

The effect of liquid nutrient doses (Leili 2000) on the vegetative growth of glutinous corn (*Zea mays var. ceratina*) on vertisol soil

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Abstract. Vertisol soils are common in semi-arid regions and are characterized by high clay content, unstable structure, and fluctuating moisture, which reduce nutrient availability and limit early crop growth. Improving nutrient use efficiency through liquid fertilization is therefore considered a practical approach to support maize cultivation under such conditions. However, information on the response of glutinous corn to liquid nutrient application during the vegetative stage remains limited. This study aimed to evaluate the effect of different doses of Leili 2000 liquid nutrient on the vegetative growth of glutinous corn (*Zea mays var. ceratina*) grown on Vertisol soil. The experiment was conducted in a greenhouse using four treatments (0, 5, 10, and 15 mL plant⁻¹) with ten replications. Growth parameters, including stem diameter, plant height, leaf length, leaf width, and leaf number, were measured weekly for four weeks. Data were analyzed using a Linear Mixed Model to account for repeated measurements and variability among replicates. The results showed that time significantly influenced all growth variables, particularly during the third and fourth weeks, while nutrient doses had no consistent or significant effects. These findings indicate that early vegetative growth is primarily driven by plant developmental factors.

1 Introduction

Maize (*Zea mays L.*) is a major food crop with high global demand and considerable economic and functional value. Vegetative growth in maize is strongly influenced by the availability of adequate nutrients during the early growth stages, which is reflected in key traits such as plant height, stem diameter, leaf width and length and leaf number. During the vegetative phase, nutrient demand is particularly high, as sufficient nutrient supply is essential to support optimal biomass synthesis [1]. In crop production systems, the application of liquid fertilizers, such as biofertilizers or liquid organic fertilizers, has

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emerged as a practical strategy to improve fertilization efficiency and ensure the rapid availability of nutrients for plants. Recent studies have shown that appropriate doses of liquid biofertilizers can enhance vegetative growth parameters, including leaf number and plant height, across different maize varieties under dryland conditions [2]. Plant responses to nutrients depend not only on the type of fertilizer used, but also on the applied dose and method of application. Studies on sweet corn treated with liquid organic fertilizers have shown that the availability of soluble nutrients can positively affect yield and vegetative growth traits; however, the magnitude of these responses varies according to dosage levels and their interaction with supplemental inorganic nutrients [3]. In addition, soil conditions such as Vertisols, which are commonly found in tropical and subtropical regions including East Nusa Tenggara, have distinct physical and chemical characteristics such as high moisture fluctuation and strong aggregate structure that can influence nutrient availability for plants. Previous studies have shown that plant responses to fertilization and nutrient management are particularly critical on Vertisol soils, due to differences in root growth patterns and nutrient mobility compared to other soil types [4].

Research on the application of liquid fertilizers to glutinous corn grown on Vertisol soils is highly relevant for understanding whether liquid nutrients can significantly enhance vegetative biomass through physiological and biochemical mechanisms that support plant growth. This approach not only has the potential to improve maize productivity but also to optimize the efficient and sustainable use of nutrient inputs on marginal lands. Ultimately, knowledge of the optimal dosage of liquid fertilizers such as Leili 2000, the vegetative response of glutinous corn, and its interaction with vertisol characteristics provides an essential foundation for the development of improved agronomic practices. Despite the increasing use of liquid fertilizers in maize cultivation, quantitative evidence regarding their effectiveness under vertisol conditions remains limited, particularly for glutinous corn during the early vegetative stage. Leili 2000, a commercially available liquid macronutrient fertilizer formulated for rapid nutrient availability and foliar uptake, has been widely adopted by local farmers; however, its agronomic performance and optimal dosage have not been systematically evaluated under controlled experimental conditions. This lack of empirical assessment creates uncertainty regarding its actual contribution to plant growth and nutrient-use efficiency on heavy clay soils. Therefore, this study aimed to determine the response of vegetative growth of glutinous corn (*Zea mays var. ceratina*) to different doses of Leili 2000 and to quantify the relative influence of nutrient application and temporal growth dynamics using a Linear Mixed Model framework. The findings are expected to provide an evidence-based reference for optimizing liquid fertilization strategies and improving maize management practices on vertisol soils.

2 Materials and methods

2.1 Place and time

This study was conducted in the greenhouse of the Department of Forestry, Kupang State Polytechnic of Agriculture, East Nusa Tenggara, Indonesia, in November 2025 for a period of 30 days. The soil used was vertisol collected from Oesao, Kupang, and placed into 40 polybags according to the number of treatments.

2.2 Tools and materials

In this study, the instruments used included a measuring tape, a digital caliper, and a ruler to measure each vegetative growth indicator of maize. The materials consisted of the liquid

macronutrient fertilizer Leili 2000, maize seeds, and Vertisol soil. To ensure measurement accuracy and methodological transparency, each vegetative growth parameter was assessed using a specific instrument selected according to its precision and measurement scale. Stem diameter was measured using a digital caliper to obtain high-resolution readings of small radial changes, while plant height and leaf length were determined with a measuring tape to accommodate longer dimensions. A ruler was used for leaf width measurements to allow consistent alignment across flat leaf surfaces. The functions and specifications of the instruments and materials applied in this study are summarized in Table 1.

