Mineral Fertilizer Improves Nitrogen Use Efficiency, Soil Quality, and Yield of Baby Corn (*Zea mays* L.). *Sustainability* **2023**, *15*, 9086. https://doi.org/10.3390/su15119086

Academic Editors: Helvi Heinonen-Tanski and Roberto Mancinelli

Received: 23 April 2023
Revised: 24 May 2023
Accepted: 1 June 2023
Published: 5 June 2023

1. Introduction

Finding the right balance between the intensification of production and sustainability is one of the top priorities of present agriculture. The development of novel agricultural practices is necessary to attain food security because of the exponential rise in the global population, climate change vulnerability, and soil degradation [1]. The current largest barriers to agriculture's ability to achieve food security goals include a lack of raw materials (environmentally friendly fertilizers, soil-health-enhancing materials, novel crop varieties, etc.), land resources, and a growing world population [2]. The two most pressing challenges for today's farmers are increasing the use efficiency of nitrogen (N) fertilizer and halting the massive loss of soil organic matter [3]. Unfortunately, the global average for N recovery by crop plants is less than 50% [4], and the remaining portion is being lost via runoff, leaching, and denitrification [5]. This has caused both an economic loss and a burden on the environment because off-site N movement in water pollutes aquifers and natural watercourses, and nitrous oxide (N_2O) contributes to the accumulation of greenhouse gases in the atmosphere [6]. Moreover, agricultural models based on productivity are mostly focused on over-fertilization and monoculture farming, leading to problems with soil degradation such as erosion, nutrient imbalance, salinization, and the loss of organic matter (OM) [7]. Soil organic matter is one of the most important indicators of soil health because it has complex effects on soil properties such as soil microbial activity, nutrient dynamics and cycling, and physical qualities [8]. Again, it is becoming increasingly difficult to enhance the efficacy of applied N fertilizers in agroecosystems with deficient organic carbon (OC), which plays a direct role in the retention of N in soil for a longer period [9].

The mitigation and reduction of fertilizer N losses from intensively managed cropping systems have been the subject of research endeavors [10]. Current methods to reduce N losses include the use of nitrification and urease inhibitors and slow- and or controlled-release fertilizers [11]. These enhanced-efficiency N fertilizers aim to match the mineral N supply according to crop requirements over the entire growing season to increase the N uptake and use efficiency of crops [12]. Furthermore, slow-release fertilizers can further cut the cost of crop production by lowering the rate of fertilizer N application and associated costs related to fuel and labor expenses [13].

Organic fertilizers can provide the soil with organic matter and nutrients; their use is also gaining popularity [14]. Unfortunately, the large-scale utilization of organic manure as a fertilizer may be difficult because of variability in nutrient composition, uneven nutrient release, variation in sources, and an extremely high rate of application because of deficient nutrient concentrations [15]. However, organo-mineral granulation has the ability to increase soil organic matter content and trigger microbial activity in soil for sustainable crop production [16]. Granulating natural organic resources with inorganic fertilizer as a source of plant nutrients may be more advantageous than using organic matter or chemical fertilizer alone. Organic matter has the ability to retain nutrients for longer periods. Therefore, OMF could reduce the release rate of nutrients and offer an option to formulate controlled- or slow-release N fertilizers [3]. Consequently, OMFs show a significant effect on plant growth [17,18], resulting in higher yield [19] and enhanced N use efficiency (NUE) [20]. Bahari et al. [18] discovered that the application of OMF showed the highest values of plant height, leaf area, tuber diameter, fresh tuber weight per clump, and dry tuber weight per clump of shallot (*Allium ascalonicum* L.). In a field experiment, wheat yield increased by 32% because of the application of OMF over commercial mineral fertilizer [21]. Furthermore, Saha et al. [20] reported about 21% higher N use efficiency (NUE) by sweet corn (*Zea mays* L.) over commercial urea under the application of OMF produced by granulating brown coal with urea. In another study, Saha et al. [22], also found significantly higher leaf chlorophyll, N uptake, and biomass yield from silver beet (*Beta vulgaris* L.) fertilized with slow-release brown coal–urea fertilizer compared with commercial urea.

Baby corn (*Zea mays* L.) is a high-value crop and requires a very short growing season, and it has multiple uses. It can be grown all year round in a wide range of climatic and soil conditions and is well suited to intensive cropping systems [23]. It is becoming more and more popular among the farmers of Bangladesh, much like in other Asian countries, because of its high demand, growing market, prospects for value addition, and high earning potential [24]. It contains a healthy amount of protein, fat, carbohydrates, ash, calcium, magnesium, phosphorus, iron, zinc, and ascorbic acid [25,26]. Besides the primary crop, it also produces a substantial amount of high-quality green fodder, which serves as a valuable cattle feed [27].

Peat soil (PS), often known as peat, is a unique soil formed by organic material and minerals under favorable climatic and topographic conditions [28]. As an organic amendment, PS has the ability to improve the physical and chemical properties of soil [29,30]. Furthermore, PS contains a higher organic carbon percentage (24.2–69.3%) [31,32] and a natural void ratio [33], resulting in lower bulk density, [34] a high water-holding capacity, and permeability [28]. Moreover, the high cation exchange capacity (CEC) (100–300 cmol kg^{-1}) and porosity of PS are responsible for higher nutrient retention and adsorption capacity in soil [35]. In addition, peat is naturally formed humified organic matter, easily available and very cheap in the southern part of Bangladesh. Recently, Dias et al. [36] showed that the chemical modification of PS with monoammonium phosphate (MAP) had a similar yield effect on corn (*Zea mays* L.), where a maximum amount of residual phosphorus was found for PS-based OMF compared with using MAP. There is, therefore, strong reason to hypothesize that the granulation of natural organics such as peat soil with urea could be a potential option for increasing N use efficiency and sustainable crop production.

Bangladesh is an agro-based country with very high cropping intensity and very low soil organic C. Agriculture heavily relies on synthetic fertilizers with very low or no application of organic matter, resulting in declining soil fertility with a very poor economic return. Therefore, OMF could play a vital role in improving crop productivity and soil fertility. To the best of our knowledge, no scientific research has been published on the agronomic performance of OMF produced by granulating peat with commercial urea on soil properties, N use efficiency, or crop yield in the context of Bangladesh. Therefore, this study was designed to evaluate the effect of PSU fertilizer on the N uptake, N use efficiency, yield, and quality of baby corn in a pot trial study.

2. Materials and Methods

2.1. Experimental Area and Soil

A pot experiment was conducted in the pothouse of the Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh, Bangladesh during the *Kharif-I* season (mid-March–mid-July) in 2022. The experimental site is physically located 19 m above sea level at latitude 24.7219° N and longitude 90.4424° E. Pre-monsoon, monsoon, and post-monsoon circulations influence the warm and humid climate of the experimental area, which is also prone to tropical cyclones and heavy precipitation. The experimental soil was collected at the agronomy field of Bangladesh Agricultural University from the 0–15 cm soil layer. The soil samples were then air-dried and passed through a 2 mm sieve. Then, dried and sieved soil samples were analyzed by following standard methods of analysis [37]. The physical and chemical properties of the collected experimental soil are presented in Table 1.

Table 1. Properties of collected experimental soil.

Parameters	Value	Parameters	Value
Textural class	Silty loam	Total N	0.06%
Bulk density	1.28 g cm^{-1}	Available P	3.12 μg g^{-1}
Soil class	Inceptisol	Available S	4.09 μg g^{-1}
pH	6.8	Available K	1.29 meq 100 g^{-1}
Total C	0.46%	Available Ca	4.9 meq 100 g^{-1}
Organic matter	0.79%	Available Mg	3.2 meq 100 g^{-1}

2.2. Experimental Setup, Design, and Treatments

Polypropylene pots (28 cm depth and 25 cm diameter) were filled with 12 kg of Inceptisol. A completely randomized design (CRD) with four replications was used to set up the experiment. The PSU fertilizers were prepared using a pin mixer and pan granulation technology as outlined by Saha et al. [22]. Three N fertilizers (urea, PSU-H, and PSU-L) (Table 2) were added to the soil at rates of 100, 75, and 50% of the recommended dose (RD) of N, which was 200 kg ha^{-1} (Table 3). A control consisting of only soil was also included as a treatment. Additionally, P (TSP), K (MOP), Ca (Gypsum), Zn ($ZnSO_4 \cdot 7H_2O$), and B (H_3BO_3) were applied at rates of 50, 100, 40, 4, and 1.5 kg ha^{-1}, respectively, at the time of filling the pots. All fertilizers were applied in granular form with the topsoil (0–5 cm) of the pots. Before sowing the seeds, the pots were given three days to reach field capacity. Three seeds of BWMRI Hybrid Baby Corn-1 (*Zea mays* L.), released by the Bangladesh Wheat and Maize Research Institute (BWMRI), were sown in each pot, 3 cm below the soil surface. The soil moisture was retained at field capacity by adding water regularly based on the weight differential, typically every two days. Throughout the experiment, no leaching was seen. Only one plant was permitted to grow in each pot after germination.

