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# The application of organic liquid fertilizer *C. glomerata* and NPK Phonska to enhance agronomic efficiency in maize cultivation on Alluvial soil

**Jamilah[1]*, Aguswanto[1], Ediwirman[1], Sunadi[1], Prima Novia[2]**

[1] Department of Agrotechnology, Faculty of Agriculture, Tamansiswa University, Padang, Indonesia
[2] Department of Agrotechnology, Faculty of Agriculture, Ekasakti University, Indonesia

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* *Corresponding Author*
*Email address:*
*jamilah@unitas-pdg.ac.id*

**ABSTRACT**

Fertilization is crucial in maize cultivation, and inorganic fertilizers can be expensive. Therefore, it is essential to provide alternative fertilizers to reduce dependence on inorganic fertilizers. This study investigated the role of organic liquid fertilizer *C. glomerata* (OLFC) in increasing the efficiency of NPK Phonska fertilizer, influencing soil chemical reactions, and enhancing the growth and yield of maize on alluvial soils. The materials used were hybrid maize of the Pioneer 32, OLFC, and NPK Phonska (15-15-15). The experiment was arranged in a completely randomized design (CRD) in factorial. The OLFC was applied at 0 mL $L^{-1}$, 5 mL $L^{-1}$, and 10 mL $L^{-1}$; NPK Phonska Fertilizer at 0, 150, and 300 kg $ha^{-1}$ in three replications. The data obtained were statistically analyzed using ANOVA at 5%. Level of significance and mean separation using the LSD at 5% probability. The following parameters were evaluated: soil chemical properties and agronomic factors, such as the height of crop, net assimilation rate, relative growth rate, weight of 100 seeds, yield, and agronomic efficiency (AE). The highest maize yield recorded was 4.83 tons per hectare, achieved by applying 150 NPK Phonska kg per hectare, supported by a fertilization efficiency of 11.28%. Adding 5 mL per liter of OLFC every two weeks to maize plants resulted in the highest AE, reaching 21.81%.

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## 1. INTRODUCTION

Maize is a primary food commodity in Indonesia, second only to rice, and is cultivated extensively in the country. Despite significant production, Indonesia imported almost 1.5 million tons of maize in 2023 (BPS, 2024). The demand for grain maize is exceptionally high due to its extensive use in the animal feed industry. Appropriate maize cultivation techniques are crucial to enhance yield productivity and quality, reducing dependence on maize imports. Intensive maize cultivation is vital in Indonesia to meet the growing demand for this staple crop. One challenge faced in Indonesia is that the land designated for maize cultivation is often classified as marginal (Jamilah et al., 2020; Jamilah et al., 2021). The generally low soil acidity (pH) also negatively impacts maize yields. The substantial reliance on inorganic fertilizers poses a challenge for farmers, as increasing fertilizer prices make their application less feasible, potentially leading to decreased maize yields (Pandey & Bhambri, 2017). Fertilization is vital for maize cultivation, and inorganic fertilizers can be expensive. Therefore, it is crucial to provide alternative fertilizers to reduce dependence on inorganic fertilizers. Fertilizers are critical in enhancing soil productivity, and two main types are organic and inorganic. While inorganic fertilizers can quickly boost soil productivity, they may adversely affect soil quality. Notably, the government-subsidized Phonska NPK fertilizer (15-15-15), with its low nutrient content, is widely used in food crop cultivation (Wildayana et al., 2018). However, its effectiveness often requires supplementation with other nutrient sources to meet the comprehensive nutritional needs of plants.

According to Kafle et al. (2022), utilizing marginal dry land for crop cultivation can result in complex nutrient deficiency stress affecting the growth of maize plants. Many of these lands suffer from deficiencies in essential macronutrients, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), while experiencing an increase in toxic elements like aluminum (Al) and iron (Fe). Although high-dose chemical fertilization is an option to address these liquid organic fertilizers, new innovations are expected to increase the effectiveness of liquid fertilizers in using inorganic fertilizers efficiently. Different types of organic matter, such as *Cladophora glomerata* (*C. glomerata*), a macroscopic blue-green algae with more than 183 species, often found in drainage canals or rivers, can be used as raw material for making liquid organic fertilizer. These algae can live in freshwater or salt water with a low nutrient content, making them more effective in procuring *C. glomerata* algae (Xiang et al., 2016). These algae will bloom when the nutrient content of lake or river water increases due to the excessive application of fertilizers on agricultural land. In shallow lakes or ponds, *C. glomerata* can breed up to 4 kg $m^{-2}$ wet weight (Michalak & Messyasz, 2021). Maximum production occurs of *C. glomerata* in summer and results from two short periods of intensive vegetative growth (June and September), where nutrients are sufficiently available from tributaries (Chomczyńska & Zdeb, 2019). Diurnal patterns of photosynthesis were studied in July and April for *C. glomerata* (L.) Kütz populations from open and on shaded sites, revealing a higher capacity for heat energy dissipation and increased total amount of xanthophyll cycling pigments (21%) in samples from the open.