Table 1. Instruments and materials used and their specific functions

Instrument/Material	Function
Digital caliper	High-precision measurement of small diameters
Measuring tape	Measurement of elongated plant organs
Ruler	Straight-line measurement on flat surfaces
Leili 2000 liquid fertilizer	Nutrient treatment source
Maize seeds	Experimental plant material
Vertisol soil	Growth medium

2.3 Experimental design

In this study, five growth parameters were measured: plant height, number of leaves, leaf length, stem diameter, and leaf width. Four treatments were applied to the maize plants, namely P0 (control), P1 (5 mL of macronutrient solution), P2 (10 mL of macronutrient solution), and P3 (15 mL of macronutrient solution). Each treatment was replicated ten times, and data were collected over a four-week observation period.

2.4 Linear mixed model

A Linear Mixed Model (LMM) is a type of statistical model that integrates fixed effects and random effects to analyze data with complex structures, such as longitudinal datasets involving repeated measurements [5]. In general, the Linear Mixed Model (LMM) offers a more flexible alternative to ordinary linear regression or classical ANOVA when the assumption of independence among observations is not met, such as in the presence of within-group correlations or repeated measurements on the same subject.

In matrix notation, the Linear Mixed Model (LMM) can be expressed as.

$$y = X\beta + Zu + \varepsilon \tag{1}$$

with.

- y : observation vector
- X : design matrix for fixed effects
- β : fixed-effects parameter vector
- Z : design matrix for random effects
- u : random-effects vector. assumed $u \sim N(0, G)$
- ε : residual vector with $\varepsilon \sim N(0, R)$ and $Cov(u, \varepsilon) = 0$.

In many field studies, particularly those involving repeated measurements on the same experimental units or data grouped into blocks, classes, or other experimental units, the assumption of independence is often violated. Differences in characteristics among groups or individuals can cause observations within the same group to be more similar to each

other than to those from other groups. If this dependence structure is ignored, the resulting analyses may yield biased conclusions and inaccurate standard errors.

Linear Mixed Models (LMM) address this issue by incorporating two types of components into the model, namely fixed effects and random effects. Fixed effects represent the systematic influence of variables of interest, such as treatments, time, or specific factor levels that are assumed to apply uniformly across the population. In contrast, random effects capture variability that cannot be explained by the fixed factors and are assumed to arise from random sources of heterogeneity, such as differences among experimental replicates, locations, or respondents. By accommodating both sources of variation, LMM enable a clearer separation between treatment-induced effects and naturally occurring variability in field conditions [6].

3 Results and discussion

3.1 Descriptive statistics

The following section presents a preliminary overview in the form of descriptive statistics for several measured parameters.

According to Figure 1, all graphs indicate that the average vegetative growth of glutinous corn under treatments P0, P1, P2, and P3 follows a relatively similar pattern, with only modest differences among treatments. This pattern is consistent with previous reports showing that maize growth responses to fertilization often remain moderate and do not always differ clearly among nutrient doses [7]. For stem diameter, treatment P3 shows the highest mean value, followed by P1, P2, and P0. However, the differences are small, suggesting that variations in liquid nutrient doses have not exerted a strong effect on stem thickening, as also reported by Szulc (2023) in [8], who found that increasing nitrogen rates did not consistently enhance vegetative traits. A comparable trend is observed for the number of leaves, leaf width, and leaf length. Treatment P3 tends to produce the highest average values, whereas P2 shows relatively lower values. Nevertheless, no single treatment consistently demonstrates a markedly superior performance. Similar moderate responses were reported by Novianti (2023) in [9] and Yulianto (2025) in [10], who observed that differences in fertilizer doses often did not result in significant variation in vegetative growth during early stages. For plant height, P3 again records the highest mean value, followed by P1, P0, and P2. Although some variation is evident among treatments, the magnitude of the differences is not large enough to indicate a strong biological effect of the treatments. Overall, these visualizations show that vegetative growth across all treatments is relatively balanced. No pronounced differences among treatments are apparent for any of the observed parameters. These findings reinforce the conclusion that during the early vegetative stage, glutinous corn growth on Vertisol soil is more strongly driven by intrinsic plant development and temporal factors, while the influence of varying doses of Leili 2000 liquid nutrient remains limited.

