

LIMITING FACTORS OF AGRONOMIC CHARACTERISTICS FOR MAIZE THROUGH NUTRIENT OMISSION TECHNIQUES

Elli Afrida¹, Koko Tampubolon²

¹ Program Study of Agrotechnology, Faculty of Agriculture, Universitas Alwashliyah (UNIVA), Medan 20147, Sumatera Utara, Indonesia

² Program Study of Agrotechnology, Faculty of Agriculture, Universitas Sumatera Utara, Medan 20155, Sumatera Utara, Indonesia

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Abstract

The deficiency of primary macronutrients can inhibit the vegetative growth of the plants. The study aimed to obtain the influence of nutrient omission techniques fertilization (NOTF) on the agronomic characteristics, nutrient uptake and to determine the growth limiting factors for maize. This research was located on the farmer field in Padang Bulan, Medan Baru, North Sumatra, Indonesia, from December 2020 to March 2021. This research was applied the Randomized Block Design within the single factor through NOTF that has been converted (urea: superphosphate: KCl = 0.15: 0.10: 0.025 g kg⁻¹). The treatment using F0 = control; F1 = N + P + K; F2 = P + K; F3 = N + K; F4 = N + P within three replications. The parameters were processed using ANOVA and continued by a Duncan Multiple Range Test (DMRT) at $P < 0.05$. The F1–F4 treatments significantly increased plant height, number of leaves, leaf area, fresh weight of root and shoot, and dry weight of root and shoot for maize. It was found in the highest plant height, the number of leaves, and the dry weight of root at the N + P fertilization. However, the N + P + K fertilization increased leaf area, fresh weight, and dry weight of shoot. It showed the highest concentration and uptake nutrient of total-N, total-P, and total-K. The novelty of this study found the limiting factor that inhibited the maize growth was the non-fertilization of nitrogen.

Keywords: deficiency, fertilization, nitrogen, phosphorus, plant nutrition, potassium

INTRODUCTION

Maize plant (*Zea mays* L.) is ranked third after wheat and rice in the yield of cereal crops in the world (Cooper *et al.*, 2014). Center for Agriculture Data and Information Systems (2020) noted that Indonesia is the 8th country with the largest maize production globally from 2014 to 2018 with an average of 24,275,445 tons, but maize exports have fluctuated. In 2019, maize exports decreased sharply to 53,566 tons from 341,523 tons or a decrease of 6.38-folds compared to 2018. The decrease in maize exports could be due to the resulting low productivity by land area, and etc. The maize productivity must continue to be increased to support national food self-sufficiency. Increasing maize productivity is inseparable from balanced fertilization techniques and several other technical efforts. Unbalanced

fertilization will be cause stunted plant growth and was characterized by symptoms of nutrient deficiency.

Valentinuz and Tollenaar (2006) stated that nitrogen is the primary nutrient limiting the growth of plants if it is untreated in sufficient quantities. Rafiq *et al.* (2010) noted that nitrogen nutrients play an essential role in increasing protein content due to the presence of amino groups, the building blocks of protein. Wayasa *et al.* (2018) reported a decrease in protein content in maize grain along with a decrease in the dose of N-fertilizer from 200 to 100 kg ha⁻¹ due to low uptake of nitrogen. However, Wang *et al.* (2014) reported that excessive use of N-fertilizers had a negative effect on plants by reducing the nitrogen use efficiency and caused significant loss of nitrate leaching (more than 50% N to the environment).

Phosphorus (P) is the second most abundant limiting nutrient in the soil after nitrogen (Balemi and Negisho, 2012). Mustonen *et al.* (2012) added that phosphorus is an essential macronutrient for plant growth and the primary constraint in crop yield due to P-deficiency. Delve *et al.* (2009) reported that the P-deficiency could reduce the nitrogen use efficiency by plants. Bukvić *et al.* (2003) also noted that the dry biomass inhibition of maize was 16.52%, along with a decrease at the dose of P-fertilizer from 0.899 to 0 g per pot.

Potassium (K) is a macronutrient that plays an important role in plant physiological processes such as uptake of nutrients and water, nutrient transport, and support the plant growth, especially in stress conditions (Zörb *et al.*, 2014). Hermans *et al.* (2006) reported that the photosynthetic disorders occurred in K-deficiency conditions due to sucrose accumulation in plant leaves. Olowoboko *et al.* (2017) also reported an increased leaf area of maize along with an increase in K-fertilizer until 90 kg ha⁻¹ by 15.49%. The K-fertilizer at 120 to 180 kg ha⁻¹ and more than 60 kg ha⁻¹ also showed higher N- and K-uptake per pot of maize than the control.