Table 2. Moisture content, C:N, crush strength, C, and N content of PSU.

Granules	Moisture (%)	Crush Strength (kg)	C:N	C content (%)	N content (%)
Peat soil urea-H (PSU-H)	4.15	4.39	1.12	28	25
Peat soil urea-L (PSU-L)	4.04	6.80	2.07	31	15

PSU-H = high N content, PSU-L = low N content.

Table 3. Treatments used in the experiment and their descriptions.

Treatment Number	Treatment Symbol	Treatment Details and Dose of N
1	Control	No N
2	Urea 100%	100% of RD of N
3	Urea 75%	75% of RD of N
4	Urea 50%	50% of RD of N
5	PSU-H 100%	100% of RD of N
6	PSU-H 75%	75% of RD of N
7	PSU-H 50%	50% of RD of N
8	PSU-L 100%	100% of RD of N
9	PSU-L 75%	75% of RD of N
10	PSU-L 50%	50% of RD of N

RD of N: 200 kg ha^{-1}/ 3 g pot^{-1} (Bangladesh Agricultural Research Council (BARC) Fertilizer Recommendation Guide-2018).

2.3. Total Chlorophyll and Cob Vitamin C Estimation

To measure the chlorophyll content, three leaf sub-samples were taken from the third leaf from the top for each treatment pot 45 days after fertilizer treatment. Using 80% aqueous acetone, leaf chlorophyll was extracted and measured using a UV visible spectrometer (T60U, UK) following the technique of Arnon [38]. The vitamin C of fresh cob samples was estimated using the 2,6-dichlorophenol indophenol (DCIP) method [39].

2.4. Plant Height and Yield Attributes of Baby Corn

The plant height was measured from the base to the top of the plant at 14, 28, 42, DAS, and at harvest (62 DAS). Cob length was measured by using a scale from the top to bottom of the cob. The cob circumference of the de-husked cob was determined at the middle position of the baby corn using a measuring tape. All measurements are expressed in centimeters (cm).

2.5. Yield of Baby Corn

After harvesting, the husk was removed from the cob, and the yield of fresh cob and fodder was recorded. Then, both cob and fodder samples were dried in an oven at 65 °C until a constant weight was obtained, and finally, the dry weight of both cob and fodder samples was recorded.

2.6. Analysis of Plant Samples

Oven-dried (65 °C) plant samples were finely ground using a grinding machine. After preparation, the samples were stored in zipper bags. Using the semi-micro-Kjeldahl method, the total N concentration of cob and fodder samples was determined via digestion with a conc. H_2SO_4 and catalyst mixture (K_2SO_4: $CuSO_4 \cdot 5H_2O$: selenium powder = 100:10:1) using a block digester (Velp Scientifica^{TM} F30100450). Then, it was distilled with 40% NaOH using an automated distillation unit (Velp Scientifica^{TM} UKD 129), and the distillate was trapped in a boric acid indicator solution. Finally, it was titrated against 0.01N H_2SO_4 [40].

The protein content was determined by multiplying 6.25 with the N content of cob and fodder samples [41].

2.7. Nitrogen Uptake, Nitrogen Use Efficiency, and Fertilizer N Use Efficiency

The nitrogen uptake (NU) by baby corn cob and fodder was calculated using the equation described by Finzi et al. [42].

$$\text{NU}\left(\text{g pot}^{-1}\right) = \frac{\text{N concentration }(\%) \times \text{ Dry weight }\left(\text{g pot}^{-1}\right)}{100} \quad (1)$$

Both N use efficiency (NUE) and fertilizer N use efficiency (FNUE) were calculated using the formula described by Moll et al. [43].

$$\text{NUE }(\%) = \frac{\text{N uptake }\left(\text{g pot}^{-1}\right)}{\text{N applied }\left(\text{g pot}^{-1}\right)} \times 100 \quad (2)$$

$$\text{FNUE }(\%) = \frac{(\text{N uptake in fertilized pot } - \text{ N uptake in control pot})\text{ g pot}^{-1}}{\text{Nitrogen applied }\left(\text{g pot}^{-1}\right)} \times 100 \quad (3)$$

2.8. Post-Harvest Soil Analysis

Soil organic carbon was determined using the wet oxidation method described by Black [44]. Soil was oxidized with an excess of 1N $K_2Cr_2O_7$ in the presence of concentrated H_2SO_4 and H_3PO_4, and then, we titrated the excess $K_2Cr_2O_7$ solution with 1N $FeSO_4$ to determine the amount of organic matter present. Soil pH was determined using homogenized soil subsamples from each pot at a ratio of 1:5, soil to water (WP 80 Reference pH Meter) [37].

2.9. Measurement of Urease Enzyme Activity in Soil

A 3-day (peak activity period for urease enzyme) incubation experiment was conducted in a polyvinyl chloride (PVC) container to measure the urease enzyme activity in soil fertilized with urea and PSU fertilizer. Each PVC container (r = 3 cm and h = 8 cm) was filled with 200 g of air-dried soil with a bulk density of 1.28 g cm^{-3} (matching with the experimental soil). Urea, PSU-H, and PSU-L were added to the soil at a rate of 104.17 mg N kg^{-1} considering a N dose of 200 kg ha^{-1}. Two control treatments were also included in this experiment consisting of an absolute control and peat soil control. For the peat soil control, the amount of peat soil added was equal to the amount of peat soil added as PSU-L. The experiment was designed following a CRD with five replicates. Deionized water was added to maintain the moisture content at 60% WFPS (soil water-filled pore space percentage). The containers were incubated at 24 ± 1 °C. After incubation, 10 g of homogenized soil was taken from the container, and ammonium N (NH_4^+-N) was extracted by using 4 M KCl. Then, the NH_4^+-N concentration was determined by using a spectrophotometer (T60U-visible, UK). The urease enzyme activity was expressed as µg N per g dry soil per 2 h [45].

2.10. Statistical Analysis

Statistically significant differences between the ten treatments were assessed by one-way analysis of variance, considering the factor fertilizer type (one-way ANOVA) using the statistical software package program Minitab® 18. Prior to performing the ANOVA, the obtained data were run for normality and equal variance checks using the Kolmogorov–Smirnov test and modified Levene's test, respectively. Tukey's HSD test was used to analyze the significant differences and multiple comparisons between the various treatments at a 5% level of significance ($p < 0.05$) [46].

3. Results

3.1. Urease Activity of Soil Amended with Urea and PSU Granules

Significant variation was observed in the urease enzyme activity in the soil because of the addition of urea and PSU as N fertilizers (Figure 1). The activity of urease in the soil amended with PSU granules was significantly lower than in soil amended with commercial urea. There was no significant difference found between the two different PSU granules, but urease activity was lower in soil amended with PSU-L granules containing a high proportion of PS than in soil amended with PSU-H granules.