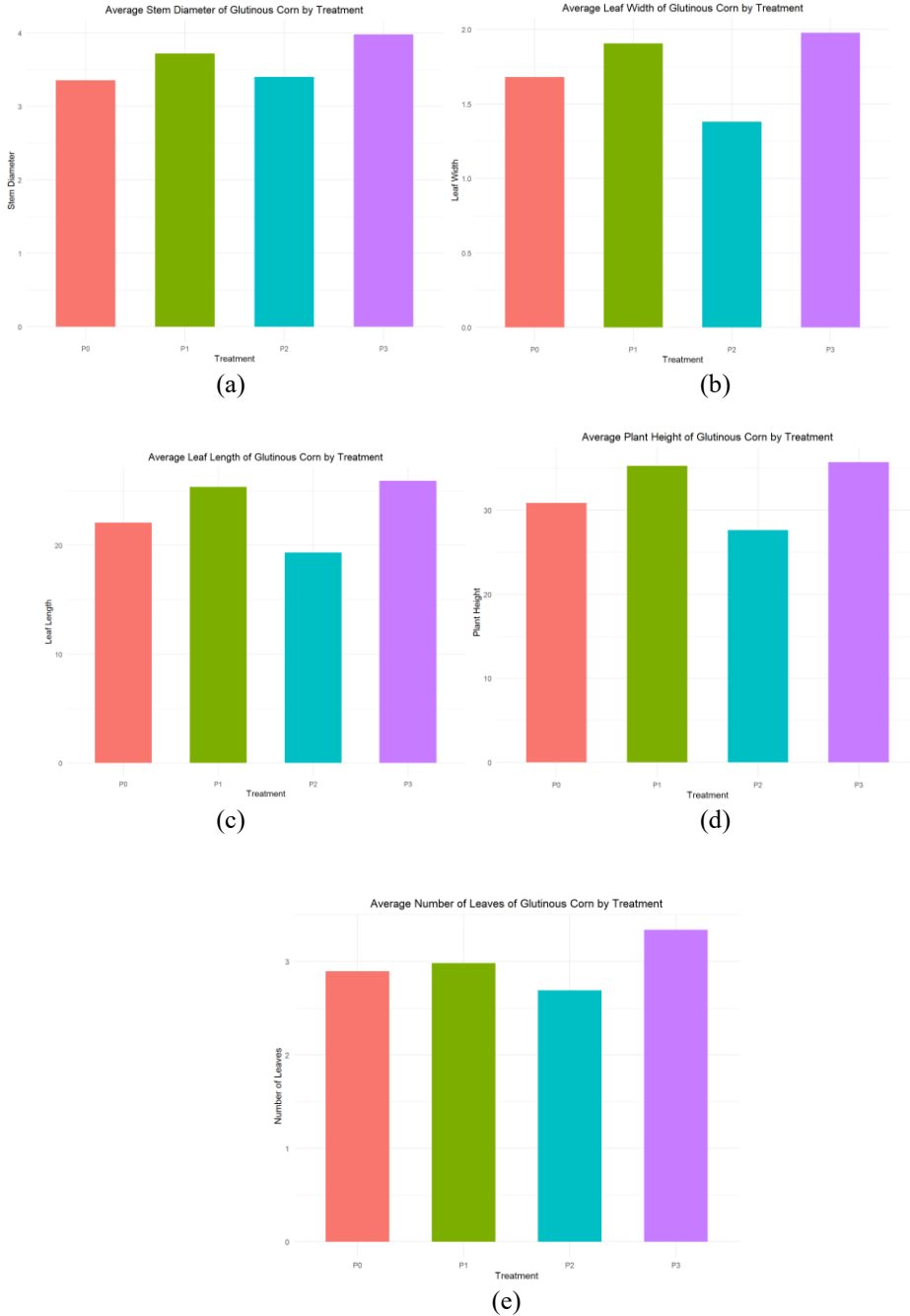


Fig. 1. Bar chart of the average (a) Stem diameter; (b) Leaf width; (c) Leaf length; (d) Plant height; (e) Number of leaves of glutinous corn by treatment

3.2 Linear mixed model analysis

Data analysis in this study was conducted using a Linear Mixed Model (LMM). This approach was selected because the data had a repeated-measures structure and were not

fully independent, making conventional linear regression models less appropriate. The Linear Mixed Model allows the integration of fixed effects and random effects within a single analytical framework, thereby providing a more realistic representation of data variability.

3.2.1 Stem diameter

Here is the fixed-effects output table for the stem diameter parameter generated using the mixed model.

Table 2. Fixed effect output of stem diameter

Fixed Effects	Estimate	Std. Error	Df	t-value	Pr(> t)
(Intercept)	1.44655	0.73495	20.03567	1.968	0.0630
Treatment 1	0.49202	0.61317	1016.26978	0.802	0.4225
Treatment 2	0.36202	0.61317	1016.26978	0.590	0.5551
Treatment 3	0.62345	0.61317	1016.26978	1.017	0.3094
Week 1	1.10571	0.60863	1015.04566	1.817	0.0696
Week 2	2.48857	0.60863	1015.04566	4.089	4.68e-05
Week 3	3.92114	0.66762	1015.04566	5.881	5.52e-09
Treatment 1 : Week 2	-0.02857	0.86073	1015.04566	-0.033	0.9738
Treatment 2 : Week 2	-0.14571	0.86073	1015.04566	-0.169	0.8656
Treatment 3 : Week 2	0.05857	0.86073	1015.04566	0.068	0.9450
Treatment 1 : Week 3	0.10900	0.86073	1015.04566	0.127	0.8981
Treatment 2 : Week 3	0.07114	0.86073	1015.04566	0.083	0.9337
Treatment 3 : Week 3	-0.27857	0.86073	1015.04566	-0.323	0.7463
Treatment 1 : Week 4	0.06729	0.94829	1015.04566	0.071	0.9432
Treatment 2 : Week 4	-0.45571	0.94829	1015.04566	-0.480	0.6311
Treatment 3 : Week 4	0.50486	0.94829	1015.04566	0.535	0.5925