*C. glomerata* algae exhibit diverse macro and trace nutrients and amino acids. The macronutrient content in *C. glomerata* algae includes approximately 1.46–4.15 ppm of nitrogen (N), 0.16–0.49 ppm of phosphorus (P), 3.2–6 ppm of potassium (K), 26.16–27.16 ppm of calcium (Ca), and 0.26–0.42 ppm of magnesium (Mg). Additionally, trace elements such as zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), and lead (Pb) are also present. The algae contain 16 types of amino acids, with glutamic acid, aspartic acid, and leucine being the most abundant. The biomass typically consists of amino acids ranging from 16.35 g $kg^{-1}$ to 37.63 g $kg^{-1}$ dry matter (Saboor et al., 2021). Nutautaitė et al. (2021) reported the nutritional content of *C. glomerata*, which includes protein (14.26%), carbohydrates (64.52%), lipids (0.55%), and ash (20.73%).

The algae also contain total chlorophyll (9.06 ± 0.07 μg $mL^{-1}$) and total carotene (756.4 ± 0.05 μg $mL^{-1}$). The high protein content can contribute nitrogen as a nutrient for plant growth (Duygu et al., 2019). Biomass from *Cladophora* can be successfully utilized as raw material to produce value-added products. *Cladophora* spp. has potential applications across various fields, including human and animal health, agriculture (such as organic fertilizers, plant growth biostimulants, and feed additives), environmental protection (acting as bioindicators of pollution/contamination and absorbing pollutants from wastewater), renewable energy sources (e.g., biogas and bioethanol), and high-tech composite materials (Michalak & Messyasz, 2021). Although *C. glomerata* has been utilized in various applications, such as animal feed and the production of cosmetic and pharmaceutical products, information on its use in the creation of liquid organic fertilizers is limited (Prazukin et al., 2021). The decomposition process of amino acids during liquid fertilizer production can release nitrogen (N) elements, contributing to the N nutrient content beneficial for plant growth. Therefore, understanding the impact of applying liquid organic fertilizer from *C. glomerata* algae (OLFC) on the development and yield of maize in alluvial soils becomes essential. This study aims to determine the role of OLFC in enhancing the efficiency of NPK Phonska fertilizer, affecting soil chemical reactions, and influencing the growth and yield of maize on alluvial soils.

## 2. MATERIALS AND METHODS

The experiment was conducted on alluvial soil in Anduriang Village, Kuranji District, Padang City. The materials used in the study were Pioneer 32 organic hybrid maize, liquid fertilizer of *C. glomerata* (OLFC), and NPK Phonska (15-15-15). The experimental design included two main factors: the first involved the application of OLFC (*Chladophora glomerata* algae-based liquid organic fertilizer) with three levels, 0, 5, and 10 mL $L^{-1}$. The second factor was the dosage of Phonska NPK fertilizer (15:15:15), comprising three levels—0, 150, and 300 kg $ha^{-1}$. The experiment was arranged in a factorial, completely randomized design (CRD). The OLFC was applied at three rates: 0 mL $L^{-1}$, 5 mL $L^{-1}$, and 10 mL $L^{-1}$; concurrently, NPK Phonska Fertilizer was used at 0, 150, and 300 kg $ha^{-1}$ in three replications. Data obtained were analyzed statistically using ANOVA at a 5% level of significance, as well as mean separation using the LSD at 5% probability. For the preparation of OLFC, the procedure involved combining 15 liters of rainwater with 1 kg of *Chladophora glomerata* algae, one young coconut water, 100 g of $Ca(OH)_2$, 100 g of NaCl, 100 g of monosodium glutamate (MSG), 100 g of onion, and 100 g of honey. All the ingredients were finely chopped to a length of 2 mm. Young coconut water, MSG, whiting, and honey were placed in a bucket and left to ferment for one week. Subsequently, 15 liters of water were added, and the mixture was dried for one week until it changed color to golden yellow. This prepared OLFC was then applied to the experimental maize plots.