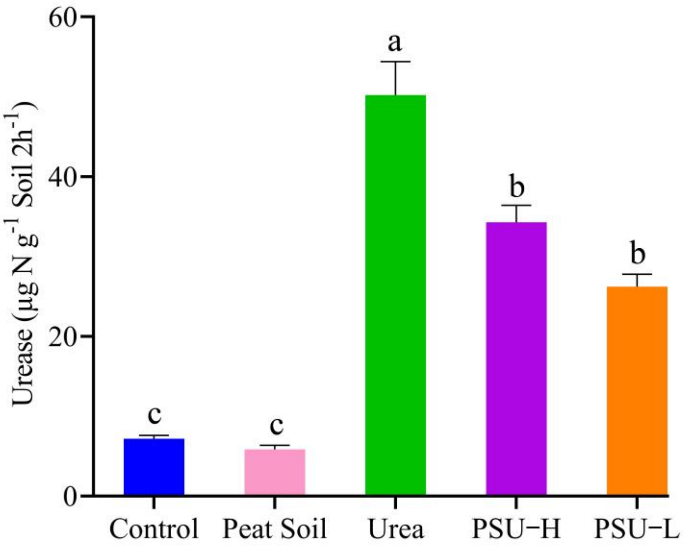

Figure 1. Urease enzyme activity of PSU-amended soil after 3 days of amendment. All presented values are expressed as mean ± standard error (n = 5). Bars bearing different letters differ significantly as per Tukey test at $p < 0.05$.

3.2. Plant Height and Yield Attributes of Baby Corn

Peat soil urea incorporation into the soil showed a significant effect on plant height and yield-contributing characteristics of baby corn. Plant height was not affected by the different treatments at 14 days after sowing (DAS), but significant variation was found at 28 DAS, 42 DAS, and at harvest (Table 4). Overall, the highest plant height was found in the PSU treatment, as compared with the commercial urea treatment. Furthermore, the maximum cob length and circumference were found in PSU-L 100% treatment (Table 4). The 75% recommended dose (RD) of PSU was able to produce identical cob lengths, as found at a 100% RD of urea and PSU. However, PSU-L showed the same result at 75% RD in the case of cob circumference.

Table 4. Growth and yield contributing characteristics of baby corn under fertilization with urea and PSU.

Treatment	Plant Height (cm)				Cob Length (cm)	Cob Circumference (cm)
	14 DAS	28 DAS	42 DAS	Harvest		
Control	30.75 ± 2.29a	60.50 ± 1.83b	82.77 ± 3.64f	100.55 ± 2.02d	4.3 ± 0.15e	4.5 ± 0.17e
Urea 50%	31.25 ± 2.10a	70.56 ± 3.66ab	94.72 ± 7.11ef	135.53 ± 2.60c	8.76 ± 0.31d	7.35 ± 0.41d
PSU-H 50%	29.25 ± 1.70a	81.58 ± 1.32a	119.29 ± 1.80bcd	169.45 ± 6.20b	10.98 ± 0.20cd	8.16 ± 0.39d
PSU-L 50%	29.23 ± 1.47a	78.75 ± 1.31a	123.52 ± 1.85abcd	170.35 ± 6.97b	11.58 ± 0.42bc	9.01 ± 0.41cd
Urea 75%	29.50 ± 1.32a	69.25 ± 5.20ab	107.55 ± 5.61de	169.55 ± 4.41b	11.71 ± 0.30bc	9.08 ± 0.30cd
PSU-H 75%	28.71 ± 1.65a	73.75 ± 2.46ab	122.25 ± 1.11bcd	185.65 ± 7.47ab	12.84 ± 0.62abc	9.49 ± 0.27bcd
PSU-L 75%	30.00 ± 1.68a	76.34 ± 1.80ab	130.42 ± 2.45abc	192.28 ± 6.10ab	13.5 ± 0.25ab	11.60 ± 0.65ab
Urea 100%	23.65 ± 3.77a	67.25 ± 8.33ab	113.26 ± 2.61cde	177.35 ± 4.77ab	13.51 ± 0.55ab	10.9 ± 0.48abc
PSU-H 100%	28.76 ± 1.89a	74.62 ± 3.35ab	135.46 ± 2.12ab	187.75 ± 6.61ab	13.66 ± 0.38ab	11.48 ± 0.10ab
PSU-L 100%	31.73 ± 2.43a	80.59 ± 2.56a	141.75 ± 5.85a	199.75 ± 5.22a	14.22 ± 1.10a	12.15 ± 0.76a

All values are expressed as mean ± standard error (n = 4). Values in a column bearing different letters differ significantly as per Tukey test at $p < 0.05$.

3.3. Leaf Total Chlorophyll, Cob Vitamin C, and Protein Content

Leaf total chlorophyll, cob vitamin C, and protein content of baby corn were significantly influenced by the application of PSU and urea as a N source (Figure 2). The highest chlorophyll content (2.97 mg g^{-1} fresh weight) was found at a 100% recommended dose (RD) for PSU-L-treated plants, which was statistically identical to all other treatments except the control, urea 50%, and PSU-H 50%. No significant variation was found in the case of cob vitamin C content at 100% and 75% RDs of both the urea and PSU treatments, but the highest vitamin C content was found in the PSU 75% treatment. However, vitamin C content at 50% RD of both the urea and PSU treatments was significantly lower than the vitamin C content at 75% RD of the PSU treatment. The protein content of the PSU-H-, PSU-L-, and urea-treated plants at 100% RD was statistically similar to the PSU-L at a 75% RD. A 25% reduction in the N dose of PSU-H and PSU-L showed no significant reduction in either cob or fodder protein content compared with a 100% RD of N with urea. On the other hand, urea at 75% of the RD showed a significant reduction in protein content compared with a 100% RD of N with urea and PSU. Around 9% higher cob protein content was found in those plants receiving PSU as a N source compared with those receiving commercial urea.

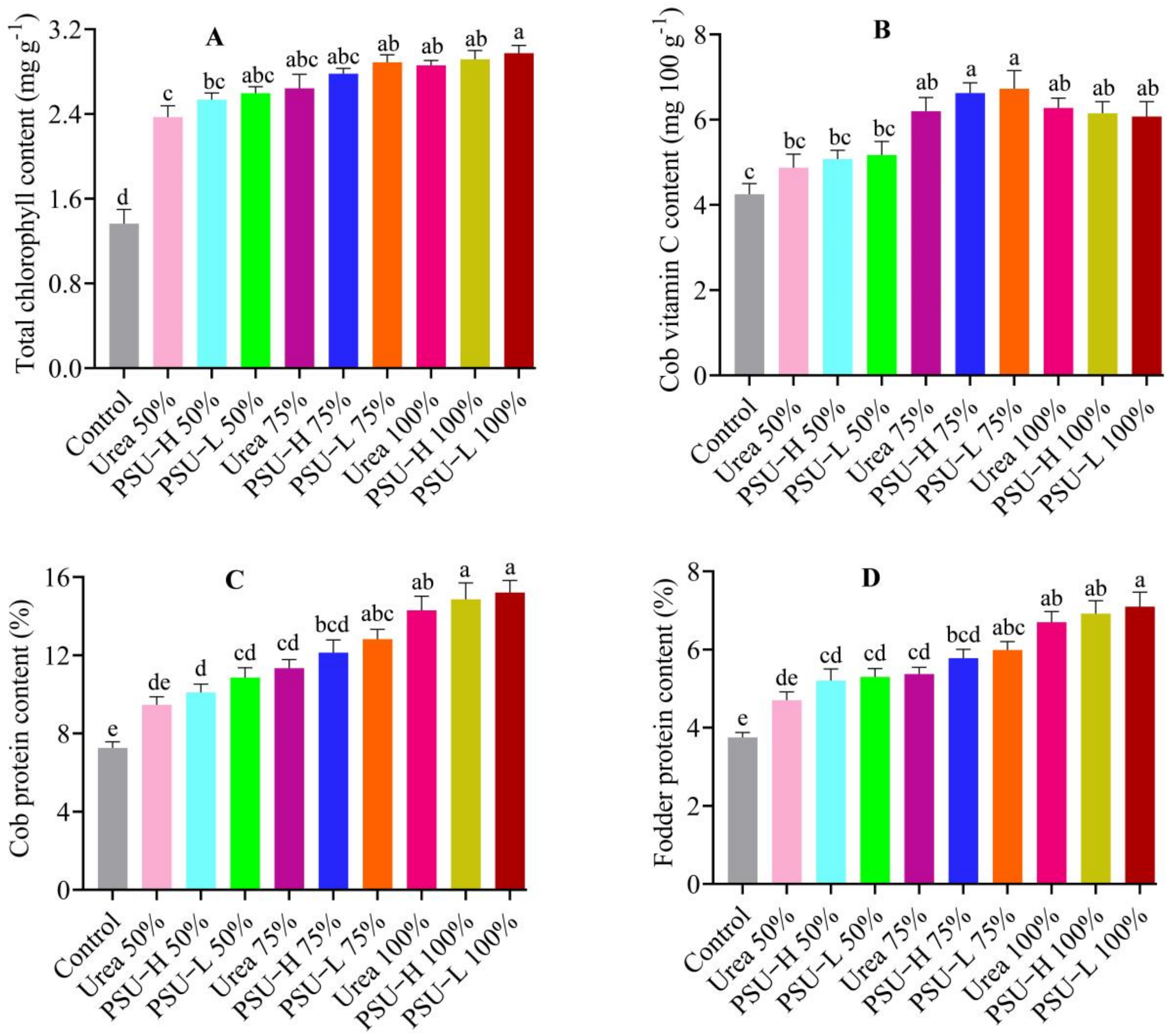

Figure 2. Leaf total chlorophyll (**A**), cob vitamin C (**B**), and cob (**C**) and fodder (**D**) protein content of baby corn fertilized with urea and PSU. All presented values are expressed as mean ± standard error (n = 4). Bars bearing different letters differ significantly as per Tukey test at $p < 0.05$.

