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COMPARATIVE STATISTICAL ANALYSIS OF PLANT GROWTH RESPONSES UNDER CONTRASTING AGRICULTURAL MANAGEMENT PRACTICES

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Abstract

Under different environmental conditions, agricultural management practices have an important effect on the growth, physiological development and yield of plants. The study sought to comparatively assess plant growth response as affected by different tillage and soil-input management practices using secondary data from agricultural field experiments in Chuka and Kandara for the growing season of 2016 and 2017. Five datasets relating to plant height, chlorophyll content, maize yield, soil water content and rainfall were studied. To determine differences among treatments and relationships among growth indicators, descriptive statistics, factorial analysis of variance (ANOVA), correlation analysis and multiple regression were employed. Soil-inputs treatments had significant effects on all of the plant growth and productivity parameters measured ($p < .001$), while the effect of tillage treatments was relatively small. Maximum maize grain yield (2.06 and 2.11) was obtained with the RFM treatment in both tillage categories, D0 and D15, respectively. Tillage had a significant effect on stover yield ($p = .007$) and there were significant interactions between treatments for some physiological and yield indicators. The correlation was significantly positive between the 10th stage plant height and grain yield ($r = .767$) and this regression accounted for 70.1% of the variability in grain yield. In general, the results suggest that management of soil inputs and site-specific agriculture practices can help to enhance maize growth and productivity, encouraging evidence-based sustainable agriculture practices.

Keywords: Agricultural Management Practices; Plant Growth; Tillage Practices; Chlorophyll Content; Maize Yield

1. Introduction

Agricultural management practices are key drivers of plant growth, crop productivity, and agricultural system sustainability. As food demand has risen, soil fertility has diminished, and the environment has become more variable, the need for management strategies that maximize crop production while maintaining soil resources has grown. Soil physical and chemical properties, nutrient supply, and plant physiological growth are affected by tillage, fertilizer, organic amendments, water management, and residue management techniques in agriculture. The adoption of conservation-oriented practices has garnered a lot of attention due to the possibility of enhancing soil productivity whilst reducing soil degradation. Crop response, however, is likely to be influenced by the environment, soil properties, and the intensity of management (Achankeng & Cornelis, 2023; Corbeels et al., 2020). Adopting suitable nutrient management practices can boost the productivity of maize in addition to increasing the efficiency of nutrient use across multiple cropping seasons (F. Fan et al., 2020; Jamakhandi et al., 2025).

Soil management and tillage practices directly impact soil structure, moisture-holding capacity, nutrient cycling and root development, and thus plant establishment and productivity. While conventional tillage can help to improve initial soil preparation, it can also lead to the disturbance of the soil and loss of moisture, while conservation tillage helps to protect the soil and conserve resources. The effects of reduced tillage and no-tillage systems on soil water storage and water-use efficiency have been well established in previous investigations, with impacts on crop yield varying based on specific local conditions (Adil et al., 2024; Afshar et al., 2022). Likewise, the use of a mineral fertilizer along with an organic source of nutrients can enhance nutrient availability and maintain maize production. Organic fertilizer substitution and integrated nutrient application have shown great potential to enhance soil fertility and crop yield (He et al., 2022; Jiang et al., 2024). Beyond that, the management of fertilizers under different tillage systems can affect the uptake and utilization of N, thus the importance of examining the interactions between the management practices rather than treating them separately (M. Fan et al., 2025; W. Li et al., 2025).

Plant growth indicators are useful pieces of information about crop development and responses to agricultural management practices. Plant height is a useful measure as an indicator of plant vegetative growth while chlorophyll is an indicator of photosynthetic capacity and plant nutritional status. These attributes are combined to account for differences in crop performance in various management practices. Fertilization may affect the physiological traits, grain development, and quality of maize by modifying nutrient availability (Dragičević et al., 2022). Yield is a crucial indicator of agricultural productivity and is a cumulative effect of plant growth and environment. It has been demonstrated that nitrogen management and irrigation strategies can enhance the productivity of maize crops while boosting resource-use efficiency (RUE) (Gu et al., 2023). Similarly, soil nutrient dynamics can be enhanced by straw incorporation and phosphorus application that can stimulate maize growth (Guo et al., 2024). Variations in maize performance under semi-arid agricultural conditions are also due to irrigation and management of organic manure (Kumar et al., 2022).