The primary macronutrient such as N, P, and K are greatly needed by maize to support its growth and yield. It was evidenced by the decrease in maize grain production by 3%; 7.7%; and 21.9%, respectively, when reducing the recommended dosage of N-fertilizer by 25%, 50%, and 100% from 300 kg ha⁻¹ (Su *et al.*, 2020). Fertilization of P₂O₅ until at a dose of 31 kg fad⁻¹ significantly increased chlorophyll content in the leaves, leaf area index, and grain production per plant for hybrid maize by 9.49%; 32.11%; and 25.43%, respectively compared to non-fertilizer of P₂O₅ (El-Shahed *et al.*, 2017). The previous studies reported that the K-nutrient plays a role in increasing biomass and yield of the plant (Amanullah *et al.*, 2015). Asghar *et al.* (2010) said that the single fertilization of N, P₂O₅, K₂O (175 + 80 + 60) shows the maximum yield of maize. Kasno and Rostaman (2013) also noted that the highest relative value of agronomic efficiency for maize was obtained by mixing combine fertilizers of NPK 15-15-15 at the dose of 300 kg ha⁻¹ with urea 250 kg ha⁻¹.

Long-term land use without balanced fertilization is thought to have decreased land productivity due to the low uptake of primary macronutrients such as N, P, and K, which can be seen from the appearance of stunted plant growth. It can also measure deficiency symptoms of primary macronutrients in plants through biological testing through the omission one test technique, which can be used as a limiting factor for plant growth. Descalsota *et al.* (1999) stated that the biological testing with the nutrient omission method using the concept of plant growth responding to the most restrictive nutrients is characterized by a decrease in plant height, the number of tillers, delay in maturity, and a change in colors such as chlorosis or necrosis. Therefore, biological testing for maize through the nutrient

omission techniques fertilization (NOTF) aims to obtain agronomic characteristics, nutrient uptake, and limiting factors through single fertilisation by single NPK sources from urea, superphosphate, and KCl fertilizers.

MATERIALS AND METHODS

Study Site and Design

The study location used a farmer's field in the Padang Bulan (3°37.760'N; 98°38.898'E; altitude 18 m above sea level), Medan Selayang Subdistrict, Medan City, North Sumatra, Indonesia, from December 2020 to March 2021. Furthermore the average humidity was 82%, temperature was 27.4 °C and the average rainfall was recorded 228.5 mm per month. The study was applied the randomized block design with a single factor, namely the NOTF using the urea by 0.30 ton ha⁻¹, Superphosphate (SP-36) of 0.20 ton ha⁻¹, and KCl was 0.05 ton ha⁻¹ (Tab. I) adopted by Sirappa and Razak (2010) that has been converted to the topsoil per kg within three replications.

I: The NOTF treatment in the initial research

Treatment	Fertilizer dose (g kg ⁻¹)		
	Urea	Superphosphate (SP-36)	KCl
F0 (Control)	0	0	0
F1 (N + P + K)	0.15	0.10	0.025
F2 (P + K)	0	0.10	0.025
F3 (N + K)	0.15	0	0.025
F4 (N + P)	0.15	0.10	0

Preparation of Growing Media

The land was cleared with an area of 5.5 m × 2.5 m. Then formed a treatment plot with a distance of 50 cm between treatments. Prepared and filled with topsoil into 5 kg of polybag. Topsoil was taken from the farmer field and incubated for two weeks. Soil samples were taken and analyzed for several chemical characteristics of topsoil with a depth 0–20 cm (Tab. II).

Application of Nutrient Omission Techniques Fertilization (NOTF)

Maize seeds were planted using the F1 Bonanza variety and planted one seed per polybag with a deep of 1 cm from the soil surface after the soil incubation period and arranged at the spacing of 75 cm × 25 cm. After seven days of planting, NOTF was carried out according to the treatment by immersion and separately between N, P, and K fertilizers. Watering and weed control was conducted by the manual until the end of the observation (8 Weeks After Planting/WAP).