Experimental plots were created with dimensions of 300 cm x 200 cm, using a spacing of 50 cm x 25 cm, employing a 2:1 Legowo pattern, and maintaining a 50 cm distance between plots. The maize seeds were treated with 5 g $kg^{-1}$ of Ridhomil 50 EC fungicide to prevent downy mildew. The OLFC was applied 14 days after planting (DAP) and continued every two weeks until the primordial phase of the plants appeared. Then, the application of OLFC was discontinued. The NPK Phonska was applied at 7 DAP by arranging them in rows between plants and buried into the soil. Observation parameters included soil chemical properties, such as pH, and agronomic properties of plants, for example, plant height, net assimilation rate (NAR), plant relative growth rate (RGR), leaf area index (LAI), weight of 100 seeds, and maize yield per hectare. Agronomic efficiency (AE) was determined using the Equation 1 (Saboor et al., 2021), where PP is plant production.

$$AE = \frac{(\text{PP with fertilizer} - \text{PP without fertilizer})}{\text{Amount of fertilizer given}} x100\% \quad ............[1]$$

The soil pH, plant height, and LAI were set at 45 DAP. Soil sampling for pH determination was conducted in each experimental plot at 0–15 cm, focusing on the rhizosphere area. Determination of NAR and plant RGR was performed by destroying the plants twice at 30 DAP and 45 DAP. The weight of 100 seeds and the yield of maize cobs per hectare are measured at 120 (the DAP). The soil chemistry analysis entailed quantifying N-total, P-total, and K-total in both the soil and OLFC. The Kjeldahl technique was employed for N-total, utilizing 5 mL of concentrated $H_2SO_4$ and 1 g of $CuSO_4$ as a catalyst. P-total and K-total were evaluated using the UV-Vis spectrophotometer method. That is, 5 mL of concentrated $HNO_3$ and 5 mL of $H_2SO_4$ were employed to ascertain the presence of P. Conversely, a pH 7 buffer solution was utilized to determine the concentration of K. pH value was assessed using a pH electrode, where a soil-to-water ratio of 1:2.5 was used for both soil and liquid fertilizer samples. To measure the pH, soil samples were collected randomly from each experimental plot at 0–15 cm depth around the root rhizosphere. These analyses provide essential information about the nutrient content and acidity of the soil as well as the liquid organic fertilizer. The Kjeldahl method is commonly used for N determination, while UV-Vis spectrophotometry is reliable for P determination. Accurate pH measurement is essential since it provides information on the acidity or alkalinity of the soil and fertilizer, which can impact the availability of nutrients to plants. The defined processes and methods guarantee precise measurements of these parameters. Before the experiment, a soil chemical study was conducted, including determining the soil pH. Furthermore, another soil pH assessment was performed at 45 DAP.

## 3. RESULTS

### 3.1 The soil chemical analysis and organic liquid fertilizer of *C. glomerata*

The results of the initial soil chemical analysis and organic liquid fertilizer of *C. glomerata* (OLFC) are presented in Table 1. The key findings are as follows: soil chemical reaction (pH): slightly acidic; nitrogen (N) content: moderate; phosphorus (P) content: very high; carbon-organic content: very low; potassium (K) content: low. The soil's slightly acidic pH, coupled with moderate N levels and very high P content, suggests conditions that may impact the growth of maize plants throughout their vegetative and generative phases. The low organic carbon content and low potassium levels can also influence plant development.

The historical land use for lowland rice cultivation and the associated intensive fertilization practices have significantly impacted the soil's nutrient composition, particularly the high phosphorus content. This information is crucial for understanding the current state of the soil and its potential implications for maize growth. While beneficial in some respects, the high phosphorus levels may also pose challenges, as excessive nutrient concentrations can lead to imbalances and affect overall plant health. Further analysis and monitoring will be essential to assess how maize plants respond to these soil conditions, especially considering their nutrient requirements at various growth stages. The initial soil characteristics are a baseline for ongoing research and management decisions. By closely monitoring the maize growth and adjusting fertilization practices accordingly, it will be possible to optimize conditions for higher productivity and better overall crop health.