The Linear Mixed Model indicated substantial variation among replicates, with a random-effect variance of 3.494 and a standard deviation of 1.869. This suggests differences in stem diameter growth responses across replicates that were not explained by treatment or time. This pattern of considerable variability attributable to random effects has been widely acknowledged in plant science research, where mixed models are emphasized for capturing inherent experimental variation and random factors such as blocks or replications in agronomic trials [11]. The residual variance (12.965) further indicates considerable variability at the individual plant level, reflecting heterogeneous responses that are common in biological field data and often require mixed-model frameworks to accurately partition variance components [11]. The intercept was marginally significant ($p = 0.063$), implying a relatively uniform initial stem diameter before treatment and time effects became evident. Individual treatments (Treatments 1, 2, and 3) did not significantly affect stem diameter, indicating no clear early growth differences among doses. In contrast, time had a strong effect, with Weeks 3 and 4 showing significant increases ($p < 0.001$). This demonstrates that stem diameter growth was driven mainly by temporal factors rather than nutrient dose. The treatment \times time interaction was not significant, indicating parallel growth trends across treatments over time. This outcome aligns with the statistical interpretation that, when nutrient dose effects are minimal relative to temporal growth trends, mixed-model analysis appropriately identifies time as the primary driver of growth responses with minimal interaction effects detectable [12].

Table 3. Type III analysis of variance output for stem diameter

Source (Effect)	Sum Sq	Mean Sq	NumDF	DenDF	F-Value	Pr(>F)
Treatment	99.88	33.29	3	1016.8	2.5679	0.05315
Week	2157.58	719.19	3	1015.0	55.4716	< 2e-16
Treatment:Week	15.49	1.72	9	1015.0	0.1327	0.99883

The Type III analysis of variance confirmed the previous results. The treatment effect showed a p-value of 0.053, indicating that its influence on stem diameter was not statistically significant at the 95% confidence level, although it approached significance. In contrast, the week factor had a very high F-value with $p < 2e-16$, demonstrating that time was the main factor consistently affecting stem diameter increase. The interaction between treatment and week yielded a p-value of 0.998, indicating no difference in growth patterns among treatments over time. Thus, stem diameter increased uniformly across treatments, and the observed growth was primarily driven by plant age rather than nutrient dose.

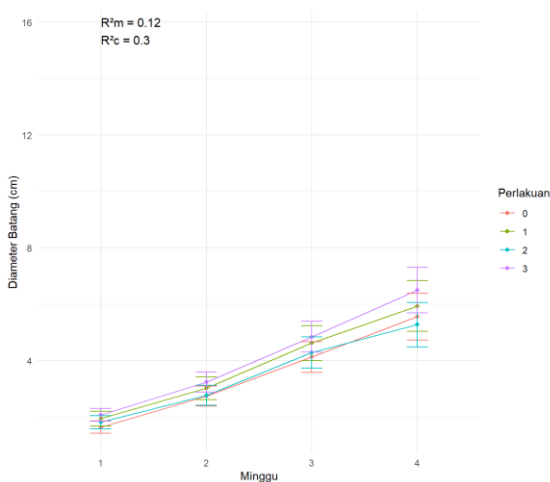


Fig. 2. Trend of stem diameter growth

The stem diameter growth curve showed a consistent increasing trend from the first to the fourth week across all treatments. The treatment lines displayed nearly parallel patterns, indicating no clear differences in growth response among treatments. Differences in mean stem diameter at each observation time were small and largely within overlapping variation ranges. The marginal R^2 value of 0.12 indicates that fixed effects explained about 12% of the total variance. In contrast, the conditional R^2 value of 0.30 shows that including random replicate effects substantially improved model performance. This result highlights the importance of accounting for random effects when analyzing repeated and heterogeneous growth data.

3.2.2 Leaf length

Here is the output table of fixed-effect parameters for leaf length generated using a mixed model.