II: Analysis of the initial topsoil characteristics

Topsoil Characteristics	Analysis Method	Values	Category*
H ₂ O-pH	Electrometric	5.67	Slightly acid
Organic-C (%)	Walkley & Black	1.06	Low
Total-N (%)	Kjeldahl	0.12	Low
Total-P (mg/100 g)	HCl 25%	0.62	Very Low
Total-K (mg/100 g)	HCl 25%	0.38	Very Low

Note: Category pH H₂O (slightly acid = 5.5–6.5); organic-C (low = 1–2%); total-N (low = 0.1–0.2%); total-P (very low < 15%); total-K (very low < 10%)

Source: Soil Research Institute 2009

Parameters and Data Analysis

The plant height, the number of leaves, and leaf area were determined at 2, 4, 6, and 8 WAP. Leaf area calculations using non-destructive estimation refer to the equation (1) from Gallais *et al.* (2006). The root length, shoot: root ratio, fresh weight of root and shoot, dry weight of root and shoot, and relative character percentage were determined at 8 WAP then weighed with analytical scales. Samples dried in oven at 80 °C for 48 h to obtain constant weight and weighed. Nutrients that limit the growth and biomass of maize were measured using the relative character percentage with all parameters at the end of observation adopted by Safuan (2007) using equation (2).

$$\text{Leaf area} = \text{length} \times \text{width} \times \text{constant} (c = 0.75). \quad (1)$$

Relative character =

$$= \frac{\text{The character of nutrient omission treatment}}{\text{The character of nutrient complete treatment}} \times 100\%. \quad (2)$$

Nutrient uptake =

$$= \text{nutrient concentration (N/P/K)} \times \text{total dry weight}. \quad (3)$$

Nutrients analyses were conducted in the shoot by taking the 2nd leaf sample in each replication, then composited and analyzed for total-N using

the Kjeldahl method, total-P, and total-K using the method of HCl 25% extract. The nutrient uptake was measured by equation (3). The data on the agronomic characteristics of maize were processed by ANOVA and processed with a Duncan Multiple Range Test (DMRT) at $P < 0.05 \pm$ standard error using SPSS statistics v.20 software.

RESULTS**Plant Height (cm)**

An increase in height growth of maize in the F1–F4 treatments at 2, 6, 8 WAP, except for F2 treatment at 4 WAP compared to the control (Tab. III). The highest increase in plant height growth sequentially at 8 WAP was found in the N + P, N + P + K, N + K, P + K of 61.11%; 54.13%; 34.25%; and 3.45%, respectively compared to the control.

Leaves Growth

The F1–F4 treatments significantly increased the number of leaves in maize at 4, 6, and 8 WAP but had an insignificant effect at 2 WAP and increased maize's leaf area at 2, 4, 6, and 8 WAP (Tab. IV). The number of leaves in the F1–F4 treatments and increased leaf area at 6 and 8 WAP except for F2 treatment at 2 and 4 WAP compared to the control (Tab. IV). The highest increase in the number of leaves found in the N + P + K and N + P treatments at 8 WAP by 44.44% than the control. The highest

III: Effect of NOTF on the maize height at 2, 4, 6, and 8 WAP

NOTF treatments	Plant Height (cm) \pm SE			
	2 WAP	4 WAP	6 WAP	8 WAP
F0 (control)	23.00 \pm 1.69 b	45.07 \pm 6.51 b	58.00 \pm 7.84 b	83.13 \pm 4.19 b
F1 (N + P + K)	34.17 \pm 1.23 a	82.70 \pm 2.20 a	103.33 \pm 2.59 a	128.13 \pm 5.48 a
F2 (P + K)	23.33 \pm 0.39 b	44.30 \pm 4.02 b	61.33 \pm 2.99 b	86.00 \pm 1.35 b
F3 (N + K)	23.17 \pm 1.74 b	66.87 \pm 4.56 ab	84.33 \pm 4.40 ab	111.60 \pm 2.33 a
F4 (N + P)	35.67 \pm 0.52 a	87.17 \pm 1.23 a	107.33 \pm 1.47 a	133.93 \pm 1.49 a
CV (%)	13.36	17.96	20.24	11.55

Note: means followed by a different letter in the same column explains significantly differently with the DMRT at $P < 0.05 \pm$ standard error (SE). WAP = Week After Planting.