3.4. Cob and Fodder Yield

The incorporation of PSU as a N source significantly influenced the fresh and dry cob and fodder yield of baby corn (Figure 3). The highest fresh and dry cob yields were found in the PSU-L treatment at a 100% RD (62.97 g pot^{-1} and 8.04 g pot^{-1}, respectively), which was about 12% higher than the urea treatment at 100% of the RD. The fresh and dry cob yield of baby corn produced by 75% RD of PSU-L and PSU-H was statistically similar to 100% RD of urea, respectively. At a 75% RD, both the fresh and dry cob yield significantly decreased in urea-treated pots than in PSU-L-treated pots. However, the overall yield increment in PSU-treated pots was about 21% more than in commercial-urea-treated pots. Again, the highest fresh (499.70 g pot^{-1}) and dry (177.16 g pot^{-1}) fodder yield were found in PSU-L 100%, which was statistically similar to PSU-H 100%, urea 100%, and PSU-L 75%, respectively. The 75% recommended dose of PSU-L and PSU-H produced a statistically identical fodder yield at a 100% recommended dose of urea. Furthermore, 50% RDs of PSU-H and PSU-L produced a statistically identical dry fodder yield at 75% of the recommended dose of urea. On average, about a 13.5% higher fodder yield was found in PSU-treated pots compared with commercial-urea-treated pots.

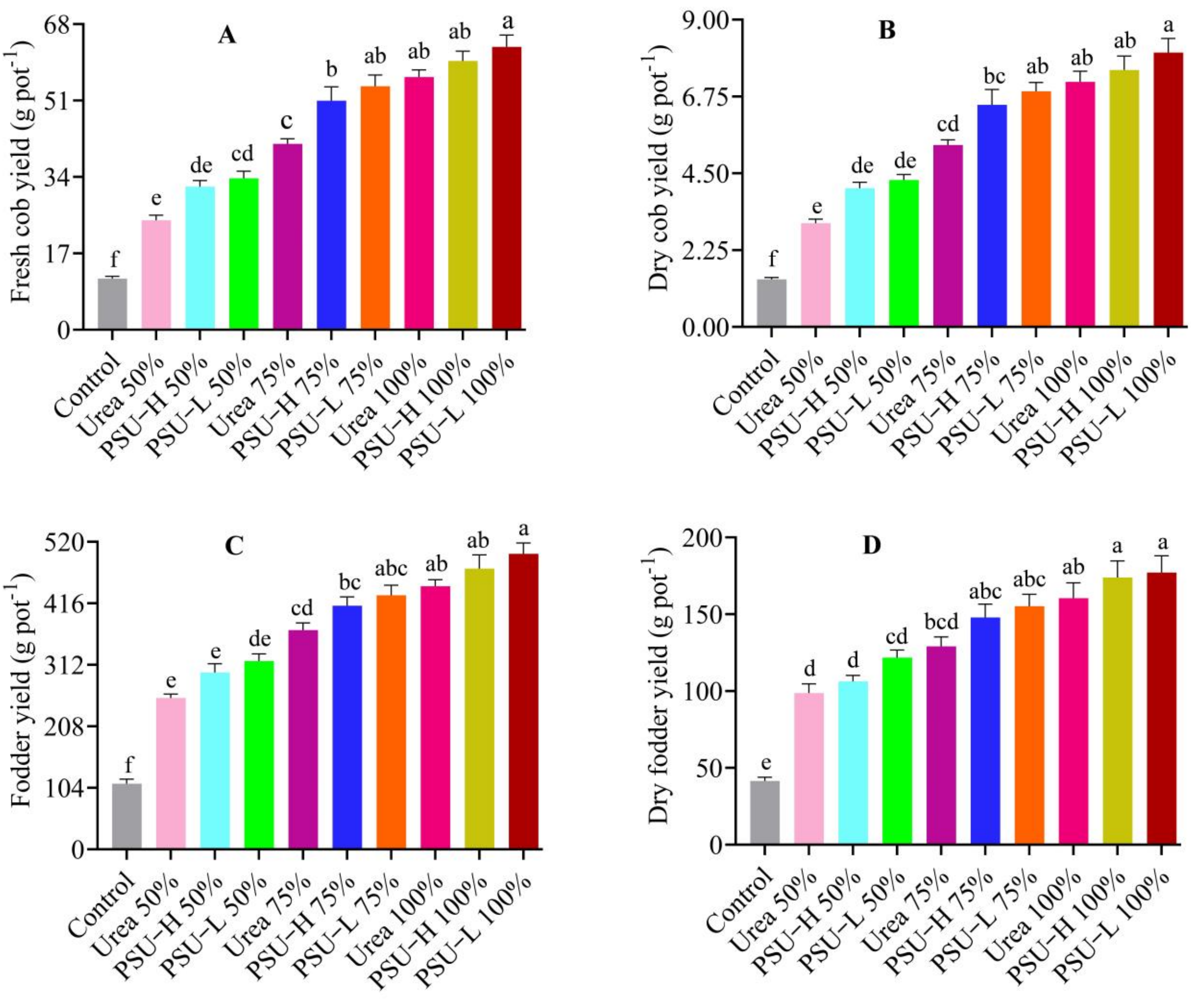

Figure 3. Fresh cob yield (**A**), dry cob yield (**B**), fresh fodder yield (**C**), and dry fodder yield (**D**) of corn fertilized with urea and PSU. [All presented values are expressed as mean ± standard error (n = 4). Bars bearing different letters differ significantly as per Tukey test at $p < 0.05$.].

3.5. Cob and Fodder N Concentration and Uptake by Baby Corn

Nitrogen concentrations in the cob and fodder of baby corn were significantly different with the application of PSU as a N source compared with commercial urea. Though the N concentrations of both the cob and fodder in the case of the PSU and urea treatments at a 100% RD were statistically identical, a substantially higher N concentration was found in the PSU-treated plants compared with the urea-treated plants (Figure 4). The application of PSU at 75% of the RD showed an identical N concentration to that of the urea treatment at 100% of the RD. The N uptake by cob and fodder was significantly different in PSU- and urea-fertilized soil. The highest N uptake by cob and fodder was found in PSU-L-treated plants at 100% of the RD (Figure 4). The cob and fodder N uptake at a 100% RD for both PSU and urea were statistically identical. The N uptake was substantially higher in PSU-treated plants than in commercial-urea-treated plants. Cob N uptake at 75% of the RD of PSU was identical to N uptake at a 100% RD of urea. On average, the total N uptake in the case of PSU-treated plants was about 22% higher than the N uptake by urea-treated plants.