Table 4. Fixed effect output of leaf length

Fixed Effects	Estimate	Std. Error	df	t-value	Pr(> t)
(Intercept)	8.5454	4.6538	21.1399	1.836	0.0804
Treatment 1	4.8803	3.9872	1016.3666	1.224	0.2212
Treatment 2	3.8060	3.9872	1016.3666	0.955	0.3400
Treatment 3	4.2632	3.9872	1016.3666	1.069	0.2852
Week 1	5.4443	3.9578	1015.0454	1.376	0.1693
Week 2	20.2157	3.9578	1015.0454	5.108	3.89e-07***
Week 3	27.8520	4.3356	1015.0454	6.424	2.04e-10***
Treatment 1 : Week 2	2.6257	5.5972	1015.0454	0.469	0.6391
Treatment 2 : Week 2	-0.9529	5.5972	1015.0454	-0.170	0.8649
Treatment 3 : Week 2	2.5014	5.5972	1015.0454	0.447	0.6550
Treatment 1 : Week 3	-2.2000	5.5972	1015.0454	-0.393	0.6944
Treatment 2 : Week 3	-9.7243	5.5972	1015.0454	-1.737	0.0826
Treatment 3 : Week 3	-0.4157	5.5972	1015.0454	-0.074	0.9408
Treatment 1 : Week 4	-2.3257	6.1314	1015.0454	-0.379	0.7045
Treatment 2 : Week 4	-12.5534	6.1314	1015.0454	-2.047	0.0409*
Treatment 3 : Week 4	1.5574	6.1314	1015.0454	0.254	0.7995

A closer examination of the fixed-effects coefficients provides a clearer view of the growth pattern. The intercept estimate of 8.5454 ($p = 0.0804$) indicates that the baseline leaf length under the reference condition (treatment 0, week 1) was not significantly different from zero at the 95% confidence level. This outcome is consistent with findings in recent plant growth studies that report non-significant baseline effects in mixed-model analyses when initial conditions or early response variables do not differ markedly among treatments (e.g., mixed model analyses in crop studies often show baseline coefficients without strong biological differentiation) [11].

For the time factor, a strong increasing trend was observed, with weeks three and four showing highly significant positive effects, with estimates of 20.2157 and 27.8520, respectively. Although the overall ANOVA indicated a significant treatment effect, none of the individual treatment levels (1, 2, and 3) differed significantly from the reference level in the coefficient tests. Regarding interactions, only one term was significant at the 5% level, namely Treatment 2 \times Week 4 (estimate = -12.5534 , $p = 0.0409$). This result slightly contrasts with the non-significant overall interaction effect reported by the ANOVA ($p = 0.4244$). However, since only one out of nine interaction terms reached significance, the interaction effects can be considered weak in the model. This pattern is supported by mixed-model methodological discussions showing that longitudinal biological data often exhibit weak or inconsistent fixed-effect interactions when factors such as time and treatment influence growth trajectories with overlapping biological variability [11].

Table 5. Type III analysis of variance output for leaf length

Source (Effect)	Sum Sq	Mean Sq	NumDF	DenDF	F-Value	Pr(>F)
Treatment	9028	3009.4	3	1016.9	5.4891	0.0009642***
Week	86665	28888.5	3	1015.0	52.6922	<2.2e-16***
Treatment:Week	5016	557.4	9	1015.0	1.0167	0.4244248

Based on the ANOVA using the Satterthwaite method, both treatment and observation week had a highly significant effect on the response variable of cycle length. The p -value for treatment was 0.0009642, while that for week was lower than $2.2e-16$, indicating that both factors contributed substantially to the observed variation. In contrast, the interaction between treatment and week was not statistically significant ($p = 0.4244$), suggesting that

the treatment response remained consistent across the observation period without marked changes among weeks.

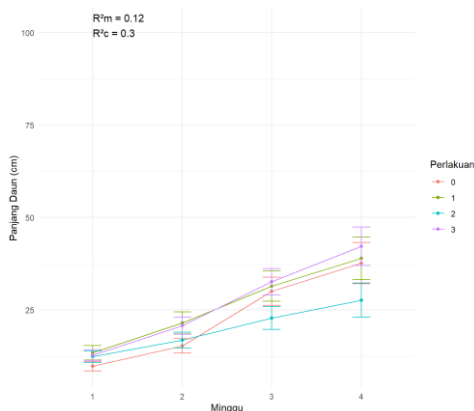


Fig. 3. Trend of leaf length growth

The marginal R^2 value of 0.12 indicates that only 12% of the data variation is explained by the fixed effects of treatment and week. When the random effect of replication was included, the conditional R^2 increased to 0.30, indicating that the full model accounted for 30% of the total variability. Based on the observed significance patterns, the final model emphasized the main effects of treatment and week without including general interactions, except for a specific interaction between Treatment 2 and Week 4.

3.2.3 Plant height

The following is the output table of fixed-effect parameters for plant height obtained using the mixed model.

Table 6. Fixed effect output of plant height

Fixed Effects	Estimate	Std. Error	df	t-value	Pr(> t)
(Intercept)	11.9988	6.5324	20.8427	1.837	0.0805
Treatment 1	6.8440	5.5593	1016.3396	1.231	0.2186
Treatment 2	5.2412	5.5593	1016.3396	0.943	0.3460
Treatment 3	6.1940	5.5593	1016.3396	1.114	0.2655
Week 1	11.3500	5.5183	1015.0435	2.057	0.0400*
Week 2	25.0171	5.5183	1015.0435	4.533	6.49e-06***
Week 3	37.5194	6.0450	1015.0435	6.207	7.87e-10***
Treatment 1 : Week 2	-1.1371	7.8041	1015.0435	-0.146	0.8842
Treatment 2 : Week 2	-4.6671	7.8041	1015.0435	-0.598	0.5499
Treatment 3 : Week 2	-1.0157	7.8041	1015.0435	-0.130	0.8965
Treatment 1 : Week 3	-0.3857	7.8041	1015.0435	-0.049	0.9606
Treatment 2 : Week 3	-9.5943	7.8041	1015.0435	-1.229	0.2192
Treatment 3 : Week 3	0.4686	7.8041	1015.0435	0.060	0.9521
Treatment 1 : Week 4	-0.8823	8.5489	1015.0435	-0.103	0.9178
Treatment 2 : Week 4	-14.4874	8.5489	1015.0435	-1.695	0.0904
Treatment 3 : Week 4	3.4077	8.5489	1015.0435	0.399	0.6903