IV: Effect of NOTF on the area and number of leaves for maize

NOTF Treatments	Week After Planting (WAP)			
	2	4	6	8
Leaf Area (cm²) ± SE				
F0 (control)	24.19 ± 2.34 b	106.78 ± 20.92 b	153.64 ± 31.70 b	248.15 ± 26.63 b
F1 (N + P + K)	39.00 ± 1.40 ab	362.28 ± 5.93 a	464.62 ± 23.92 a	580.10 ± 19.13 a
F2 (P + K)	23.94 ± 1.30 b	106.69 ± 8.65 b	155.67 ± 2.81 b	256.27 ± 18.81 b
F3 (N + K)	24.75 ± 2.32 b	152.62 ± 19.14 b	236.80 ± 27.46 b	356.48 ± 19.79 b
F4 (N + P)	49.75 ± 3.46 a	276.56 ± 17.78 a	411.78 ± 8.63 a	510.25 ± 20.25 a
CV (%)	25.62	25.84	26.39	19.39
Number of Leaves ± SE				
F0 (control)	0.15 ± 3.67 ns	5.00 ± 0.45c	6.67 ± 0.39 c	9.00 ± 0.45 b
F1 (N + P + K)	4.33 ± 0.15 ns	8.00 ± 0.26 a	11.00 ± 0.00 a	13.00 ± 0.26 a
F2 (P + K)	4.33 ± 0.15 ns	5.67 ± 0.15 bc	8.33 ± 0.15 b	10.00 ± 0.26 b
F3 (N + K)	4.00 ± 0.26 ns	7.00 ± 0.00 ab	10.00 ± 0.00 a	12.33 ± 0.15 a
F4 (N + P)	5.00 ± 0.00 ns	8.00 ± 0.00 a	11.00 ± 0.00 a	13.00 ± 0.00 a
CV (%)	12.47	10.32	8.56	9.01

Note: means followed by a different letter in the same column explains significantly differently with DMRT at the level of 5% ± standard error (SE). ns= not significant. WAP= Week After Planting.

increase in leaf area growth in maize was found in the N + P + K treatment at 8 WAP by 133.77% compared to the control.

Root Length (cm)

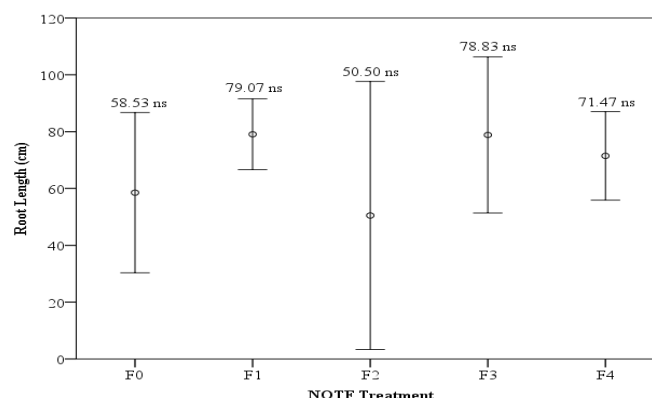
Based on the ANOVA, the NOTF had an insignificant effect on the root length growth of maize (Fig. 1). The root length growth of maize in the F1, F3, and F4 treatments was higher by 35.09; 34.68; and 22.11%, respectively, compared to the control at 8 WAP.

Fresh and Dry Weight of Roots and Shoots (g)

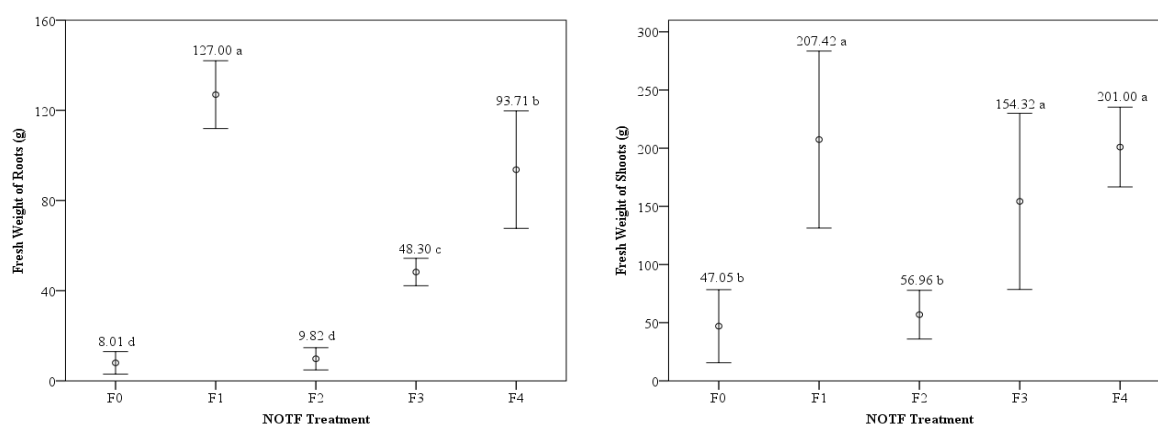
Based on the ANOVA, the NOTF significantly increased the fresh weight of roots and shoots for

maize (Fig. 2). An increase in the fresh weight of roots and shoots for maize in the NOTF treatment (F1–F4) compared to the control. The highest increase in fresh weight of roots and shoots for maize was found in the N + P + K fertilizers by 15.86 and 4.41-folds, respectively, compared to the control.

