# Effects of biochar-based compound fertilizer (BCF)-urea on growth, yield, N-uptake and protein content of corn (*Zea mays* L.) in Madura Alfisol

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**Abstract** The low Nitrogen (N) and organic Carbon (C-organic) content typical of Alfisol in Madura presents a significant agricultural challenge. To address this, a study was conducted into the effects of Biochar-Based Compound Fertilizer (BCF)-Urea on the growth, yield, N uptake efficiency, and protein content of corn (*Zea mays* L.) grown in Madura Alfisol. The study, arranged in a Completely Randomized Design (CRD) at the Experimental Field of the East Java Horticultural Field Garden in Bangkalan, Madura, included five treatments: P0 (control, no fertilizer), P1 (rice husk biochar coating), P2 (corn cob biochar coating), P3 (biochar compost coating), and P4 (urea only, no coating). The application of BCF-Urea significantly affected all parameters observed. BCF-Urea increased N absorption efficiency from 37.84% to 45.49%, and the yield potential tended to be higher (5.71 - 5.99 ton/ha) compared to the urea-only treatment (5.14 ton/ha). Furthermore, corn treated with BCF-Urea demonstrated a significantly higher protein content (56.86% to 82.84% increase) than corn fertilized with urea only (P4). These results suggest that BCF-Urea is an efficient fertilization strategy for improving both crop yield and quality in dryland Alfisol soil in Madura.

## 1 Introduction

Corn is one of the important cereals; besides as the second staple food, it is also as livestock feed [10]. In Indonesia, the demand for corn continues to increase, and the quantity cannot be met by domestic production. Data from BPS [24] shows that corn production in Indonesia reached 19.56 million tons, a decrease of 2.80 million tons or 12.50% compared to 2022, which reached 22.36 million tons.

Dry land of Madura, with its predominantly alfisol, is an important corn-producing area in East Java. To increase corn production in Madura Will face the problems in alfisol. This soil is characterized by intensive weathering and low chemical fertility, especially N, P, and K. While the soil's physical properties are good, it has a low organic matter content. The main problem in Madura's Alfisol related to low soil fertility is the low total N and organic C content [18]. Therefore, cultivating Madura's Alfisol requires input of nitrogen and organic C.

The N requirement is usually met with urea fertilizer, which has the highest N content, 46% N. Urea is hygroscopic, easily absorbing water vapor from the air. This property aids urea dissolution in water, making N more easily absorbed by plants. The availability of N in the soil can be reduced by various processes such as volatilization, leaching by rainwater, soil erosion that removes nitrogen, and denitrification by microorganisms that convert N into $N_2$ gas, which then escapes into the air. This impacts N absorption efficiency [12]. In tropical regions, its absorption efficiency is only 30-50%, meaning the remaining 50-70% is lost due to volatilization (2-20%), mineralization of soil organic matter through amination, ammonification, and nitrification (15-25%), denitrification (>20%), and leaching (2-10%). Volatilization ($NH_3$ gas) and denitrification ($N_2O$ and NO gas) can cause air pollution, and $NO_3^-$ leaching can cause groundwater contamination. This results in a lack of nutrients for the plants, leading to soil degradation, a decrease in soil microorganisms that help the nutrient cycle, and pollution problems due to excessive fertilizer use [23]. Such problem could be tacled by the use of Based Compound Fertilizer (BCF) can be an effective strategy to increase plant absorption efficiency [2][22].

Based Compound Fertilizer (BCF) releases nutrients slowly; it can be produced by coating urea using biochar [8]. Biochar is a material that can adsorb and plays a role in creating carbon-based fertilizer with a gradual release mechanism [5]

Biochar's characteristics include a large surface area, microporosity, graphitic structure, and various functional groups [23], making it a highly potential soil conditioner.

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Biochar's release process is not direct but involves soil improvement and gradual nutrient release, which then supports more optimal plant growth, especially in the long term.