The fixed-effects analysis showed that time (weeks of observation) had a highly significant effect on plant height ($p < 0.01$), indicating a consistent increase in height with each successive

week. This pattern aligns with recent findings that plant developmental progression and observation time frequently exert a stronger influence on maize growth than treatment variations, especially under conditions where treatments do not differ markedly in nutrient supply [10]. In contrast, the treatments did not produce significant differences compared with the control, suggesting that the applied doses did not markedly affect plant height. The interaction between treatment and time was also not significant, indicating that growth patterns over time were similar across all treatments. This non-significant interaction between fertilizer/treatment and temporal growth has been observed previously in maize studies, where neither timing nor level of nutrient treatments substantially modified plant height progression over time during early vegetative growth [13].

Table 7. Type III analysis of variance output for plant height

Source (Effect)	Sum Sq	Mean Sq	NumDF	DenDF	F-Value	Pr(>F)
Treatment	14844	4948	3	1016.9	4.6424	0.3132
Week	163531	54510	3	1015.0	51.1446	<2.2e-16
Treatment:Week	6432	715	9	1015.0	0.6705	0.736132

Time (week) remained the most dominant factor affecting plant growth. In contrast, treatment effects and their interactions with time were not significant, indicating that plant growth followed a similar increasing pattern across all treatments.

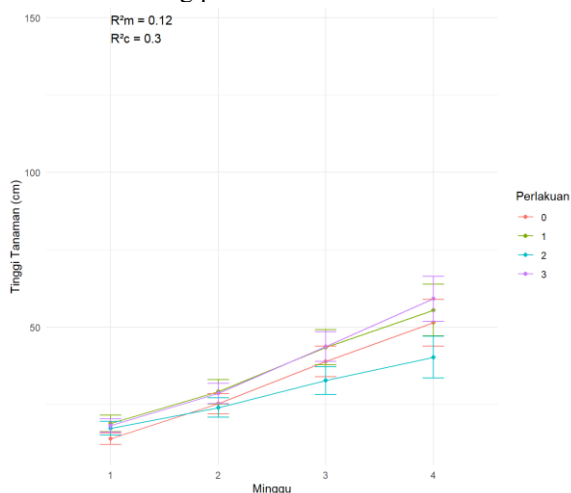


Fig. 4. Trend of plant height growth

The growth curves show that plant height increased steadily with each observation week across all treatments. Treatment 3 tended to produce slightly taller plants, particularly in the later weeks. However, the overlapping error bars among treatments indicate that these differences were not statistically significant. Overall, the graph confirms that time was the dominant factor affecting growth, while fertilizer treatments did not produce clearly distinct growth patterns.

3.2.4 Leaf width

Here is the output table of fixed effect parameters for leaf width generated using a mixed model.

Table 8. Fixed effect output of leaf width

Fixed Effects	Estimate	Std. Error	df	t-value	Pr(> t)
(Intercept)	0.65665	0.35831	19.96243	1.833	0.0818
Treatment 1	0.29192	0.29857	1016.25552	0.978	0.3284
Treatment 2	0.16192	0.29857	1016.25552	0.542	0.5877
Treatment 3	0.31478	0.29857	1016.25552	1.054	0.2920
Week 1	0.53714	0.29636	1015.03411	1.812	0.0702
Week 2	1.40143	0.29636	1015.03411	4.729	2.58e-06***
Week 3	1.92686	0.32465	1015.03411	5.935	4.02e-09***
Treatment 1 : Week 2	0.08286	0.41912	1015.03411	0.198	0.8433
Treatment 2 : Week 2	-0.20429	0.41912	1015.03411	-0.487	0.6261
Treatment 3 : Week 2	0.09571	0.41912	1015.03411	0.228	0.8194
Treatment 1 : Week 3	0.14143	0.41912	1015.03411	0.337	0.7359
Treatment 2 : Week 3	-0.51143	0.41912	1015.03411	-1.220	0.2227
Treatment 3 : Week 3	0.14857	0.41912	1015.03411	0.354	0.7231
Treatment 1 : Week 4	0.02857	0.45912	1015.03411	0.062	0.9504
Treatment 2 : Week 4	-0.71743	0.45912	1015.03411	-1.563	0.1185
Treatment 3 : Week 4	0.25371	0.45912	1015.03411	0.553	0.5807

Based on the fixed-effect estimates, leaf width increased significantly in Weeks 3 and 4, as indicated by very low p-values (***). This result shows that leaf expansion intensified during these weeks regardless of the applied treatments. In contrast, most treatment effects and their interactions were not significant, indicating that treatment responses on leaf width did not differ markedly over time.