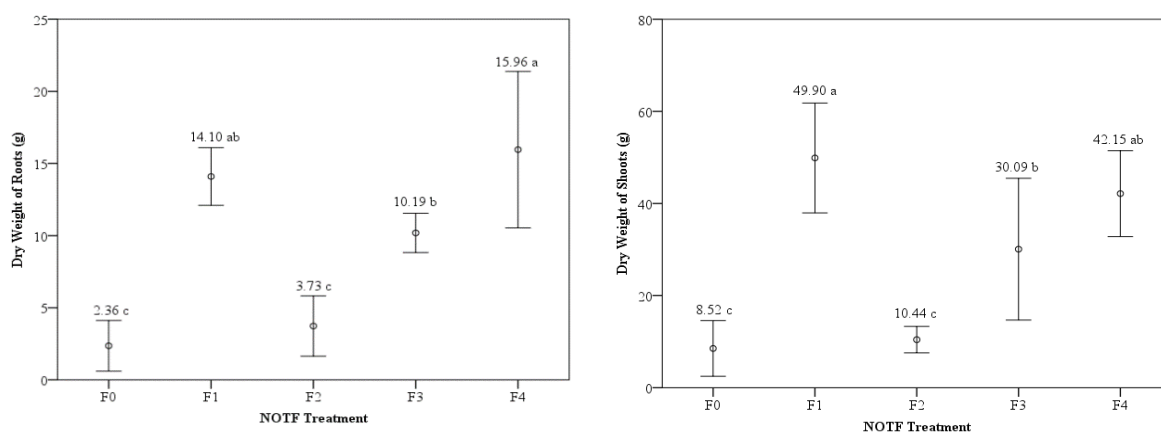
The NOTF significantly increased the dry weight of roots and shoots for maize (Fig. 3). An increase in the dry weight of roots and shoots for maize in the NOTF treatment (F1–F4) compared to the control. The highest growth in the dry weight of roots and shoots for maize was found in the N + P and N + P + K fertilizers of 6.76 and 5.86-folds, respectively, compared to the control.



1: The NOTF effect on the root length of maize (CV = 36.62%). ns = not significantly different with DMRT at the level of 5%. The vertical line indicated the standard error. NOTF treatments (F0 = control; F1 = N + P + K; F2 = P + K; F3 = N + K; F4 = N + P).



2: The NOTF affects the fresh weight of roots ($CV = 22.75\%$) and shoots ($CV = 31.97\%$) of maize. Means followed by different letters explained that significantly with DMRT at the level of 5%. The vertical line indicated the standard error. NOTF treatments (F0 = control; F1 = N + P + K; F2 = P + K; F3 = N + K; F4 = N + P).



3: The NOTF affects the dry weight of roots ($CV = 29.97\%$) and shoots ($CV = 30.65\%$) of maize. Means followed by different letters explained that significantly with DMRT at the level of 5%. The vertical line indicated the standard error. NOTF treatments (F0 = control; F1 = N + P + K; F2 = P + K; F3 = N + K; F4 = N + P).

Shoot/Root Ratio (S/R)

Based on the ANOVA, the NOTF had an insignificant effect on the S/R ratio of maize (Fig. 4). There was a decrease in the S/R ratio of maize in the NOTF treatment (F1–F4) compared to the control. The highest decrease in the S/R ratio of maize was found in the N + P fertilization by 27.08% compared to the control.

Relative Agronomic Percentage

Relative agronomic percentage based on the plant height, the number of leaves, leaf area, root length, fresh weight of roots and shoots, dry weight of roots and shoots, and maize's shoots/roots ratio on the NOTF treatment could be presented in Fig. 5. The percentage of the highest limiting factor from NOTF treatment for maize in sequence in the non-fertilization by 6.31–105.89%; P + K of 7.73–87.01%; N + K of 38.03–99.70%; and N + P of 73.78–113.22% compared to the N + P + K fertilization. Among the fertilization treatments, the highest limiting factor percentage on the agronomic character of