The BCF not only ensures the plant's need for N but also the BCF-Urea will slowly release N nutrients, matching the plant's uptake and ultimately reducing losses through both evaporation and leaching, thereby increasing N uptake efficiency, yield and yield quality. Biochar contains organic C and possibly increase the soil's organic C content both directly from the C compounds contained in the biochar and indirectly through the accumulation of organic compounds and the increase in soil organisms, and soil productivity. We focus on the effects of the application of BCF-Urea on plant growth and yield as well as quality of yield.

## 2 Research method

Research was carried out at Experimental Field of Horticultural Research Center, Bangkalan, Madura, East Java from August 2024 to January 2025. Treatments consisted of 5 levels labelled as P0, P1, P2, P3, and P4. All treatments were arranged in completed randomized. Each treatment (Table 1) was replicated for 4 times to end up in 20 research units. BCF_urea was made from urea coated by rice husk (P1) biochar, oorn cob (P2) biochar, and composted biochar (P3). The characteristics of both biochar used were can be found on [19]

### 2.1 Plant assay

The land was ploughed with a tractor to invert the soil layer and loosen the soil. The next stage involved making beds with dimensions of 2.8 m in length and 1.2 m in width, with a distance of 60 cm between beds. After processing, the soil was left for 2 weeks, and the soil was watered every 2 days to maintain moisture.

**Table 1.** Treatments applied in this study.

| Code | Description of Treatment |
|---|---|
| P0 | Without fertilizer (control) |
| P1 | Urea 100% coated with rice husk biochar |
| P3 | Urea 100% coated with corn cob biochar |
| P4 | Urea 100% coated with composted biochar |
| P5 | Urea 100% without coating |

Hybrid corn seeds (BISI-2), meeting the criteria of being uniform, of the same size, and healthy, were planted in planting holes. Seeds were planted by inserting them into the planting hole (at a depth of 3 cm) using the dibbling system with a planting distance of 20 x 70 cm. Two seeds were placed in each hole. Each bed contained 20 planting holes.

Corn crop maintenance included fertilization, watering, thinning, weeding, and pest/disease control. The conventional fertilizers used were urea, SP-36, and KCL with respective dosages of 350, 200, and 100 kg/ha. Fertilization for treatment P4 (likely the control or conventional treatment) was carried out on 10, 30, and 45 Days After Planting (DAP). Fertilization for treatments P1, P2, and P3 (for all fertilizers) was conducted only once at 10 DAP.

Watering was done once a day in the morning or adjusted according to soil moisture. If the soil was already moist, the plants were not watered. Thinning was carried out at 14 DAP by uprooting the weaker plant, leaving only one plant per planting hole. Weeding was done by mechanically cleaning and pulling out weeds around the plants.

Pest and disease control involved spraying with the insecticide Starban 585 EC to control the fall armyworm (*Spodoptera frugiperda*) in the corn plants. Harvesting was carried out at 105 DAP or when the corn husk turned yellow and dried, the corn silk was brown, and the kernels hardened and became shiny yellow. The observed variables were: Plant height, Plant biomass, N absorption efficiency, Potential yield, and Protein content in grain yield.

### 2.2 Data analysis

The data analysis used was Analysis of Variance (ANOVA, $p$ = <0.05) to determine the effect of the treatments. If the treatment was found to have a significant effect, a post-hoc test using Duncan's Multiple Range Test (DMRT, $p$ = <0.05) was performed to determine the best treatment.

## 3 Results and discussion

### 3.1 Plant height

The ANOVA ($p$<0.05) showed that the BCF-Urea treatments had a significant effect on plant height when at 35-49 DAP but was not significant at 14-28 DAP. The average value of plant height due to BCF-Urea treatments was showed at Table 2. Treatment P1 (urea coated with rice husk biochar) tended to have the highest mean plant height at 49 DAP, reaching 66.08 cm. However, the result of this treatment was not significantly different from that of Treatment P4 (conventional urea application).