### 3.2. Plant height of maize

The application of OLFC, accompanied by the use of Phonska compound NPK fertilizer (15-15-15), showed a highly significant interaction with the height of maize at 45 DAP (Table 2). Providing OLFC alone did not increase plant height if Phonska's artificial fertilizer was not applied. With the administration of 150 kg ha$^{-1}$ Phonska, increasing the OLFC dose led to an increase in maize plant height, reaching 122; however, this was not the case when increasing the dose of Phonska further.

### 3.3. The net assimilation rate (NAR) and relative growth rate (RGR) of maize plants

The statistical analysis results revealed an interaction between the application of Phonska's NPK and OLFC on the NAR and RGR, as shown in Table 3.

**Table 1**. Results of initial soil chemical analysis and OLFC.

| Substance | pH | Total N (%) | P | K | Organic- C (%) |
|---|---|---|---|---|---|
| Soil | 6.18$^{sa*}$ | 0.326$^{m*}$ | 36.62 ppm$^{vh}$ | 18.59 me/100g$^{l}$ | 1.026$^{l}$ |
| Algae *C. glomerata* | - | 2.30% | 0.20% | 2.60% | 13.12 |
| OLFC | 6.2$^{sa}$ | 0.720% | 0.342 (%) | 0.692% | Not measurement |

**Remarks**: *m: moderate; vh: very high; l: low; a: acid; sa: slightly acid; criteria for determining soil chemical analysis based on Tripathi et al. (2018)

**Table 2**. Effect of OLFC application and Phonska compound fertilizer on maize height at 45 DAP.

| NPK (kg ha$^{-1}$) | OLFC (ml L$^{-1}$) | | |
|---|---|---|---|
| | 0 | 5 | 10 |
| | cm | | |
| 0 | 68.08 Ac | 68.33 Ac | 69.75 Ac |
| 150 | 125.75 Bb | 152.08 Ab | 159.17 Ab |
| 300 | 168.83 Aa | 171.58 Aa | 172.92 Aa |
| CC (%) | 6.23 | | |
| LSD.05 | 13.74 | | |

**Remarks**: Numbers followed by the same uppercase letters in the same rows and lowercase letters in the same columns are not considered statistically significant according to the LSD (least significant difference) at a 5% level.

**Table 3.** Net assimilation rate (NAR) and relative growth rate (RGR) of maize from 30 DAP to 45 DAP.

| NPK (kg ha$^{-1}$) | NAR mg cm$^{-2}$day$^{-1}$ | | | RGR mg g$^{-1}$ hari$^{-1}$ | | |
|---|---|---|---|---|---|---|
| | OLFC (ml L$^{-1}$) | | | OLFC (ml L$^{-1}$) | | |
| | 0 | 5 | 10 | 0 | 5 | 10 |
| 0 | 1.307Aa | 1.439Aa | 0.671Bb | 31.600 Ba | 48.200 Aa | 25.100 Bb |
| 150 | 0.308 Bb | 0.750Ab | 0.711Ab | 16.863 Bb | 31.233 Ab | 23.400 ABb |
| 300 | 0.690 Bb | 0.817ABb | 0.943Aa | 19.867 Bb | 30.233 ABb | 36.033 Aa |
| CC (%) | | 18.52 | | | 19.96 | |
| LSD.05 | | 0.000270 | | | 0.00999 | |

**Remarks**: Numbers followed by the same uppercase letters in the same rows and lowercase letters in the same columns are not considered statistically significant according to the LSD (least significant difference) at a 5% level.

The highest NAR was observed when applying 0 kg ha$^{-1}$ of NPK Phonska and 10 mL L$^{-1}$ of OLFC, resulting in 1.439 mg cm$^{2}$ per day. This implies that the photosynthate production was higher in the treatment without inorganic fertilizers. The highest RGR of maize plants occurred in the treatment with 0 kg ha$^{-1}$ of NPK Phonska combined with 10 mL L$^{-1}$ of OLFC, reaching 48.2 mg day$^{-1}$. As the OLFC dose increased, there was a corresponding decrease in the RGR of maize, mirroring the pattern seen with a dose of 150 kg ha$^{-1}$ of NPK Phonska. In the case of the administration of 300 kg ha$^{-1}$ of NPK Phonska, an increase in the OLFC dose led to a linear increase in RGR. The optimal application of NPK Phonska fertilizer in this treatment was found to be 300 kg ha$^{-1}$. These plants exhibited a positive response to OLFC, as an increase in OLFC doses correlated with an increase in the RGR of maize. When 300 kg ha$^{-1}$ of Phonska NPK was administered, the linear graphical representation suggested the potential for further increasing the OLFC dose to enhance the RGR.