Table 9. Type III analysis of variance output for leaf width

Source (Effect)	Sum Sq	Mean Sq	NumDF	DenDF	F-Value	Pr(>F)
Treatment	67.70	22.568	3	1016.8	7.3414	7.18e-05***
Week	487.16	162.385	3	1015.0	52.8239	<2.2e-16***
Treatment:Week	19.55	2.173	9	1015.0	0.7068	0.7031

The ANOVA results showed that both treatment and week had a significant effect on leaf width ($p < 0.001$). This indicates overall differences in leaf width among weeks and among treatments. This suggests that variation in nutrient treatment and the progression of time each independently influenced leaf width development, consistent with other studies reporting significant main effects of treatment and temporal factors on vegetative traits in crops (e.g., leaf area or related morphological traits showing significant main effects across growth stages) [14]. However, the interaction between treatment and week was not significant ($p = 0.703$), suggesting that changes in leaf width over time did not differ consistently among treatments. These findings show that although nutrient treatments and growth progression each affect leaf width, their combined interaction does not generate unique temporal responses in leaf width, highlighting that the response dynamics of leaf width in maize are more strongly tied to overall growth progression than to treatment–time synergies [15].

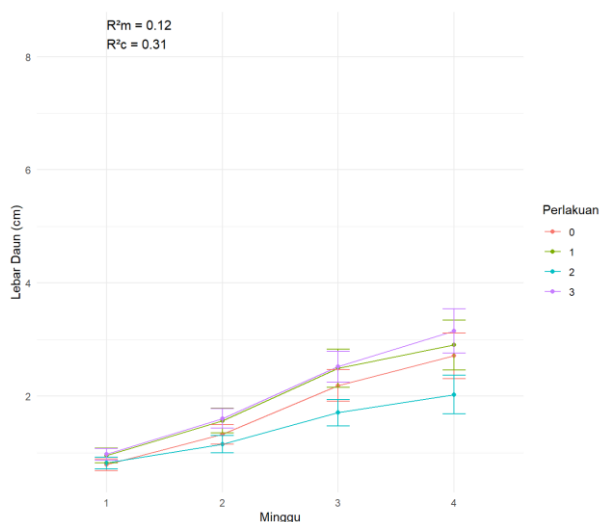


Fig. 5. Trend of leaf width growth

The graph illustrates leaf width growth trends over four weeks across different treatments. All treatments showed similar growth patterns with only minor variation among groups. Comparable findings in reduced fertilizer rate experiments showed that lower nutrient inputs sometimes do not significantly alter vegetative growth traits, supporting the observation of modest differences in leaf width [13]. Treatment 2 tended to produce slightly narrower leaves than the others; however, LMM and ANOVA results indicated that these differences were not statistically significant. The marginal R^2 value of 0.12 suggests that fixed effects explained only a small proportion of the total variation, whereas the conditional R^2 of 0.31 indicates that the combined fixed and random effects provided a better representation of leaf width variability. Overall, leaf width increased significantly with observation time, showing progressive expansion as plants aged. Although treatment effects were significant in aggregate, no single treatment or interaction consistently produced distinct responses. The mixed-effects model confirms that temporal factors had a stronger influence on leaf development than specific nutrient treatments, while variability among replicates remained an important component of the growth analysis.

3.2.5 Number of leaves

In the random-effects component, the variance among experimental blocks (replicates) reached 2.233, indicating substantial between-block variability and explaining why the conditional R^2 was markedly higher than the marginal R^2 . This aligns with recent methodological guidance that highlights how mixed models partition variance into fixed and random components, with random effects often explaining a large proportion of total variation in plant experiments with repeated measurements or hierarchical designs [11]. In the fixed-effects model, only two estimates were statistically significant. First, the significant intercept confirms a meaningful baseline response under the reference condition (Treatment 0, Week 1). Second, the positive and significant coefficient for Week 4 (estimate = 1.400, $p = 0.00197$) indicates that measurements in the fourth week were significantly higher than those in the first week. Among treatment, only Treatment 1 differed significantly from the reference level (Treatment 0), with an estimate of 1.927. In contrast, all interaction terms (e.g., Treatment 1 \times Week 2) showed large p -values, consistent with the absence of significant interactions reported in the ANOVA results. The

lack of treatment × time interaction significance reflects patterns seen in other experiments where temporal changes dominate over treatment interactions, and models without significant interaction effects suggest relatively stable responses across treatment levels when random variation is accounted for [11]. Here is the fixed-effects parameter output table for leaf number generated using the mixed model.