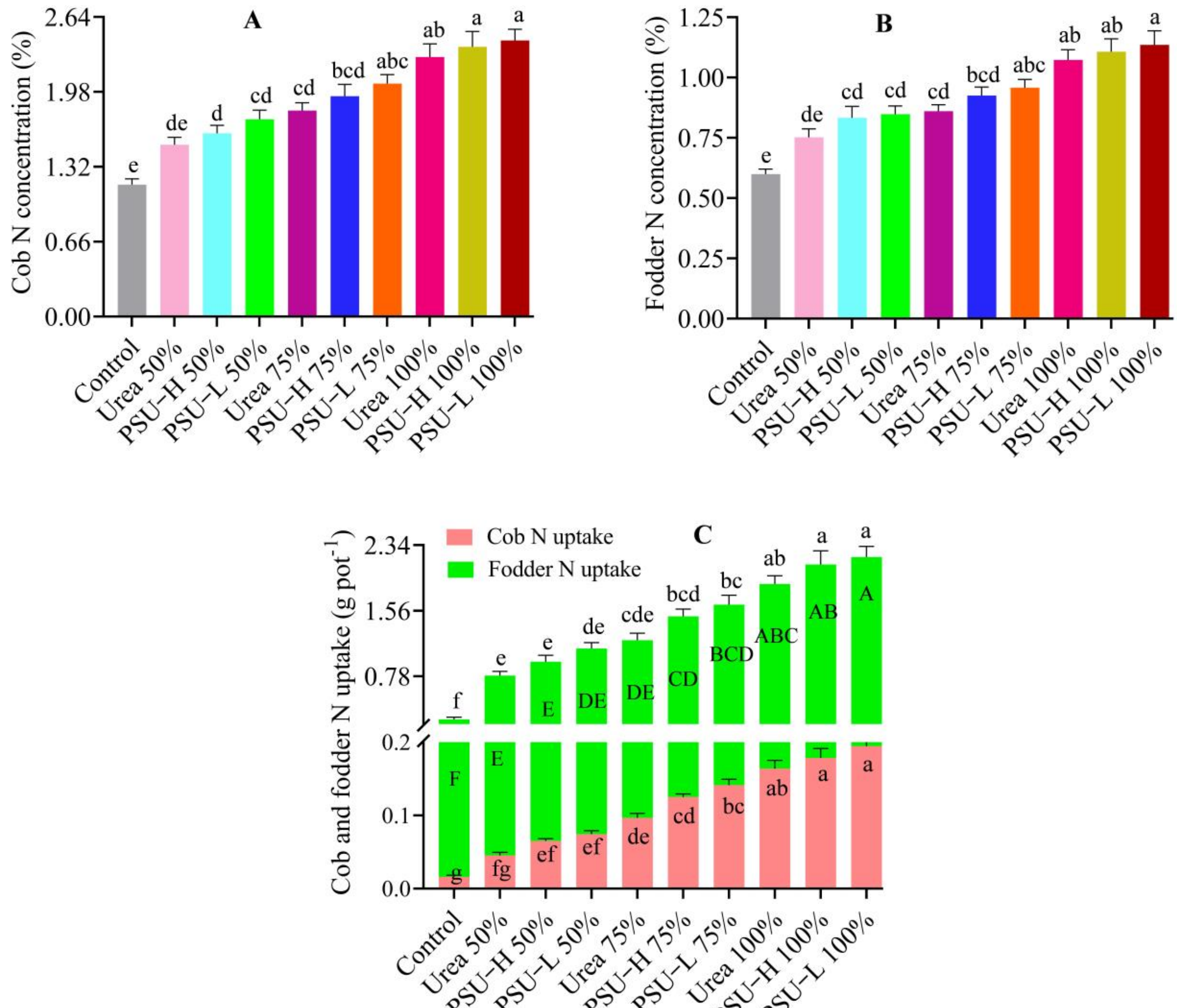

Figure 4. Cob N content (**A**), fodder N content (**B**), and N uptake (**C**) of corn fertilized with urea and PSU. All presented values are expressed as mean ± standard error (n = 4). Bars bearing different letters differ significantly as per Tukey test at $p < 0.05$.

3.6. Nitrogen Use Efficiency (NUE) and Fertilizer N Use Efficiency (FNUE)

The granulation of commercial urea with PS and its application to the soil as a N source showed a significant ($p < 0.05$) effect on the NUE and FNUE of baby corn compared with commercial urea (Figure 5). The NUE of baby corn was higher at a lower application rate of PSU and urea as a N source, but the FNUE was higher at a high N application rate than at a lower rate. The application of a 50% RD of PSU-L showed a significantly higher NUE value than that of urea, which was statistically identical at 75% and 100% RDs of PSU. The NUE was substantially higher in the PSU treatment than in the commercial urea treatment at 75% and 100% RDs of N. Conversely, the highest FNUE was found in the PSU-L treatment at a 100% RD of N. The FNUE was substantially higher in the PSU treatment at a 100% RD compared with the commercial urea treatment. On average, the NUE and FNUE increased by 24 and 33%, respectively, in the PSU-treated plants compared with the commercial-urea-treated plants.

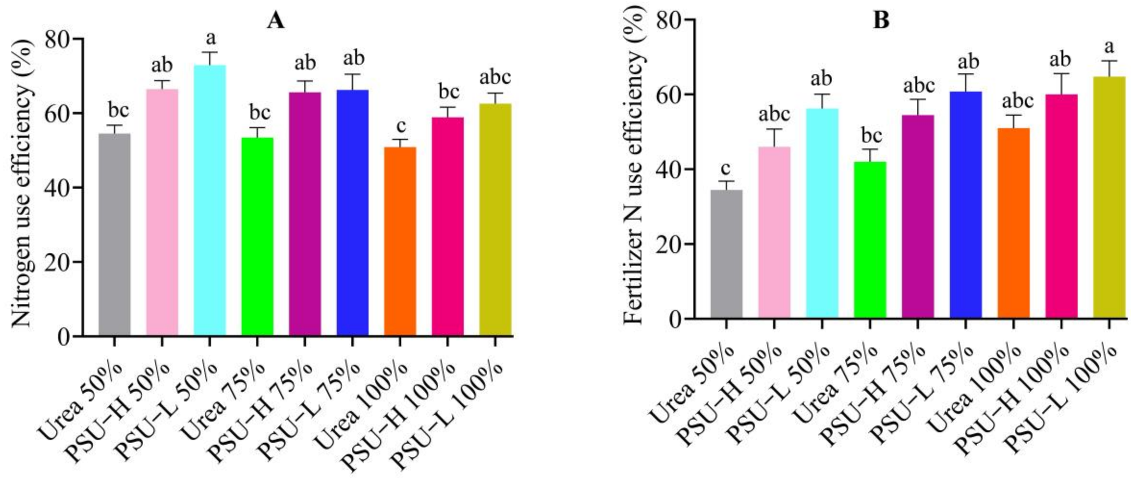

Figure 5. Nitrogen use efficiency (**A**) and fertilizer nitrogen use efficiency (**B**) of baby corn fertilized with urea and PSU. All presented values are expressed as mean ± standard error (n = 4). Bars bearing different letters differ significantly as per Tukey test at $p < 0.05$.

3.7. Soil Organic Carbon (SOC) and Soil pH after Harvest

The soil organic carbon and soil pH of the post-harvest soil were not significantly affected by the application of PSU and urea (Table 5). However, SOC slightly increased in the soil fertilized with PSU compared with the urea-treated soils. The increase in SOC was high in soil receiving PSU containing a higher quantity of peat than the soil treated with PSU containing a lower quantity of peat. On the other hand, soil pH decreased slightly in both PSU- and urea-treated soils, whereas the decreasing rate was higher in the PSU-treated soil than the urea-treated soil.

Table 5. Soil organic carbon and pH of initial and post-harvest soil fertilized with urea and PSU.

Treatment	SOC	pH
Initial soil	0.46 ± 0.030a	6.76 ± 0.082a
Control	0.44 ± 0.030a	6.80 ± 0.203a
Urea 50%	0.43 ± 0.024a	6.61 ± 0.082a
PSU-H 50%	0.46 ± 0.029a	6.75 ± 0.067a
PSU-L 50%	0.48 ± 0.027a	6.68 ± 0.030a
Urea 75%	0.42 ± 0.027a	6.56 ± 0.094a
PSU-H 75%	0.48 ± 0.023a	6.77 ± 0.149a
PSU-L 75%	0.51 ± 0.020a	6.65 ± 0.052a
Urea 100%	0.40 ± 0.027a	6.64 ± 0.067a
PSU-H 100%	0.50 ± 0.029a	6.77 ± 0.066a
PSU-L 100%	0.53 ± 0.034a	6.72 ± 0.072a

All values are expressed as mean ± standard error (n = 4). Values in a column with the same letter are statistically similar as per Tukey test at $p < 0.05$.