### 3.4. The soil pH, LAI, and weight of 100 maize seeds

The soil pH range at 45 DAP was from 5.71 to 6.01. Interestingly, the higher the dose of Phonska fertilizer, the lower the soil pH compared to the effect of a low Phonska NPK dose (0 kg ha$^{-1}$) (Table 4). Compared to the initial pH of 6.18 (Table 1), the soil pH at 45 DAP was generally lower. The application of Phonska fertilizer had a significant effect on LAI. In contrast, OLFC and the interaction between the two treatments had no significant influence on the LAI or the 100-seed weight of maize. The LAI reflects the amount of sunlight penetrating the leaf surface, which is influenced by the leaf arrangement pattern. Therefore, LAI provides an overview of plants' photosynthetic and assimilate activity to generate components for the growth and production of maize.

### 3.5. The yield and agronomic efficiency of maize plants

The single-factor application of Phonska and OLFC significantly increased the maize yield, as presented in Table 5 and the accompanying figure. The highest yield, amounting to 5.03 tons ha$^{-1}$, was obtained from the application of 300 kg ha$^{-1}$ Phonska, and this was not significantly different from the treatment with a dose of 150 kg ha$^{-1}$ Phonska. Similarly, there was no significant difference in yield between the concentrations of 5 and 10 mL L$^{-1}$ OLFC.

Fertilization efficiency, evaluated in terms of AE, can be determined by calculating nutrient uptake or agronomic components. Fertilization efficiency becomes evident upon analyzing the maize yield production data, as shown in Table 5 and Figure 1. While the dose of 300 kg ha$^{-1}$ Phonska NPK resulted in a higher maize yield than that of 150 kg ha$^{-1}$ Phonska NPK, the difference was not statistically significant. The 5 ml L$^{-1}$ OLFC treatment was the optimal dose. The highest AE from OLFC application occurred at the 150 kg ha$^{-1}$ NPK Phonska level, reaching 11.275%. However, when the NPK dose was increased to 300 kg ha$^{-1}$, the fertilization efficiency decreased to 8.45%. In contrast, maize plants treated with OLFC exhibited a different trend. Applying 5 mL L$^{-1}$ resulted in the highest efficiency, reaching 21.81%. However, when the OLFC dose was increased to 10 mL L$^{-1}$, AE decreased to 12.71%.

## 4. DISCUSSION

Similarly, the 10 mL L$^{-1}$ OLFC treatment resulted in the highest maize kernel weight, reaching 5.03 tons ha$^{-1}$, and this was not significantly different from the maize yield obtained from the 5 ml L$^{-1}$ OLFC treatment. These treatments did not significantly interact with the results of dry-shelled maize. When assessed based on fertilization efficiency, the highest efficiency was observed with the application of 150 kg ha$^{-1}$ NPK Phonska and 5 mL L$^{-1}$ OLFC, as detailed in Table 5 and Figure 1. The peak fertilization efficiency was achieved by applying 150 kg ha$^{-1}$ Phonska NPK fertilizer, resulting in 11.275% and 5 mL L$^{-1}$ OLFC, reaching 21.81%. Notably, Karimuna et al. (2023) demonstrated, in the context of maize, that applying a 300 kg ha$^{-1}$ NPK Phonska dose could enhance the growth and yield of high-quality sweet maize based on its fresh weight. Kosmowski et al. (2021) reported that maize yield could potentially reach an average of 7.7 tons ha$^{-1}$ for hybrid varieties. The average production of hybrid maize varieties was 8.1 tons ha$^{-1}$. However, the results of this experiment did not achieve the productivity outlined for hybrid maize, which is significantly influenced by soil fertility.

The soil used in this experiment was alluvial with a moderate fertility rate and belongs to the Cambisol order. Nevertheless, it is essential to note that the organic matter content in the soil was very low. The results of the soil analysis in Table 1 reveal that the soil contained high nutrients, including 0.32% N-total (moderate), 36.62 ppm available-P (very high), 18.59 me g$^{-2}$ K (very high), 22.75 me g$^{-2}$ Ca (very high), 19.75 me g$^{-2}$ Mg (very high), and 11.09 me g$^{-2}$ Na (very high), with a pH of 6.18 (slightly acidic) and organic –C 1.026 (low) (Abagyeh et al., 2016). Low soil organic matter can contribute to soil compaction, restricting root penetration and limiting the plant's access to nutrients and water. The changes in soil pH after planting maize, particularly with increasing doses of NPK (Table 4), can further exacerbate these challenges, resulting in somewhat hindered plant height growth. Moreover, alterations in soil pH can significantly influence maize plant development.