**Table 2.** The average of corn height due to BCF-Urea treatments (P1, P2, P3), dan Urea without coating (P4).

| Code | 14 | 28 | 35 | 42 | 49 |
|---|---|---|---|---|---|
| P0 | 2.47 | 6.01 | 7.74 a | 9.46 a | 11.92 a |
| P1 | 3.17 | 14.01 | 17.30 b | 32.56 c | 66.08 c |
| P2 | 3.44 | 16.24 | 19.62 b | 32.92 c | 56.39 c |
| P3 | 3.84 | 12.73 | 15.80 b | 25.46 b | 44.57 b |
| P4 | 3.43 | 12.83 | 17.71 b | 30.49 bc | 55.15 bc |
| ANOVA (P <0,005 | ns | ns | * | * | * |

Description: Numbers that followed by similar letter at similar colom was not significantly different based on DMRT ($p$<0.05); *: significantly difference; ns: not significantly difference based on ANOVA ($p$ <0.05).

### 3.2 Plant biomass

Result of ANOVA ($p$<0.05) showed that the BCF-Urea treatments had a significant effect on corn biomass. The average of plant biomass due to BCF-Urea treatments was

showed at Table 3 Treatment P4 tended to result in the highest biomass up to 85.42 g, while Control (P0) had the lowest plant biomass (11.68 g).

**Table 3.** Average of plant biomass (g) of corn dur to *BCF*-Urea treatments (P1, P2, P3), dan Urea without coating (P4).

| Treatments | Plant biomass (g) | | | |
|---|---|---|---|---|
| | Root | Shoot | Leaves | Total |
| P0 | 1.12 a | 5.49 a | 5.07 a | 11.68 a |
| P1 | 12.41 | 37.71 | 29.04 | 79.16 |
| | | | | |
| P2 | 10.34 | 28.42 b | 35.77 c | 74.52 |
| P3 | 14.35 | 36.17 | 27.95 b | 78.47 |
| P4 | 13.56 | 43.98 c | 27.88 b | 85.42 |
| ANOVA ($p$ <0.05) | * | * | * | * |

Description: Numbers that followed by similar letter at similar colom was not siginificantly different based on DMRT ($p$<0.05); *: significantly difference based on ANOVA ($p$ <0.05).

### 3.3 N-Uptake, N content, and Uptake efficiency

Result of ANOVA ($p$<0.05) showed that the BCF-Urea treatments had a significant effect on N content, N Uptake, and N Uptake-efficiency. The average of N content, N Uptake, and N Uptake-efficiency of corn due to BCF-Urea treatments was showed at Table 4 Treatment P1, P2, and P3 had similar result in N Uptake-efficiency to P4. In term of N uptake and N content, the treatment of P3 was similar to P4; indicating P3 had effect as good as P4 in provide N.

**Tabel 4.** Average of of N content, N Uptake, and N Uptake-efficiency of corn due to BCF-Urea treatments (P1, P2, P3), dan Urea without coating (P4).

| Treatments | N content (g/100g) | N uptake (g/plant) | N uptake-efficiency (%) |
|---|---|---|---|
| P0 | 1.80 b | 0.21 a | - |
| P1 | 1.45 a | 1.15 bc | 37.84 bc |
| P2 | 1.34 a | 1.03 b | 33.01 b |
| P3 | 1.70 b | 1.34 bc | 45.49 bc |
| P4 | 1.67 b | 1.43 c | 49.11 c |
| ANOVA (p<0.05) | * | * | * |

Description: Numbers that followed by similar letter at similar colom was not significantly different based on DMRT (p <0.05); *: significantly difference based on ANOVA (p <0.05).

### 3.4 Corn yield

Result of ANOVA ($p$<0.05) showed that the BCF-Urea treatments had a significant effect on weight of seed in one plant, weight of 100 seeds, and potential yield of corn. The average of average of weight of seed, weight of 100 seeds, and potential yield of corn due to BCF-Urea treatments was showed at Table 5. Treatment P1, P2, and P3 had similar result as that of P4. Treatment of P3 indicated the highest result in all corn yield parameters investigated.