4. Discussion

The availability of N is crucial for primary productivity in terrestrial ecosystems because N is frequently the limiting factor in plant development [47]. Organo-mineral granulated fertilizer with slow-release properties can offer the plant plenty of fertilizer N uptake throughout the whole growing season. The slow-release properties of granulated

PSU fertilizer can be supported by urease enzyme data. In this experiment, the application of PSU showed a significant reduction in urease enzyme activity (Figure 1) in soil compared with commercial urea. This is in agreement with the findings of Saha et al. [3], who also observed significantly lower urease activity in soil fertilized with brown coal–urea than with urea. The urease enzyme is responsible for hydrolysis and the release of mineral N from urea. Therefore, reduced urease activity is a very good indication of the slow-release properties of PSU. The lower urease activity in PSU-treated soil might be because of the retention of urea molecules in the porous structure of peat and the presence of numerous phenolic groups. It is evident from past experiments that organic matter consisting of huge phenolic groups has the potential to reduce urease activity in soil [48]. On the other hand, high urease activity indicates the fast and speedy release of mineral N from urea fertilizer because of rapid hydrolysis. This finding justifies the experiment of Araújo et al. [49], who found urea N was released more slowly from chitosan–peat–urea (CPTU) than from urea.

In the pot experiment, the growth parameters, total chlorophyll, cob vitamin C, and cob protein of baby corn were substantially higher in PSU-treated plants compared with urea-treated plants. The higher chlorophyll content in the PSU treatments was probably due to the greater enzymatic activity in leaves along with the higher amount of fertilizer N available to the plants over a longer period of time given the slow and steady release of mineral N. Moreover, the enhanced availability of fertilizer N in PSU might trigger photosynthetic activity as well as plant growth, resulting in the accumulation of more chlorophyll in the leaf tissue. Similarly, Ullah et al. [50] showed that biochar–urea-treated plots had higher chlorophyll content in rice than in urea-treated plots. Much higher vitamin C content was determined in plants grown with a PSU treatment compared with those grown with urea. The results of our study are supported by the findings of Zhao et al. [51], who found higher vitamin C content in Chinese cabbage treated with OMF than in cabbage treated with urea. However, a slight reduction in vitamin C content at a 100% RD of both urea and PSU might be the dilution effect of the enhanced cob size and diameter [52] at a high N application rate. Again, the higher chlorophyll accumulation together with the higher amount of available N in PSU-treated plants might be responsible for higher protein synthesis compared with plants treated with commercial urea, resulting in high protein content. In line with our findings, Zhao et al. [51] also observed higher protein content in OMF-treated plants over commercial-urea-treated plants.

The N uptake of baby corn was significantly higher in PSU-fertilized soil compared with urea-fertilized soil. In agreement with our findings, Dawar et al. [53] found higher N uptake in wheat treated with biochar–urea-composite fertilizer than with commercial urea alone. Other findings by Haque et al. [54] showed higher N uptake by sorghum in OMF-treated plots than in urea-treated plots. Several factors might be responsible for higher N uptake by baby corn in PSU-fertilized pots than in urea-treated pots. Usually, baby corn takes up very lower amounts of mineral N during the early growth stage, whereas a large amount of urea N becomes available during this time. In comparison with urea, PSU has the capacity to decrease fertilizer N releases because of the prolonged retention of urea or mineral N in a large surface area, porous microsites, the favorable surface charge of peat, and the cation exchange (peat soil CEC = 100–300 cmol kg^{-1}) of ammonium N with excessive functional groups and the active carbon fraction of peat [35,53,54]. As a result, a higher amount of fertilizer N might be available at the later growth stage, facilitating more N uptake by baby corn. Moreover, the higher accumulation of leaf chlorophyll and synthesis of cob protein in PSU-treated soil further confirms the hypothesis of higher N uptake in PSU over urea. In contrast, the very high solubility and speedy release of fertilizer N in urea might be responsible for the higher loss of N via leaching and gaseous emission. The higher loss of urea N might also reduce the availability of mineral N in the later growth stage of baby corn and be responsible for lower N uptake.

Significantly higher cob and fodder yield in baby corn was noticed in PSU-treated soil rather than urea. The higher cob and fodder yield in PSU-treated soil could be the result of better synchronization and fertilizer N supply to plants from PSU during the growing season compared with commercial urea. The higher amount of available N might be responsible for better photosynthetic and metabolic functions in accumulating more dry matter in the biomass and cob of baby corn [1,12,55]. This is supported by growth and yield attribute data (Table 4) where significantly higher plant height and larger-sized cobs were obtained from PSU-treated pots than urea-treated plants. Moreover, the higher amount of chlorophyll also contributed to enhancing cob yield in PSU-treated plants in relation to urea. This is supported by Dias et al. [36], who reported that OMF produced from peat soil and monoammonium phosphate (MAP) showed remarkably higher corn yields than those using MAP alone. The increased yield (cob and fodder) and enhanced N uptake by baby corn in the PSU treatment might be the main reason for increased NUE and FNUE compared with urea. A similar finding was reported by Ibrahim et al. [56], who found that MgO-modified biochar–urea showed higher N use efficiency than commercial urea. However, the NUE and FNUE results showed the higher efficiency of PSU, especially at a low N percent (15%)-containing formulation, showing that the application of N doses to baby corn could be reduced by around 30% by applying PSU as an alternate source of N instead of urea.

Additionally, the application of PSU containing a high amount of organic C [1] could also contribute to building soil organic C gradually over a longer period of time [57] and improve soil quality by triggering soil microbial activity and soil health properties. Although no significant differences were found between the treatments, post-harvest soil C was slightly higher in PSU than in urea, which may suggest increases in long-term soil carbon content. Similar results were also published by Zheng et al. [58], who found that biochar-based urea fertilizer (BBNF) significantly improved soil C by 16% compared with inorganic N fertilizers.

5. Conclusions

Organo-mineral fertilizer could be a promising technology and sustainable alternative to commercial N fertilizers such as urea for better crop productivity, with a smaller environmental footprint. The application of PSU fertilizer to soil showed a significant influence on the growth, yield, soil quality, N uptake, and NUE of baby corn. Substantially higher leaf chlorophyll, cob protein, and vitamin C content were found in PSU than in urea. On average, the cob yield was about 21% higher in the PSU treatment compared with the use of urea. The application of PSU to soil exhibited a significant reduction in urease enzyme activity in soil, indicating the slower release of fertilizer N. A significantly higher N concentration was found in baby corn cobs resulting in 22% higher N uptake for PSU than urea. The enhanced N uptake in PSU-treated plants contributed to an increase in NUE by 24% and FNUE by 33% with respect to commercial urea. In addition, the application of peat-based organo-mineral fertilizer as a N source could help reduce the N application rate by 30% without reducing the yield and quality of baby corn. Furthermore, soil quality can be improved gradually by adding extra C to PSU. These results may be used as baseline data to formulate and apply PSU as a N fertilizer source for crop production. However, further research will be needed on a large scale under various climatic and soil conditions with multiple crops before any final recommendations are made.