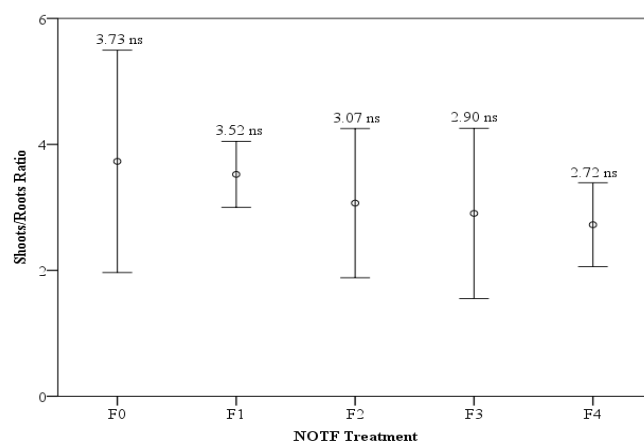
maize was found in the P + K fertilization or non-fertilization of nitrogen.

Visual performance of maize on NOTF treatment at 8 WAP could be seen in Fig. 6. The growth of plant height for maize in the N + P and N + K fertilizers were not significantly different visually from the N + P + K fertilization (there was no difference notation in Tab. III), but the leaf area of N + P and N + P + K fertilizers significantly different from N + K (Tab. IV). Fertilization P + K (non-fertilizer of nitrogen) showed stunted growth and was not significantly different from the control.

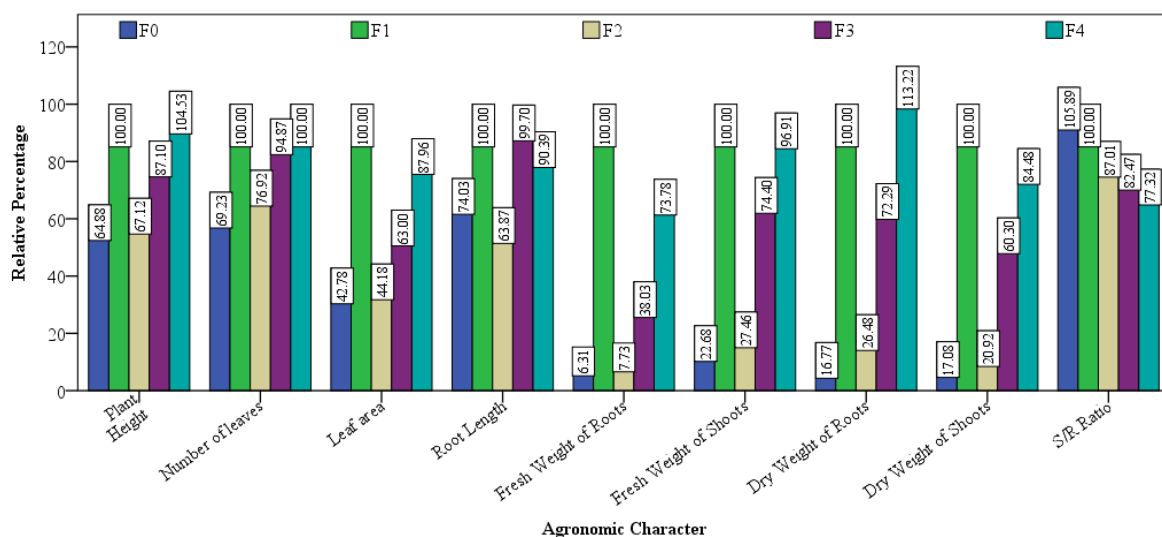
Concentration and Uptake of Nutrient

The concentration and uptake of nitrogen in the NOTF treatment ranged by 0.19 to 0.37% and 2.07 to 23.68 mg per plant. The phosphorus ranged from 0.71 to 1.02% and 7.73 to 65.27 mg per plant. Likewise, the potassium were 0.53 to 1.62% and 7.19 to 78.71 mg per plant (Tab. V).

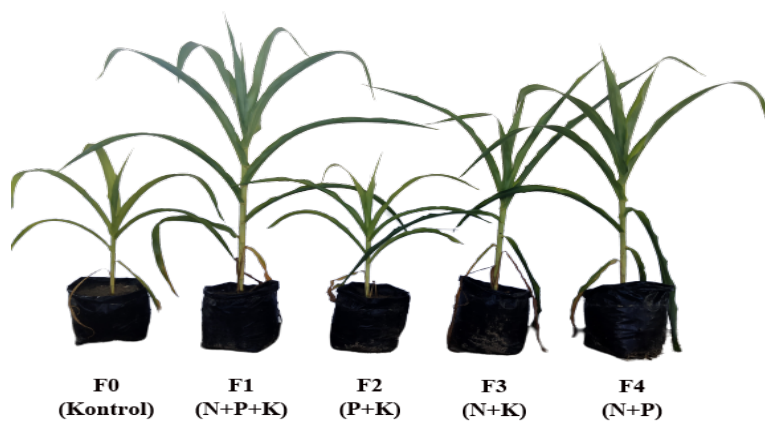
An increase in concentration and nutrient uptake of N, P, K in the NOTF treatment (F1–F4) compared to the control. Fertilization of N + P + K



4: The NOTF effect on the S/R ratio of maize (CV = 32.50%). ns = not significantly different with DMRT at the level of 5%. The vertical line indicated the standard error. NOTF treatments (F0 = control; F1 = N + P + K; F2 = P + K; F3 = N + K; F4 = N + P).



