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Research Artikel

The role of liquid inorganic fertilizer (11% N - 9% CaO) in increasing growth, production, and N, P, K fertilizer efficiency in sweet corn

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ABSTRACT

Fertilization determines sweet corn growth and production and should be efficient to reduce costs and pollution. This study aimed to find out the role of liquid inorganic fertilizer (LIF) (11% N and 9% Ca) in growth, production, and the efficiency of N, P, and K fertilization. The experiment was conducted at Babakan Garden, Dramaga, Bogor. There are 6 fertilizer combinations: control without fertilization (P0), Standard NPK (P1), Standard NPK+2 L ha-1 LIF (P2), Standard NPK+4 L ha-1 LIF (P3), Standard NPK+6 L ha-1 LIF (P4), and 0.75 Standard NPK+4 L ha-1 LIF (P5). The Standard NPK fertilizer is 300 kg of Urea, 200 kg of SP36, and 200 kg of KCl per hectare. Sweet corn with the NPK plus LIF combinations produced plant height, stem diameter, and leaf number that were not different from Standard NPK and were higher than the control. LIF increased relative agronomic effectiveness (RAE) and the agronomic efficiency (AEi) values. RAE of Standard NPK with LIF increased by 119.77–140.32% compared to Standard NPK. The agronomic efficiency (AEi) of N fertilizer with LIF increased from 35.7 to 42.8–64.3, P fertilizer increased from 68.5 to 82.0–123.2, and K fertilizer increased from 41.1 to 49.2–73.9 kg of cobs per kg of fertilizer. The AEi of NPK fertilizer increased by 19.8–80.0%. The highest NPK fertilization efficiency (80%) was in P5. The findings or novelty of this research is that the application of 4L ha-1 of LIF saved 25% of NPK.

Keywords: *agronomic efficiency, calcium nutrition, fertilizer combination, foliar fertilizers, relative agronomic effectiveness*

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INTRODUCTION

The increasing global demand for food is pushing agricultural production systems to optimize the efficiency of agronomic inputs to maintain crop productivity sustainably. Sweet corn (*Zea mays* L. saccharata), as one of the high-value horticultural commodities, has substantial nutrient requirements during both vegetative and generative growth phases, making fertilization a key factor for successful production (Siram et al. 2025). Various studies show that fertilization efficiency, especially nitrogen, plays an important role in boosting yields while reducing nutrient losses to the environment (Lee and Ku 2025; Govindasamy et al. 2023). Therefore, innovations in fertilizer forms and application methods are crucial for improving nutrient use efficiency and supporting a more sustainable corn production system (Wang et al. 2025).

The growth and productivity of corn are greatly influenced by the availability of macronutrients, including nitrogen (N) and calcium (Ca), which play important physiological roles in plant metabolism. Nitrogen is a key component in the formation of chlorophyll, enzymes, and structural proteins that determine the plant's photosynthetic caLIFity and biomass production (Shivashankar et al. 2025; Zhang et al. 2021). Calcium is

important for cell wall stability, membrane permeability regulation, and cellular signaling activities related to root growth and plant resistance to abiotic stress (Kabir and Diaz-Perez 2025; Thor 2019). The research in Indonesia has been conducted. The right combination of nitrogen and calcium availability has been shown to boost photosynthetic efficiency, vegetative growth, and corn yield quality (Ren et al. 2026; Liang et al. 2025). The number of studies on the combination of nitrogen and calcium in sweet corn in Indonesia is still very limited. Most studies only look at nitrogen + potassium (Aryani et al., 2023), or the use of compound fertilizers like NPK+Mg (Nindita et al., 2024), while explicit research on the interaction between nitrogen and calcium (for example, $Ca(NO_3)_2$) (Rosyad, 2024) has only appeared in recent years. This shows a research gap that could be explored further.

Besides the amount of nutrients applied, the type of fertilizer and how it's applied also play a big role in how efficiently plants absorb nutrients. Liquid inorganic fertilizer (LIF) has an advantage when it comes to high solubility and faster nutrient availability compared to solid fertilizers, so it can boost plant response during critical growth phases (Anugroho et al. 2025). Applying liquid fertilizer, whether through leaves or soil, allows for more efficient nutrient uptake and reduces losses due to fixation or leaching in the soil (Rajasekar et al. 2017). In this context, LIF containing nitrogen and calcium (11% N - 9% CaO) has the potential to increase fertilization efficiency by providing quickly available nutrients while also supporting the plant's physiological functions at the same time.