### 3.5 Protein content

Result of ANOVA ($p$<0.05) showed that the BCF-Urea treatments had a significant effect on protein content of seed corn. The average of average of protein content of seed corn due to BCF-Urea treatments was showed at Table 3.5. Treatment P1, P2, and P3 had higher result than that of P4; The protein content of corn under BCF-urea from P3, P1 and P2 was respectively about 56.86%, 70.78% and 80.84% compared to that of P4 indicating the higher potential of BCF Urea to increase protein content in hybrid corn.

**Table 5.** Average of weight of seed, weight of 100 seeds, and Potential Yield of corn due to BCF-Urea treatments (P1, P2, P3), dan Urea without coating (P4).

| **Treatments** | **Weight of Seed per Plant (g)** | **Weight of 100 Seeds (g)** | **Potential Yield (ton/ha)** |
|---|---|---|---|
| P0 | 0.00 a | 0.00 a | 0.00 a |
| P1 | 81.43 b | 59.10 b | 5.82 b |
| P2 | 79.90 b | 66.85 b | 5.71 b |
| P3 | 83.85 b | 68.95 b | 5.99 b |
| P4 | 76.08 b | 65.95 b | 5.14 b |
| ANOVA ($p$ <0.05) | * | * | * |

Description: Numbers that followed by similar letter at similar colom was not significantly different based on DMRT (p<0.05); *: significantly difference based on ANOVA (p<0.05).

**Tabel 5.** Average of Protein content in corn seed due to BCF-Urea treatments (P1, P2, P3), dan Urea without coating (P4).

| **Treatments** | **N content** | **Protein Content (%)** |
|---|---|---|
| P0 | 0.00 a | 0.00 a |
| P1 | 2.79 c | 17.42 c |
| P2 | 2.91 c | 18.65 c |
| P3 | 2.56 c | 16.00 c |
| P4 | 1.63 b | 10.20 b |
| ANOVA ($p$ <0.05) | * | * |

Description: Numbers that followed by similar letter at similar colom was not significantly different based on DMRT (p<0.05); *: significantly difference based on ANOVA (p <0.05).

## 4 Discussion

Research results showed that the BCF-Urea treatments began to show a significant effect at 35 DAP (Table 3.1). This suggests that the treatments had less influence during the early vegetative growth phase but showed an effect in the later phase. The results indicated that Treatment P1 (rice husk biochar) resulted in higher plant height compared to the un-coated treatment (P4). Therefore, the quality and dosage of biochar are crucial aspects to consider for accelerating the vegetative growth process. Furthermore, the slow release time of nitrogen from the coated fertilizer only impacted the active growth phase (35-49 DAP), where nitrogen demand increases drastically due to rapid cell

division and elongation. Thus, the significant effect of coated fertilizers is typically observed in the advanced growth phase, not the early phase [9]. This is likely because corn growth is highly influenced by nitrogen availability in the soil, which supports growth, thereby increasing the number and area of leaves. Nitrogen is a fundamental nutrient for plant development, required in large quantities to achieve optimum growth [20].

Meanwhile, treatment P4 yielded the highest plant biomass, tending to be 85.42 g. This treatment was not significantly different from the coated treatments (Table 3.2). Previous potting research of BCF-urea in sandy soil gave the similar effect of corn growth [19]. This is likely because the nitrogen from the P4 treatment (un-coated urea, applied three times) was more rapidly available and absorbed by the plant, thus being immediately utilized for the formation of structural tissues such as roots, stems, and leaves [ 1].