Author Contributions: Conceptualization, M.K.U.; Methodology, M.K.U. and S.Y.; Software, M.A.H.C.; Validation, B.K.S.; Formal analysis, M.K.U. and S.Y.; Investigation, S.Y. and M.A.H.C.; Resources, K.M.M.; Data curation, K.M.M. and M.A.H.C.; Writing—original draft, M.K.U.; Writing—review & editing, S.Y., K.M.M., M.A.H.C. and B.K.S.; Visualization, M.A.H.C. and B.K.S.; Supervision, B.K.S.; Project administration, K.M.M. and B.K.S.; Funding acquisition, B.K.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Bangladesh Agricultural University Research System (BAURES) grant number (386). The APC was funded by B.K.S.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data will be made available on request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bouhia, Y.; Hafidi, M.; Ouhdouch, Y.; Boukhari, M.E.M.E.; Mphatso, C.; Zeroual, Y.; Lyamlouli, K. Conversion of Waste into Organo-Mineral Fertilizers: Current Technological Trends and Prospects. *Rev. Environ. Sci. Bio/Technol.* **2022**, *21*, 425–446. [CrossRef]
2. Reynolds, M.P.; Quilligan, E.; Aggarwal, P.K.; Bansal, K.C.; Cavalieri, A.J.; Chapman, S.C.; Chapotin, S.M.; Datta, S.K.; Duveiller, E.; Gill, K.S. An Integrated Approach to Maintaining Cereal Productivity under Climate Change. *Glob. Food Sec.* **2016**, *8*, 9–18. [CrossRef]
3. Saha, B.K.; Rose, M.T.; Van Zwieten, L.; Wong, V.N.L.L.; Patti, A.F. Slow Release Brown Coal-Urea Fertilizer Potentially Influences Greenhouse Gas Emissions, Nitrogen Use Efficiency, and Sweet Corn Yield in Oxisol. *ACS Agric. Sci. Technol.* **2021**, *1*, 469–478. [CrossRef]
4. Fageria, N.K.; Baligar, V.C. Enhancing Nitrogen Use Efficiency in Crop Plants. *Adv. Agron.* **2005**, *88*, 97–185.
5. Cameron, K.C.; Di, H.J.; Moir, J.L. Nitrogen Losses from the Soil/Plant System: A Review. *Ann. Appl. Biol.* **2013**, *162*, 145–173. [CrossRef]
6. Vitousek, P.M.; Aber, J.D.; Howarth, R.W.; Likens, G.E.; Matson, P.A.; Schindler, D.W.; Schlesinger, W.H.; Tilman, D.G. Human Alteration of the Global Nitrogen Cycle: Sources and Consequences. *Ecol. Appl.* **1997**, *7*, 737–750. [CrossRef]
7. Hartemink, A.E.; Gerzabek, M.H.; Lal, R.; McSweeney, K. Soil Carbon Research Priorities. In *Soil Carbon*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 483–490.
8. Hoffland, E.; Kuyper, T.W.; Comans, R.N.J.; Creamer, R.E. Eco-Functionality of Organic Matter in Soils. *Plant Soil* **2020**, *455*, 1–22. [CrossRef]
9. Dong, L.; Córdova-Kreylos, A.L.; Yang, J.; Yuan, H.; Scow, K.M. Humic Acids Buffer the Effects of Urea on Soil Ammonia Oxidizers and Potential Nitrification. *Soil Biol. Biochem.* **2009**, *41*, 1612–1621. [CrossRef]
10. Naz, M.Y.; Sulaiman, S.A. Slow Release Coating Remedy for Nitrogen Loss from Conventional Urea: A Review. *J. Control. Release* **2016**, *225*, 109–120. [CrossRef] [PubMed]
11. Davidson, D.; Gu, F.X. Materials for Sustained and Controlled Release of Nutrients and Molecules to Support Plant Growth. *J. Agric. Food Chem.* **2012**, *60*, 870–876. [CrossRef]
12. Barbosa, C.F.; Correa, D.A.; Carneiro, J.S.d.S.; Melo, L.C.A. Biochar Phosphate Fertilizer Loaded with Urea Preserves Available Nitrogen Longer than Conventional Urea. *Sustainability* **2022**, *14*, 686. [CrossRef]
13. Akiyama, H.; Yan, X.; Yagi, K. Evaluation of Effectiveness of Enhanced-efficiency Fertilizers as Mitigation Options for N_2O and NO Emissions from Agricultural Soils: Meta-analysis. *Glob. Chang. Biol.* **2010**, *16*, 1837–1846. [CrossRef]
14. Wu, W.; Ma, B. Integrated Nutrient Management (INM) for Sustaining Crop Productivity and Reducing Environmental Impact: A Review. *Sci. Total Environ.* **2015**, *512*, 415–427. [CrossRef] [PubMed]
15. Quilty, J.R.; Cattle, S.R. Use and Understanding of Organic Amendments in Australian Agriculture: A Review. *Soil Res.* **2011**, *49*, 1–26. [CrossRef]
16. Bhunia, S.; Bhowmik, A.; Mallick, R.; Mukherjee, J. Agronomic Efficiency of Animal-Derived Organic Fertilizers and Their Effects on Biology and Fertility of Soil: A Review. *Agronomy* **2021**, *11*, 823. [CrossRef]
17. Marwanto, M.; Silitinga, M.O.; Bertham, Y.H.; Handajaningsih, M. Prasetyo Azolla Compost-Based Organomineral Fertilizer for Increasing N Uptake, Growth, and Yield of Green Onion. In Proceedings of the AIP Conference Proceedings, Göttingen, Germany, 4–8 September 2023; AIP Publishing LLC: New York, NY, USA, 2023; Volume 2583, p. 20035.
18. Bahari, M.T.P.; Marwanto, M.; Fahrurrozi, F.; Handajaningsih, M. Zeolite Oil Palm Compost-Based Organomineral Fertilizer for Shallot Agronomic Performances and N Substitution. *TERRA J. L Restor.* **2022**, *5*, 1–7.
19. Gao, Y.; Fang, Z.; Van Zwieten, L.; Bolan, N.; Dong, D.; Quin, B.F.; Meng, J.; Li, F.; Wu, F.; Wang, H. A Critical Review of Biochar-Based Nitrogen Fertilizers and Their Effects on Crop Production and the Environment. *Biochar* **2022**, *4*, 36. [CrossRef]
20. Saha, B.K.; Rose, M.T.; van Zwieten, L.; Wong, V.N.L.; Rose, T.; Patti, A.F. Fate and Recovery of Nitrogen Applied as Slow Release Brown Coal-Urea in Field Microcosms: 15N Tracer Study. *Environ. Sci. Process. Impacts* **2023**, *25*, 648–658. [CrossRef] [PubMed]
21. Orekhovskaya, A.A.; Klyosov, D.N. Effect of Application of Organomineral Fertilizers. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *723*, 022010. [CrossRef]
22. Saha, B.K.; Rose, M.T.; Wong, V.N.L.; Cavagnaro, T.R.; Patti, A.F. A Slow Release Brown Coal-Urea Fertiliser Reduced Gaseous N Loss from Soil and Increased Silver Beet Yield and N Uptake. *Sci. Total Environ.* **2019**, *649*, 793–800. [CrossRef] [PubMed]
23. Shahi, J.P.G.V. Baby Corn. In *Genesis and Evolution of Horticultural Crops*; Peter, K.V., Ed.; Kruger Brentt Publishere: London, UK, 2017; pp. 47–65.
24. Roy, S.D. Baby Corn Farming Gains, Farmers Need Market Facility. *The Daily Star*, 28 May 2015.
25. Hooda, S.; Kawatra, A. Nutritional Evaluation of Baby Corn (*Zea mays*). *Nutr. Food Sci.* **2013**, *43*, 68–73. [CrossRef]
26. Das, S.; Ghosh, G.; Kaleem, M.D.; Bahadur, V. Effect of Different Levels of Nitrogen and Crop Geometry on the Growth, Yield and Quality of Baby Corn (*Zea mays* L.) Cv.'golden Baby'. In Proceedings of the International Symposium on the Socio-Economic Impact of Modern Vegetable Production Technology in Tropical Asia, Chiang Mai, Thailand, 3–6 February 2008; pp. 161–166.