The effectiveness of nitrogen and calcium-based LIF under field conditions still needs a comprehensive evaluation, especially in sweet corn farming systems in tropical environments. Variations in soil conditions, climate, and the dynamics of nutrient interactions in the soil can affect the availability and uptake of nutrients like N, P, and K by plants (Djalovic et al. 2024). This study aims to understand the role of LIF (11% N-9% CaO) in improving the growth and yield of sweet corn, as well as the efficiency of N, P, and K fertilization.

MATERIALS AND METHODS

The field experiment was carried out from April to July 2026 at the Babakan experimental farm, Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University (IPB University). The materials used in this research were corn seed, 4 L LIF (11% N - 9% CaO), 300 kg of Urea, 200 kg of SP-36, 200 kg of KCL per hectare, and pesticides. The equipment used was hoes, digging tools, sprayers, and sample plant stakes. The data were processed on a computer using the SAS statistical analysis program.

There were 6 combinations of fertilizer treatments, namely control without fertilization (P0), Standard NPK (P1), Standard NPK + 2 L ha-1 LIF (P2), Standard NPK + 4 L ha-1 LIF (P3), Standard NPK + 6 L ha-1 LIF (P4), and 0.75 Standard NPK + 4 L ha-1 LIF (P5) designed in a Randomized Complete Block Design with four replications. Standard NPK fertilizer consists of 300 kg Urea (46% N), 200 kg SP36 (36% P2O5), and 200 kg KCl (60% K2O) per hectare (Saefudin et al., 2024; Kinata et al., 2022; Ariefiyanti & Diah, 2008). There were 24 experimental plots. Each experimental plot measured 5 m x 5 m (25 m^2). Sweet corn was planted at 75 cm x 25 cm sLIFing, with each plot containing 6 rows and 20 plants per row. Seeds were planted 2 per hole and thinned to 1 plant per hole at 4 weeks after planting (WAP). At planting, ½ dose of Urea and KCl is applied, and the full dose of SP36 is applied in furrows. The remaining fertilizer, half a dose of Urea and KCl, was given to the plants at 4 MST. LIF was dissolved in water at concentrations of 2.5, 5.0, and 7.5 mL L-1 (for doses of 2 L ha-1, 4 L ha-1, and 6 L ha-1) with a spray volume of 750 mL per experimental plot or 300 L per hectare, and sprayed twice on the leaf surface of the plants at 4 WAP and 6 WAP.

The observed growth variables were plant height, stem diameter, and the number of leaves at 4, 6, and 8 WAP. Production components, including biomass weight, cobs with and without husks, cob length and diameter, and husked cob weight per plot, were observed at harvest, which was at 75 days after planting. Productivity was calculated by

converting the husked cob weight per plot to per hectare. Growth and production component data were statistically analyzed using analysis of variance and further tested with Duncan's Multiple Range Test at a 95% confidence interval.

The relative agronomic effectiveness (RAE) and agronomic efficiency (AEi) of N, P, and K fertilization are calculated based on productivity values. RAE is calculated by Mackay et al. (1984) with the formula: RAE = ((Yi-Yo)/(Ys-Yo)) x 100%; Yi = productivity with the Standard NPK+LIF fertilizer treatment, Yo = productivity in the control treatment, Ys = productivity with the Standard NPK fertilizer treatment. The AE of N, P, and K fertilization is calculated using the formula from Liu et al. (2011) as follows:

1. Nitrogen (N) fertilization efficiency (EAi) = (Yn – Yo)/Fn; Yn = productivity with N fertilization (kg N ha-1), Yo = productivity in the control treatment (kg ha-1), Fn = N fertilization dose (kg N ha-1).
2. Phosphor (P) fertilization efficiency (EAi) = (Yp – Yo)/Fp); Yp = productivity with P fertilization (kg P2O5 ha-1), Yo = productivity in the control treatment (kg ha-1), Fn = P fertilizer dose (kg P2O5 ha-1).
3. Potassium (K) fertilization efficiency (EAi) = (Yk – Yo)/Fk); Yk = productivity with K fertilization (kg K2O ha-1), Yo = productivity in the control treatment (kg ha-1), Fk = dose of K fertilization (kg K2O ha-1).

RESULTS AND DISCUSSION

The fertilizer quality analysis results from Sucofindo Ltd. on February 6, 2026, show that the LIF in this study contains 11.42% total nitrogen, 9.56% CaO, and some heavy metal contents below the maximum standards, namely Cadmium (Cd) < 0.002 ppm, Lead (Pb) < 0.24 ppm, Arsenic (As) < 0.0003 ppm, and Mercury (Hg) < 0.0002, making it suitable for agricultural fertilizer. The land used, based on soil analysis results from the Testing Laboratory of the Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University (IPB University) on April 27, 2026, is acidic (pH = 6.00), contains low organic carbon (1.52%), medium total N (0.22%), very high available P (78.1 ppm P2O5), high exchangeable K (0.73 cmol K kg-1), and medium CEC (16.4 cmol kg-1). With medium N content, the land is suitable for testing LIF, which contains nitrogen and calcium.