The treatments had a significant effect on N absorption efficiency. Treatment P4 (without coating) tended to yield the highest N absorption efficiency at 49.11% which was not significantly different from Treatments P1 and P3, with absorption efficiency values of 37.84% and 45.49%, respectively (Table 3.3). It is suspected that the BCF treatments were able to increase N uptake and its usage efficiency by the plant. This is related to the biochar's characteristic of having large pores, allowing nitrogen to be used more effectively and to be available to the plant for a longer period. This means that plants can absorb more nitrogen more efficiently, thus increasing N absorption efficiency [14]. This study indicates that the effect of using conventional fertilizer (P4) on corn was similar to the coated treatments. This is because the coated urea could release nitrogen gradually and more efficiently in fertilization. Crucially, P4 (un-coated) was fertilized 3 times, whereas the coated treatments (P1, P2, P3) were applied only once.

The main product of corn is the grain, and grain weight varies according to the variety. Based on Table 4.4, the parameters for grain weight per plant, 100-grain weight, and potential yield for the biochar and biochar compost-coated urea treatments were not significantly different from the un-coated urea treatment (P4). However, the biochar-coated urea treatments tended to be higher than the un-coated one. The coated urea treatments increased potential yield by 13.22% (P1), 11.28%(P2), and 16.54% (P3). This is because biochar, as a urea coating, plays a role in regulating the slow release of nitrogen and maintaining nutrient availability for a longer period, which supports the plant's generative growth [2]). Grains require a relatively high amount of nitrogen during the grain filling process for photosynthate production. If the nitrogen supply decreases during this phase, it can cause the leaves to senescent quickly as the plant relocates nitrogen from the leaves to the grain [16].

Protein content, an important nutrient in food [17] under biochar-coated urea increases, in which P1 increased by 70.78%, P2 by 82.84%, and P3 by 56.86%. The BCF-urea was able to increase corn grain protein content by improving nitrogen use efficiency and nutrient availability in the soil. According to [21], the use of biochar-based fertilizers, including biochar-coated urea, has been shown to increase nitrogen use efficiency, which is crucial for the plant's protein synthesis process. Biochar acts as a binding agent that slows the release of nitrogen into the soil, giving the plant more time to maximize the absorption of this nutrient.

This study shows that the combination of biochar and urea not only enhances nitrogen absorption but possibly also improve the availability of phosphorus, which together contribute to the increased protein content in the corn grain. Phosphorus is essential for photosynthesis and plant growth, which indirectly supports protein formation in corn grain [4]. Additionally, biochar enhances soil microbial activity. These microorganisms play a role in decomposing organic matter and releasing nutrients, such as nitrogen and phosphorus, allowing plants to absorb them more efficiently to support protein synthesis [6]. According to [11], NPK fertilizer application plays a very important role in corn protein content, particularly the N composition, which affects protein production in corn. Furthermore, biochar helps reduce nitrogen loss due to leaching and volatilization, ensuring the nutrient remains available in the soil for a longer period. Biochar also has a high Cation Exchange Capacity (CEC), which efficiently adsorbs and releases nutrients, and improves soil structure while supporting beneficial microorganism activity [7].

Research by [15] demonstrated that under environmental conditions with high nitrogen availability, protein content in corn grain increased with the amount of nitrogen absorbed by the plant. This finding emphasizes the importance of optimal nitrogen availability in supporting the improvement of corn grain quality, particularly its protein content. This aligns with [13] statement that an increase in N levels will raise the protein content in corn grain. Optimal and continuous nitrogen availability supports the more effective formation of amino acids and proteins in the corn grain, ultimately contributing to an increase in the protein content of the harvest. This implies that the BCF treatment can be an effective option for increasing productivity and lowering fertilizer costs.

## 5 Conclusion and recomendation

The BCF-Urea treatments had a significant effect on the plant growth including plant height, and plant biomass. as well as N absorption efficiency. The N uptake efficiency on P4 was not significantly different from Treatments P1 and P3. Compared to P4, BCF Urea tended to increase yield by 13.22% (P1), 11.28%(P2), and 16.54%(P3) and significantly increased protein content; P1 by 70.78%, P2 by 82.84%, and P3 by 56.86%.

Further research is needed on to investgate effects the residu of BCF_urea for the next planting season, and as well as effecgt of BCF_urea on reduction in N emission.

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