Applying NPK Phonska and OLFC fertilizers to the soil used for maize cultivation decreased soil pH (Table 4). Nciizah et al. (2020) and Chomczyńska and Zdeb (2019) highlight that plants tend to lower the soil pH around their roots during growth and development. This phenomenon is attributed to the release of organic acids and amino acids from plant roots into the soil. These acids react with minerals in the soil, producing hydrogen ions ($H^+$), which are acidic cations. Bashir et al. (2020) explained that the pH tends to decrease with increased hydrogen ions (H+) concentration in the soil. Consequently, prolonged cultivation leads to a lower pH due to maize's increased release of hydrogen ions. If the soil pH becomes excessively low, it can lead to nutrient deficiencies and heavy metal toxicity, adversely affecting plant growth. Sheshu et al. (2022) and Dhaliwal et al. (2021) underscored the importance of enhancing fertility in alluvial soil, especially when nutrients are scarce, particularly in alluvial soil with very low organic carbon content (C-organic).

It is suspected that nutrients in alluvial soil may not be readily available, leading to suboptimal nutrient absorption by plants. Therefore, it is crucial to provide adequate fertilization to alluvial soil using the right fertilizers, namely, NPK Phonska and OLFC. The effectiveness of inorganic fertilizers is expected to increase when applied by OLFC fertilizers. OLFC fertilizer, derived from *C. glomerata* algae, contains lower nutrient levels than the original algae, except for a 0.14% increase in P content.

According to Nutautaitė et al. (2021) and Korzeniowska et al. (2020), *C. glomerata* is rich in various vitamins, ranging from 2% to 5%, including vitamins A, B1, B2, B3, B5, B6, B9, C, and E. *Chladophora glomerata* also contains a diverse array of minerals, constituting 5%-15%, such as calcium, potassium, magnesium, phosphorus, iron, and zinc.

Plants that received higher levels of nutrition from the NPK Phonska and OLFC treatments exhibited optimal growth in height, as indicated in Table 2. The increase in plant height is expected to result in a higher NAR, RGR, and LAI. Applying 5 mL $L^{-1}$ OLFC also demonstrated optimal average NAR and RGR. This aligns with achieving optimal AE in corn plants treated with 5 mL $L^{-1}$ OLFC. Particularly, when no NPK Phonska fertilizer is applied (0 kg $ha^{-1}$), the plant height does not reach 100 cm. In comparison, based on the description of the maize variety planted, the height has the potential to reach 222 cm (Irfan et al., 2021). This underscores the importance of optimizing nutrient levels, especially those classified as high to very high, to ensure optimal nutrient absorption by maize plants. If maize can optimally absorb nutrient levels classified as high to very high, these plants will grow well and align with the previously described characteristics (Griffiths et al., 2020). The alluvial soil used in this research was previously a paddy field. The land had undergone intensive application of inorganic fertilizers, resulting in soil chemical levels categorized as high to very high (Table 1). . However, when OLFC was applied at doses ranging from 5 to 10 mL $L^{-1}$, the increase in maize plant growth exhibited a quadratic relationship. This indicates that adding OLFC enhances plant growth when applied with Phonska fertilizer. Therefore, applying NPK Phonska fertilizer and OLFC is necessary for maize to achieve optimal growth.

**Table 4.** Effect of OLFC application and NPK Phonska on the soil pH, weight of 100 seeds, and leaf area index (LAI) at 45 DAP of maize.

| NPK Phonska (kg $ha^{-1}$) | Soil pH | LAI | Weight of 100 seeds (g) |
|---|---|---|---|
| 0 | 6.01 | 1.31 b | 20.42a |
| 150 | 5.81 | 2.50 ab | 21.60a |
| 300 | 5.71 | 3.22 a | 21.86a |
| CC (%) | 4.70 | 18.65 | 7.15 |
| LSD.05 | | 0.59 | |

**Remarks:** Numbers followed by the same uppercase letters in the same rows and lowercase letters in the same columns are not considered statistically significant according to the LSD (least significant difference) at a 5% level.