5: Relative agronomic percentage of maize in NOTF treatment at 8 WAP



6: The visual performance of the growth of maize in the NOTF treatment at 8 WAP

V: Analysis of concentration and nutrient uptake of N, P, K in leaf tissue of maize at 8 WAP

NOTF Treatments	Nutrient Concentration (%)			Nutrient Uptake (mg/plant)		
	Total-N	Total-P	Total-K	Total-N	Total-P	Total-K
F0 (control)	0.19	0.71	0.66	2.07	7.73	7.19
F1 (N + P + K)	0.37	1.02	1.23	23.68	65.27	78.71
F2 (P + K)	0.18	0.93	0.87	2.55	13.18	12.33
F3 (N + K)	0.30	0.78	1.16	12.08	31.42	46.72
F4 (N + P)	0.32	0.88	0.69	18.60	51.14	40.10

on maize showed that the highest concentration of total-N, total-P, and total-K were 94.74%; 43.66%; and 86.36%, respectively, and the highest uptake of total-N, total-P, and total-K was 11.44; 8.44; and 10.95-folds, respectively compared to the control.

DISCUSSION

The results showed that the NOTF fertilization significantly increased plant height, leaf area, number of leaves, fresh weight of roots and shoots, dry weight of roots and shoots for maize until the age of 8 WAP, but it had an insignificant effect on root length and shoot/root ratio. The N + P + K fertilization on maize showed the highest concentration and uptake of total-N, total-P, and total-K compared to the P + K, N + K, and N + P fertilization.

The highest increase in plant height, number of leaves, and dry weight of root were found in the N+P fertilization by 61.11%; 44.44%; and 6.76-folds, respectively, compared to the control. The higher concentration and uptake of nutrients for total-N in the N + P fertilization were 1.68 and 8.99-folds, respectively. The higher for total-P was 1.24 and 6.62-folds, respectively compared to the control (Tab. V) that it can affect the photosynthesis process and support the vegetative growth of maize such as the number of leaves, plant height, and dry weight of roots for as seen from the relative agronomic percentage greater than 100% (Fig. 5). The results are similar to Ma and Biswas (2016) that the application of N fertilizers could increase the rate of photosynthesis (carbon assimilation per leaf area) and the nitrogen-use efficiency (carbon production). Fosu-Mensah and Mensah (2016) reported that the N and P fertilization significantly increased grain production, total biomass, and N-uptake in seed maize. Biswas and Ma (2016) added that the highest chlorophyll content (a, b, total) in maize was found in the nitrogen fertilization at the dose of 150 and 200 kg ha⁻¹. Mohammed *et al.* (2015) reported that the combined fertilizers of N + P (64 + 20 kg ha⁻¹) significantly increased the highest of maize height by 178.24 cm compared to the single fertilizers of N or P. Zhang *et al.* (2020) also reported that the higher photosynthetic rate of NP fertilizers was 1.05 and 1.15-folds, respectively compared to the PK and NK fertilizers.