27. Singh, M.K.; Singh, R.N.; Singh, S.P. Effect of Integrated Nutrient Management on Growth, Yield and Yield Attributes of Baby Corn (*Zea mays*). *Veg. Sci.* **2009**, *36*, 77–79.
28. Wang, X.; Cao, X.; Xu, H.; Zhang, S.; Gao, Y.; Deng, Z.; Li, J. Research on the Properties of Peat Soil and Foundation Treatment Technology. *E3S Web Conf.* **2021**, *272*, 2019. [CrossRef]
29. Cao, S. Research and Application of Peat in Agriculture. In Proceedings of the IOP Conference Series: Earth and Environmental Science, Moscow, Russia, 27 May–6 June 2019; IOP Publishing: Bristol, UK, 2019; Volume 384, p. 12174.
30. Davis, J.G.; Whiting, D.; Wilson, C.R. Choosing a Soil Amendment: Fact Sheet No. 7.235. In *Gardening Series Basics*; Colorado State University Extension: Fort Collins, CO, USA, 2013; pp. 1–4.
31. Ali, M.R. Potential of Peatlands in Bangladesh and Sustainable Management Strategy. *Agric. Eng. Int. CIGR J.* **2020**, *22*, 65–74.
32. Uddin, M.J.; Mohiuddin, A.S.M. Estimation of Carbon Stock in the Peat Soils of Bangladesh. *J. Asiat. Soc. Bangladesh Sci.* **2019**, *45*, 127–136. [CrossRef]
33. Sutejo, Y.; Saggaff, A.; Rahayu, W. Hanafiah Physical and Chemical Characteristics of Fibrous Peat. *AIP Conf. Proc.* **2017**, *1903*, 90006.
34. Warren, M.W.; Kauffman, J.B.; Murdiyarso, D.; Anshari, G.; Hergoualc'h, K.; Kurnianto, S.; Purbopuspito, J.; Gusmayanti, E.; Afifudin, M.; Rahajoe, J. A Cost-Efficient Method to Assess Carbon Stocks in Tropical Peat Soil. *Biogeosciences* **2012**, *9*, 4477–4485. [CrossRef]
35. Putri, C.S.; Saharjo, B.H.; Wasis, B. The Chemical Properties of Burnt Peat Soil in Teluk Bakung Village, West Kalimantan. In Proceedings of the IOP Conference Series: Earth and Environmental Science, Virtual, 25–27 February 2022; IOP Publishing: Bristol, UK, 2022; Volume 959, p. 12055.
36. Dias, R.d.C.; Stafanato, J.B.; Zonta, E.; Polidoro, J.C.; Gonçalves, R.G.d.M.; Teixeira, P.C. Effect of Phosphate Organomineral Fertilization on the Dry Matter Production and Phosphorus Accumulation of Corn. *Embrapa* **2022**, *14*, 78–89. [CrossRef]
37. Forster, J.C. Soil Sampling, Handling, Storage and Analysis. In *Methods in Applied Soil Microbiology and Biochemistry*; Elsevier: Amsterdam, The Netherlands, 1995; pp. 49–121.
38. Arnon, D.I. Copper Enzymes in Isolated Chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol.* **1949**, *24*, 1–15. [CrossRef] [PubMed]
39. Williams, S.U. *Official Methods of Analysis*; Association of Official Analytical Chemists: Washington, DC, USA, 1984.
40. Jackson, M.L. *Soil Chemical Analysis: Advanced Course: A Manual of Methods Useful for Instruction and Research in Soil Chemistry, Physical Chemistry of Soils, Soil Fertility, and Soil Genesis*; UW-Madison Libraries Parallel Press: Madison, WI, USA, 2005; ISBN 1893311473.
41. Chang, S.K.C.; Zhang, Y. Protein Analysis. *Food Anal.* **2017**, 315–331. [CrossRef]
42. Finzi, A.C.; Norby, R.J.; Calfapietra, C.; Gallet-Budynek, A.; Gielen, B.; Holmes, W.E.; Hoosbeek, M.R.; Iversen, C.M.; Jackson, R.B.; Kubiske, M.E. Increases in Nitrogen Uptake Rather than Nitrogen-Use Efficiency Support Higher Rates of Temperate Forest Productivity under Elevated CO_2. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 14014–14019. [CrossRef]
43. Moll, R.H.; Kamprath, E.J.; Jackson, W.A. Analysis and Interpretation of Factors Which Contribute to Efficiency of Nitrogen Utilization 1. *Agron. J.* **1982**, *74*, 562–564. [CrossRef]
44. Black, C.A. Soil-Plant Relationships. *Soil Sci.* **1958**, *85*, 175. [CrossRef]
45. Kandeler, E.; Gerber, H. Short-Term Assay of Soil Urease Activity Using Colorimetric Determination of Ammonium. *Biol. Fertil. Soils* **1988**, *6*, 68–72. [CrossRef]
46. Gomez, K.A.; Gomez, A.A. *Statistical Procedures for Agricultural Research*; John Wiley & Sons: Hoboken, NJ, USA, 1984; ISBN 0471870927.
47. Liu, X.-Y.; Koba, K.; Koyama, L.A.; Hobbie, S.E.; Weiss, M.S.; Inagaki, Y.; Shaver, G.R.; Giblin, A.E.; Hobara, S.; Nadelhoffer, K.J. Nitrate Is an Important Nitrogen Source for Arctic Tundra Plants. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 3398–3403. [CrossRef] [PubMed]
48. Bollmann, A.; Laanbroek, H.J. Continuous Culture Enrichments of Ammonia-Oxidizing Bacteria at Low Ammonium Concentrations. *FEMS Microbiol. Ecol.* **2001**, *37*, 211–221. [CrossRef]
49. Araújo, B.R.; Romao, L.P.C.; Doumer, M.E.; Mangrich, A.S. Evaluation of the Interactions between Chitosan and Humics in Media for the Controlled Release of Nitrogen Fertilizer. *J. Environ. Manag.* **2017**, *190*, 122–131. [CrossRef]
50. Ullah, S.; Zhao, Q.; Wu, K.; Ali, I.; Liang, H.; Iqbal, A.; Wei, S.; Cheng, F.; Ahmad, S.; Jiang, L. Biochar Application to Rice with 15N-Labelled Fertilizers, Enhanced Leaf Nitrogen Concentration and Assimilation by Improving Morpho-Physiological Traits and Soil Quality. *Saudi J. Biol. Sci.* **2021**, *28*, 3399–3413. [CrossRef]
51. Zhao, H.; Xie, T.; Xiao, H.; Gao, M. Biochar-Based Fertilizer Improved Crop Yields and N Utilization Efficiency in a Maize–Chinese Cabbage Rotation System. *Agriculture* **2022**, *12*, 1030. [CrossRef]
52. Zhang, L.; Zhang, F.; Wang, Y.; Ma, X.; Shen, Y.; Wang, X.; Yang, H.; Zhang, W.; Lakshmanan, P.; Hu, Y. Physiological and Metabolomic Analysis Reveals Maturity Stage-Dependent Nitrogen Regulation of Vitamin C Content in Pepper Fruit. *Front. Plant Sci.* **2023**, *13*, 1049785. [CrossRef]
53. Dawar, K.; Fahad, S.; Alam, S.S.; Khan, S.A.; Dawar, A.; Younis, U.; Danish, S.; Datta, R.; Dick, R.P. Influence of Variable Biochar Concentration on Yield-Scaled Nitrous Oxide Emissions, Wheat Yield and Nitrogen Use Efficiency. *Sci. Rep.* **2021**, *11*, 16774. [CrossRef] [PubMed]

54. Haque, A.N.A.; Uddin, M.K.; Sulaiman, M.F.; Amin, A.M.; Hossain, M.; Solaiman, Z.M.; Aziz, A.A.; Mosharrof, M. Combined Use of Biochar with 15Nitrogen Labelled Urea Increases Rice Yield, N Use Efficiency and Fertilizer N Recovery under Water-Saving Irrigation. *Sustainability* **2022**, *14*, 7622. [CrossRef]
55. Wang, C.; Luo, D.; Zhang, X.; Huang, R.; Cao, Y.; Liu, G.; Zhang, Y.; Wang, H. Biochar-Based Slow-Release of Fertilizers for Sustainable Agriculture: A Mini Review. *Environ. Sci. Ecotechnol.* **2022**, *10*, 100167. [CrossRef] [PubMed]
56. Ibrahim, M.M.; Wu, F.; Chen, Y.; Liu, D.; Zhang, W.; He, Z.; Hou, E.; Xing, S.; Mao, Y. Impacts of MgO-and Sepiolite-Biochar Composites on N-Partitioning and Dynamics of N-Cycling Bacteria in a Soil-Maize System: A Field-Based 15N-Urea Tracer Study. *Geoderma* **2023**, *429*, 116236. [CrossRef]
57. Rashid, M.; Hussain, Q.; Khan, K.S.; Alwabel, M.I.; Hayat, R.; Akmal, M.; Ijaz, S.S.; Alvi, S. Carbon-Based Slow-Release Fertilizers for Efficient Nutrient Management: Synthesis, Applications, and Future Research Needs. *J. Soil Sci. Plant Nutr.* **2021**, *21*, 1144–1169. [CrossRef]
58. Zheng, J.; Han, J.; Liu, Z.; Xia, W.; Zhang, X.; Li, L.; Liu, X.; Bian, R.; Cheng, K.; Zheng, J. Biochar Compound Fertilizer Increases Nitrogen Productivity and Economic Benefits but Decreases Carbon Emission of Maize Production. *Agric. Ecosyst. Environ.* **2017**, *241*, 70–78. [CrossRef]