Table 10. Fixed effect output of number of leaves

Fixed Effects	Estimate	Std. Error	df	t-value	Pr(> t)
(Intercept)	1.927e+00	5.729e-01	1.830e+01	3.364	0.003396*
Treatment 1	2.445e-01	4.546e-01	1.016e+03	0.538	0.590775
Treatment 2	3.026e-02	4.546e-01	1.016e+03	0.067	0.946944
Treatment 3	6.017e-01	4.546e-01	1.016e+03	1.323	0.185993
Week 1	6.286e-01	4.513e-01	1.015e+03	1.393	0.163951
Week 2	1.400e+00	4.513e-01	1.015e+03	3.102	0.001973**
Week 3	1.746e+00	4.943e-01	1.015e+03	3.531	0.000432***
Treatment 1 : Week 2	-7.143e-02	6.382e-01	1.015e+03	-0.112	0.910905
Treatment 2 : Week 2	-1.286e-01	6.382e-01	1.015e+03	-0.201	0.840376
Treatment 3 : Week 2	-1.5713e-01	6.382e-01	1.015e+03	-0.246	0.805550
Treatment 1 : Week 3	-7.143e-02	6.382e-01	1.015e+03	-0.112	0.910905
Treatment 2 : Week 3	-2.857e-01	6.382e-01	1.015e+03	-0.448	0.654466
Treatment 3 : Week 3	-1.143e-01	6.382e-01	1.015e+03	-0.179	0.857911
Treatment 1 : Week 4	-1.771e-01	6.991e-01	1.015e+03	-0.253	0.800019
Treatment 2 : Week 4	-2.029e-01	6.991e-01	1.015e+03	-0.290	0.771745
Treatment 3 : Week 4	5.714e-03	6.991e-01	1.015e+03	0.008	0.993480

Table 11. Type III analysis of variance output for number of leaves

Source (Effect)	Sum Sq	Mean Sq	NumDF	DenDF	F-Value	Pr(>F)
Treatment	62.11	20.702	3	1016.6	2.9045	0.03385*
Week	408.48	136.161	3	1015.0	19.1040	4.681e-12***
Treatment:Week	3.04	0.337	9	1015.0	0.0473	0.99998

The analysis of variance showed that the main effect of treatment was statistically significant at the 95% confidence level ($p = 0.03385$), indicating meaningful differences in mean responses among treatments after controlling for time. The effect of week was highly significant ($p = 4.681 \times 10^{-12}$), demonstrating a strong temporal influence on the response variables. In contrast, the interaction between treatment and week was not significant ($p = 0.99998$), indicating parallel response patterns over time and no differential treatment effects across observation weeks.

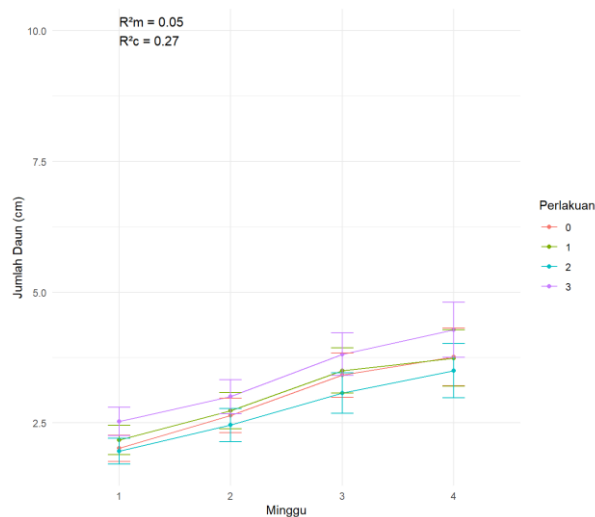


Fig. 6. Trend of number of leaves growth

The marginal R^2 (R^2m) of 0.05 indicates that fixed effects (treatment and week) explain only 5% of the total data variation, reflecting a weak contribution. In contrast, the conditional R^2 (R^2c) of 0.27 shows that including random effects from experimental replication allows the model to explain 27% of the variation. The large difference between R^2c and R^2m (22%) suggests that heterogeneity among experimental blocks strongly contributed to data variability. The line graph shows a consistent increase in responses from Week 1 to Week 4 across all treatments, with nearly parallel trends, confirming the absence of a significant interaction between the two factors.

4 Conclusion

Based on the analysis of vegetative growth of glutinous corn (*Zea mays var. ceratina*) grown on vertisol soil under different doses of Leili 2000 liquid nutrient, time was identified as the main factor controlling all growth parameters, including stem diameter, plant height, leaf length, leaf width, and leaf number. Significant increases were observed mainly in the third and fourth weeks, indicating that plant growth was primarily driven by natural physiological development as plant age increased. Individual nutrient doses did not significantly affect stem diameter or plant height and showed no meaningful interaction with time. Treatment effects appeared only in aggregate for leaf width, leaf number, and leaf length, without a consistent superior dose. This suggests that during the early vegetative stage, Leili 2000 application did not produce clear growth differences among doses. Variation among replicates contributed substantially to data variability, as reflected by higher conditional than marginal R^2 values, highlighting the importance of field heterogeneity. Overall, vegetative growth was more strongly influenced by temporal factors than by liquid nutrient dosage. Further studies with wider dose ranges, longer observation periods, and optimized application timing are required to improve the effectiveness of liquid fertilization.

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