The combination of Standard NPK fertilizer + LIF doses had a significant effect on plant height, stem diameter, and the number of leaves at the end of the vegetative phase at 8 WAP, as well as various yield components including biomass weight, cob weight with husk and without husk, cob length and diameter, weight of husked cobs per plot, and sweet corn productivity per hectare. Different combinations of Standard NPK + LIF doses resulted in noticeably taller plants, thicker stems, and more leaves compared to the unfertilized control (Table 1).

Table 1. Plant height, stem diameter, and number of leaves under various combinations of N, P, K and LIF (11% N - 9% CaO) treatments at 8 WAP.

Treatment	Growth variable		
	Plant height (cm)	Stem diameter (mm)	Leaves number (leaves)
Control	152.17c	16.3b	11.4c
Standard NPK	204.39a	22.1a	13.5ab
1.0 Standard NPK + 2 L ha-1 LIF	189.34b	20.4a	13.3b
1.0 Standard NPK + 4 L ha-1 LIF	197.44ab	21.2a	14.1a
1.0 Standard NPK + 6 L ha-1 LIF	205.59a	22.4a	14.1ab
0.75 Standard NPK + 2 L ha-1 LIF	201.71a	22.3a	13.5ab

Note: numbers followed by the same letter in the same column indicate no significant difference according to the 5% DMRT test.

There was no significant difference between standard NPK fertilizer and most of the combinations of standard NPK + LIF. This means that as a supplementary fertilizer, LIF (11% N + 9% Ca) sprayed on the leaves does not boost the vegetative growth of sweet

corn. This is because the additional N from the nitrogen content in LIF spray is only about 0.22 kg to 0.66 kg (for doses of 2 to 6 L) per hectare. This contribution is very small compared to the N content in various standard NPK doses, which ranges from 101.25 to 135.00 kg per hectare. The study by Solihin et al. (2025) showed almost the same results as this research, that the height and leaf number of sweet corn between standard NPK (with 300 kg N ha-1) and standard NPK + ½ dose of LIF were not significantly different, with an average plant height around 198 cm and 12 leaves.

In terms of yield components, the standard NPK fertilizer treatment and the combination of NPK+LIF doses produced higher fresh cob weight, cob weight with husk (CWiH), and cob weight without husk (CWtH), cob length (CL), and cob diameter (CD) (Table 2) compared to the control treatment. Among the NPK fertilizer treatments with and without LIF, there was no significant difference in sweet corn yield components, namely ear weight per plant, ear length, and ear diameter (Table 2).

Table 2. Weight, length, and cob diameter under the combined treatment of NPK and LIF fertilizer (11% N - 9% CaO)

Treatment	CWiH (kg plant-1)	CWtH (kg tan-1)	CL (cm)	CD (cm)
Control	0.111b	0.080b	14.9b	34.9
Standard NPK	0.200a	0.147ab	17.5a	41.2
1.0 Standard NPK + 2 L ha-1 LIF	0.222a	0.166a	18.3a	44.4
1.0 Standard NPK + 4 L ha-1 LIF	0.245a	0.183a	18.7a	44.1
1.0 Standard NPK + 6 L ha-1 LIF	0.244a	0.183a	18.8a	43.2
0.75 Standard NPK + 2 L ha-1 LIF	0.239a	0.179a	18.7a	43.6

Note: numbers in the same column followed by the same letter are not significantly different according to the 5% DMRT test. CWiH: cob weight with husk, CWtH: cob weight without husk, CL: cob length, CD: cob diameter

Plants that received standard NPK fertilizer with LIF were not significantly different from standard NPK without LIF in production per plot and productivity (Table 3). Nevertheless, based on sweet corn productivity, Table 4 shows increasing relative agronomic effectiveness (EAR) and agronomic efficiency (EAi) of N, P, and K fertilization in plants fertilized with standard NPK plus LIF (11% N - 9% CaO). This supports He et al. (2023)'s statement that calcium (Ca), that also applied by foliar spray, plays an important role in starch synthesis in the seeds. Both variables (EAR and EAi) show that using LIF (11% N - 9% CaO) improves the efficiency of N, P, and K fertilizer use.

Table 3. Production per plot and productivity of sweet corn with the combination treatment of NPK and LIF fertilizers (11% N - 9% CaO).