**Table 5**. Effect of OLFC application and Phonska NPK fertilizer on maize yield weight and fertilization efficiency.

| Phonska NPK (kg $ha^{-1}$) | Yield (tonnes $ha^{-1}$) OLFC ( ml $L^{-1}$) 0 | 5 | 10 | Average | Fertilizer efficiency Phonska NPK (%) |
|---|---|---|---|---|---|
| 0 | 2.14 | 3.42 | 3.87 | 3.14 b | 0.000 |
| 150 | 4.32 | 5.45 | 4.73 | 4.83 a | 11.275 |
| 300 | 4.83 | 5.69 | 6.50 | 5.67 a | 8.446 |
| Everage | 3.76 B | 4.85 A | 5.03 A | | |
| Efficiency OLFC (%) | 0.00 | 21.81 | 12.71 | | |
| CC (%) | 14.77 | | | | |
| LSD.05 | 0.67 | | | | |
| LSD.01 | 0.91 | | | | |

**Remarks:** Numbers followed by the same uppercase letters in the same rows and lowercase letters in the same columns are not considered statistically significant according to the LSD (Least Significant Difference) at a 5% level.

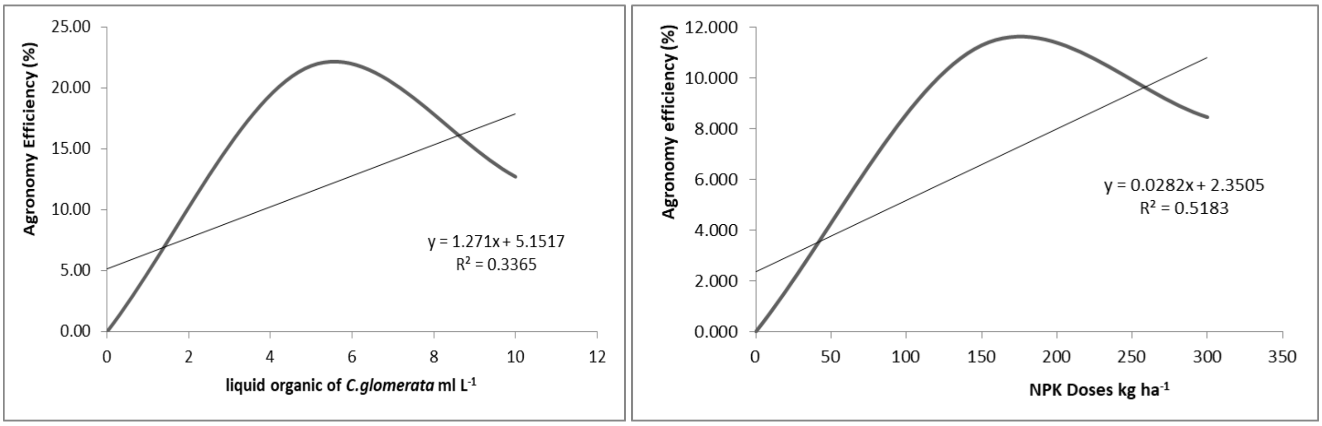


**Figure 1**. The relationship between the application of OLFC to fertilization efficiency from the agronomical characteristics of the application of liquid fertilizer or NPK Phonska fertilizer.

Plants that grow taller will produce more leaves, affecting the total leaf area and increasing maize plants' LAI, NAR, and RGR. A higher LAI indicates that the resulting plant assimilation will be higher, further influencing production or yield. According to Yamaguchi et al. (2023), an LAI greater than 3 indicates that the leaves absorb 95% of sunlight. However, if the LAI exceeds 5, absorption decreases due to leaf overlapping or shading. This occurs when plants are densely packed due to narrow spacing or rapid leaf development, causing overshadowing. LAI values are also significantly determined by leaf size and exposure to sunlight. The highest dose of Phonska NPK received by the leaves increased leaf size, resulting in a wider LAI of 3.22. This optimized photosynthetic activity compared to plants receiving 0–150 kg ha$^{-1}$ of Phonska NPK fertilizer, with an LAI ranging from 1.31 to 2.50. Compared to other studies, Asfaw (2022) tested chicken manure up to a maximum dose of 10 tons ha$^{-1}$ for sweet maize, resulting in an LAI of 2.71.

By applying cow manure, Wang et al. (2022) achieved a maize LAI of 2.25. Cheng et al. (2022) and Berdjour et al. (2020) obtained maize LAI values of 2.45 and 0.41, respectively, using 7.5 tons ha$^{-1}$ of manure and a spacing of 25 x 40 cm, along with basic fertilizers. These values are still lower than the results of this study. However, when maize plants were arranged in 75 x 25 x 25 cm and given 300 kg ha$^{-1}$ N, the LAI reached 3.08 (Kafle et al., 2022).