The highest increase in biomass growth (fresh weight of roots, fresh and dry weight of shoots) was found in the N + P + K fertilization compared to other fertilization. The percentage increase was 15.86; 4.41; and 5.86-folds, respectively, compared to the control. It was due to the higher nutrient uptake of total-N, total-P, and total-K in the N + P + K fertilization in the leaf tissue of maize were 11.44; 8.44; 10.95-folds, respectively (Tab. V), and the resulting leaf area was also higher of 133.77% compared to the control (Tab. IV). The character of leaf area and nutrient uptake in maize will affect the results of photosynthesis that plants will use to produce biomass (fresh and dry weight). The results are similar to Massignam *et al.* (2012) who explained that nitrogen plays an important role in seed formation due to photosynthesis, and nitrogen reduction negatively affects photosynthetic performance in maize. Coetzee *et al.* (2017) reported that the nutrients uptake of N, P, Ca, S, and B increased with increasing doses of P-fertilizer, and the highest was found in P-fertilizer dose of 40 kg ha⁻¹. Du *et al.* (2017) described that the potassium deficiency significantly decreased the total length, root surface area, root diameter, and root volume in both the tolerant and sensitive genotypes of potassium deficient, especially root length and root surface area in fine roots (0 to 0.4 mm). Therefore, three nutrients are very useful in supporting the growth phase of plant biomass, marked by an increase in leaf area. Ray *et al.* (2019) reported that the fertilization of N + P₂O₅ + K₂O (200 + 60 + 60 kg ha⁻¹) showed the higher N-uptake in the seed and grains production of maize by 144.32 kg ha⁻¹ and 9.43 ton ha⁻¹, respectively, compared to the N + P₂O₅ (200 + 60 kg ha⁻¹), N + K₂O (200 + 60 kg ha⁻¹), and P₂O₅ + K₂O (60 + 60 kg ha⁻¹).

The highest concentration and nutrient uptake of total-N, total-P, and total-K were found in the N + P + K compared to the control. The results showed that the topsoil used can still provide nutrients even though the conditions are slightly acidic with pH 5.67 and organic-C, total-N, total-P, and total-K were classified as very low until low (Tab. II). The results are similar to Sirisuntornlak *et al.* (2020) that an increase the highest of nutrient concentration for N, P, K in maize leaves and leaf area at 60 days in the soil-pH of 5.3 (slightly acidic)

by 20%; 20%; 9.17%; and 1.51%, respectively compared to the soil-pH of 7.4 (neutral).

The limiting factor based on the relative agronomic percentage for maize was found in the P + K fertilization or non-fertilizer of nitrogen. It is seen from the characteristics of plant height, leaf area, number of leaves, fresh weight of roots and shoots, dry weight of roots and shoots were lower compared to the N + K and N + P fertilization. If the maize plant has nitrogen-deficient, then its growth will be stunted (Fig. 6). It was due to the lack of photosynthate production. The results similar to Getnet and Dugasa (2019) added that the plant height of maize increased with nitrogen fertilization. Olusegun (2015) reported that non-fertilization nitrogen combined with phosphorus fertilizer up to 45 kg ha⁻¹ showed a lower of 100-seeds weight in maize compared to the nitrogen fertilizer until at dose of 90 kg ha⁻¹. Wang *et al.* (2019) reported that the fertilizer ratio of NO₃⁻/NH₄⁺ (75/25%) could be increased the adenosine triphosphate (ATP), photosynthesis rate, and the number of carbon per plant by 51; 17; and 63%, respectively and could be increased the nutrient uptake of N, P, Cu and Fe

with the density of 667 seedlings/m² of maize. Qiu *et al.* (2015) reported that the maximum production of maize grains was at the dose of 210 kg ha⁻¹ in Northeast China. Lamptey *et al.* (2017) reported the optimal range of N fertilization for maize in summer as 200 to 300 kg ha⁻¹. Flores-Sánchez *et al.* (2019) said that P and K nutrients are not a limiting factor but due to N nutrients because soil only contributes 11% of total-N availability. Tampubolon *et al.* (2021) reported that the limiting factor for the maize growth was found in the non-fertilization of nitrogen at the age of 7 WAP. Kolawole *et al.* (2018) also added that the nutrients limiting factors for maize growth in the three soil types (rhodic paleult, oxic paleult, abruptic tropaqualf) were nitrogen and phosphorus.

Therefore, the results suggest using single fertilizer at the dose of urea + SP-36 + KCl (0.15 + 0.10 + 0.025 g kg⁻¹) is more appropriate in supporting vegetative growth as a basis for determining generative maize plants. Fertilization of N, P, K from a single fertilizer must be following a balanced proportion when the maize in the vegetative phase (8 WAP).

CONCLUSION

The NOTF treatments significantly increased the vegetative growth of maize. The highest increase in plant height, number of leaves, and dry weight of roots was found in N + P fertilization. The highest increase in leaf area, fresh weight of roots, fresh and dry weight of shoots was found in N + P + K fertilization. The fertilization of N + P + K also showed the highest concentration and nutrient uptake of total-N, total-P, and total-K. A limiting factor for the vegetative growth of maize was found in the non-fertilizing nitrogen. It is recommended that nitrogen fertilizers should be balanced with phosphorus and potassium fertilizers during the vegetative phase in maize.

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Contact information

Elli Afrida: ellilubis@gmail.com (corresponding author)

Koko Tampubolon: koko.tampubolon@gmail.com



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