Treatment	Cob weight per plot (kg)	Productiviy (ton ha-1)
Control	9.143b	5.805b
Standard NPK	16.910a	10.735a
1.0 Standard NPK + 2 L ha-1 LIF	18.445a	11.710a
1.0 Standard NPK + 4 L ha-1 LIF	20.043a	12.723a
1.0 Standard NPK + 6 L ha-1 LIF	19.967a	12.678a
0.75 Standard NPK + 2 L ha-1 LIF	19.623a	12.460a

Note: numbers in the same column followed by the same letter are not significantly different according to the 5% DMRT test. CWiH: cob weight with husk, CWtH: cob weight without husk, CL: cob length, CD: cob diameter.

The increase in production per plot and productivity is suspected to be related to the presence of calcium (Ca) nutrients in LIF (11% N - 9% CaO). He et al. (2024) reported that calcium (Ca) and magnesium (Mg) are essential nutrients that play a major role in corn growth and development, as well as in the synthesis of starch content in the kernels. Calcium is important during corn kernel filling to maintain cell wall strength, support nutrient transport, and ensure strong stems to prevent lodging, which ultimately helps produce higher yield and kernel quality. Weng et al. (2022) stated that calcium regulates growth and nutrient absorption in poplar seedlings. Ca2+ signaling regulates plant

mineral nutrition (Wang et al., 2023). Mulyana (2025) reported that using calcium nitrate (15.5% N, 26% CaO, 0.3% B) to replace nitrogen in the Standard NPK doses (135 kg N, 72 kg P2O5, and 200 kg KCl) and adding CaO resulted in a relative agronomic effectiveness (EAR) of 151%. This means that there was an increase in cobs with husks compared to the unfertilized control, in sweet corn that received additional calcium fertilizer.

Table 4. EAR and EAi values of N, P, and K fertilizers in NPK and LIF (11% N - 9% CaO) fertilizer combination treatments.

Treatment	EAR (%)	EAi of N Fertlizer (kg kgN^{-1})	EAi of P Fertlizer (kg kgP^{-1})	EAi of K Fertlizer (kg kgK^{-1})	EAi Increasing of N, P, K Fertilizer (%)
Control	-	-	-	-	-
Standard NPK	100.00	35.7	68.5	41.1	-
1.0 Standard NPK + 2 L ha^{-1} LIF	119.77	42.8	82.0	49.2	19.8
1.0 Standard NPK + 4 L ha^{-1} LIF	140.32	50.1	96.1	57.7	40.3
1.0 Standard NPK + 6 L ha^{-1} LIF	139.37	49.8	95.5	57.3	39.4
0.75 Standard NPK + 2 L ha^{-1} LIF	134.95	64.3	123.2	73.9	80.0

Based on EAR values, sweet corn productivity with LIF increased by 119.77 – 140.32% compared to standard NPK. Nitrogen fertilizer agronomic efficiency (AEi) with the addition of LIF increased to 42.8 – 64.3 from 35.7 kg of cobs per kg of N fertilizer in standard NPK without LIF. For phosphorus fertilizer, there was an increase to 82.0 – 123.2 from 68.5 kg of cobs per kg of P fertilizer, and for potassium fertilizer, an increase to 49.2 – 73.9 from 41.1 kg of cobs per kg of K fertilizer. The increase in N, P, and K fertilizer efficiency ranged from 19.8 – 80.0%. The highest N, P, K fertilization efficiency (80%) was in the treatment with 0.75 of the standard NPK dose with LIF. This means LIF can improve agronomic efficiency and save up to 25% of NPK use without any significant difference in yield compared to the full 1.0 dose of standard NPK.

CONCLUSIONS

The combination of NPK and LIF resulted in plant height, stem diameter, and leaf number that were not different from Standard NPK but were higher than the control. LIF increased the relative agronomic effectiveness (ERA) and agronomic efficiency (EAi) values. The ERA of Standard NPK with LIF increased by 119.77 – 140.32%. The agronomic efficiency (EAi) of N fertilizer with LIF increased by 42.8 – 64.3 from 35.7; the EAi of P fertilizer increased by 82.0 – 123.2 from 68.5, and the EAi of K fertilizer increased by 49.2 – 73.9 from 41.1 kg ear per kg of fertilizer. The EAi values of NPK fertilizer increased by 19.8 – 80.0%. The highest NPK fertilization efficiency (80%) was in the treatment of 0.75 Standard NPK dose + 2 L ha^{-1} LIF, which saved 25% of NPK in the research condition, with total soil N moderate and available P and K being high.

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