However, when applying 300 kg ha$^{-1}$ Phonska NPK fertilizer, increasing the OLFC dose linearly increases the NAR of maize, with a correlation value (R) = 1. Comparing this with previous research conducted by Koynarska et al. (2023) on maize, it was observed that as maize matures, the NAR of plants also increases. Marchesini et al. (2018) reported that the NAR of maize in the age range of 21-28 DAP was approximately 20-40 mg cm$^{-2}$ day$^{-1}$, while at 28-35 dap, it increased to around 40-50 mg cm$^{-2}$ day$^{-1}$. Similarly, reports from Wang et al. (2022) indicated that the NAR of maize ranged from 1.80-2.19 mg cm$^{-2}$ day$^{-1}$ at 14-28 DAP, and at 28-42 DAP, it was obtained at 0.9-1.2 mg cm$^{-2}$ day$^{-1}$. The NAR is closely related to photosynthetic activity. A higher NAR corresponds to increased photosynthate production. Elevated photosynthate levels indicate well-functioning photosynthetic activities, commencing with the fixation of $CO_2$ in maize and its conversion into glucose, essential for optimal growth and the development of maize seeds.

The RGR value indicates how rapidly a plant has grown over a specific period and how it has grown relative to its current size. A higher RGR value signifies a faster growth rate for the organism. However, it is essential to note that RGR solely provides information on growth velocity concerning the plant's initial size and does not offer insights into the quality of growth or the health of the plant. As Ravi et al. (2020) demonstrated, the RGR values ranging from 98 to 102 mg g$^{-1}$ day$^{-1}$ were associated with maize yields reaching 8-9.23 tons ha$^{-1}$. In comparison, when examining the RGR values presented in Table 3, it is evident that only around 30% of the RGR achievement from the aforementioned report was attained.

Plants that absorb large amounts of nutrients will inevitably need additional nutrients to maintain their nutritional balance. Plants that receive optimal amounts of nutrients will experience a faster increase in the RGR than those that do not receive optimal nutrition. According to Sepat et al. (2023), one of the commonly used analytical tools for characterizing plant growth is the RGR, and its value can vary for each maize plant under different conditions. This variation has been reported by Alves et al. (2022) showing that purple grain maize, under salinity conditions, exhibits an RGR ranging from 30 to 80 mg week$^{-1}$ or 4.2 mg to 11.42 mg day$^{-1}$. Additionally, Li et al. (2020) reported that the RGR of maize plants ranges from 10 to 50 g m$^{-2}$. Another study by Dietrich et al. (2020) demonstrated that the RGR of maize plants can reach 180 mg g$^{-1}$ day$^{-1}$.

In this case, OLFC cannot completely replace the role of Phonska fertilizer in plants. However, OLFC can enhance plant growth even more when plants receive their basic nutrient requirements from Phonska fertilizer. Abagyeh et al. (2016) also explained that inorganic fertilizers are crucial to meet the basic nutritional requirements of plants. However, incorporating organic fertilizers and soil improvement materials can enhance the efficiency of these inorganic fertilizers. Previous studies (Gutiérrez-Gamboa, Garde-Cerdán, Gonzalo-Diago, et al., 2017; Gutiérrez-Gamboa, Garde-Cerdán, Portu, et al., 2017) demonstrated that OLFC can increase growth and yield when accompanied by basic NPK fertilizer.

Made et al. (2022) demonstrated that applying a dose of 300 kg ha$^{-1}$ NPK Phonska could increase the growth and yield of the highest sweet maize. The evaluation was based on the fresh weight of sweet maize. Shojaei et al. (2024) reported that the yield of maize can reach 7.7 tons ha$^{-1}$. The average production of hybrid maize varieties was 8.1 tons ha$^{-1}$. Several parameters influence the high yield of maize. Before this treatment, there was a positive impact on LAI, the RGR, the NAR, and the weight of 100 maize seeds.

## 5. CONCLUSION

The highest maize yield recorded was 4.83 tons per hectare, achieved by applying 150 NPK Phonska kg per hectare, supported by a fertilization efficiency of 11.28%. Providing 5 ml per liter of OLFC every two weeks to maize plants resulted in the highest AE, reaching 21.81%.

## Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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