While much work has concentrated on individual agricultural management practices, far fewer studies have involved the joint assessment of several plant growth indicators under a range of soil and site conditions, as well as different tillage and soil-input treatments and under various seasonal conditions. The current literature has focused on yield, soil fertility, and efficiency of resource use, and comparative evaluations of growth, chlorophyll pigment properties and productivity are still useful to know about treatment responses. The results of the residue management studies also included productivity, economic performance, and soil sustainability trade-offs (J. Li et al., 2024). Hence, a comparative statistical analysis, using several crop indicators, can give a more complete picture of the effectiveness of the agricultural management system.

The objective of the present study is to compare the growth responses of the plants under the different agricultural practices through agricultural field data. Specifically, the study is focusing on the differences in plant height, chlorophyll content and maize yield between the different tillage and soil management treatments and on relationships between these growth and production measurements. The results help to interpret the agricultural management practices and their implications for sustainable crop production based on evidence.

2. Materials and Methods

2.1. Research Design and Data Source

A comparative quantitative research design was used in this research, adopting a secondary field experimental approach in agricultural research to study plant growth responses to contrasting management practices. Five data sets – plant height, chlorophyll content, maize yield, soil water content and rainfall – were taken into account. The study comprised two experimental sites (Chuka and Kandara), in the agricultural seasons of 2016 and 2017.

2.2. Description of the Dataset and Study Variables

The datasets included 448 plant-height measurements, 336 chlorophyll measurements, 448 grain yields, 2408 water content of the soil, and 761 rainfall observations. The factors considered as independent were tillage practice, soil-input treatment, experimental site and growing season. Plant height at sixth leaf stage, tenth leaf stage, chlorophyll content, grain yield and stover yield were dependent variables. The supplemental environmental variables were soil moisture and precipitation (Felix Kipchirchir Ngetich, 2022).

2.3. Agricultural Management Treatments and Experimental Conditions

There were two tillage treatments (D0 and D15) and seven soil-input categories (C, F, RF, RFM, RML, RTiM, and RTiP) which resulted in 14 tillage × soil-input treatment combinations. The data for plant height and yield were

observed over four growing seasons (LR16, SR16, LR17, and SR17); four replicates were used per site–season–treatment combination. Three seasons had measurements of chlorophyll.

2.4. Data Cleaning and Preprocessing
Data preprocessing included the identification of missing values, duplicate data, inconsistent variable formats, and treatment identifiers. Soil-water data that were not entered as numbers were considered missing data. Available site, season, treatment and replicate identifiers were used to match datasets, which were standardized for variables. Only seasons when chlorophyll measurements were available were used for analyses. Original treatments and recorded values were maintained.

2.5. Measurement of Plant Growth and Yield Parameters
Plant growth was measured by measuring plant height and chlorophyll at the 6th and 10th leaf stage. Maize grain yield and stover yield were used to assess crop productivity. Environmental conditions were characterized by soil water measurements taken from the depths of 10–50 cm and by the observations of rainfall. Variations in crop performance were assessed by comparing the measurements of plant growth and yield among agricultural management treatments.

2.6. Statistical Analysis
The plant growth and yield characteristics were summarized with descriptive statistics such as mean and standard deviation. To look at the effect of tillage and the effect of soil input and the interaction of tillage and soil input, the data were analyzed using factorial ANOVA, with site and season as factors. Post hoc tests were used for pairwise comparisons and were specified according to Tukey's adjustment. Pearson correlation was employed to assess the relationship between growth indicators and yield and regression was suggested to assess relationships with productivity of the crop. Replications were accommodated by appropriate experimental grouping. The analyses were performed with Python and the statistical significance was set at $p < 0.05$.

3. Results
3.1. Descriptive Characteristics of Plant Growth and Agricultural Management Practices
The descriptive analysis showed that there were significant differences in plant growth, physiological traits and yield under different agricultural management conditions. The mean height of plants rose from 30.34 cm at the sixth plant leaf stage to 110.34 cm at the tenth plant leaf stage. The variability was comparatively low in chlorophyll measurement with mean values of 38.26 and 39.33 at the respective developmental stages. Average yield of grain of maize was 1.46 and the mean yield of stover was 4.45. Large standard deviations in both plant height and grain yield in the tenth stage of plant development suggested variability in crop response among experimental treatments, locations and seasons. Descriptive statistics of all major plant growth and productivity indicators are in Table 1.

Table 1. Descriptive Statistics of Plant Growth, Chlorophyll Content, and Yield Parameters

Variable	N	Mean	SD	Minimum	Maximum
Plant height, sixth leaf stage	448	30.34	10.45	11.00	62.00
Plant height, tenth leaf stage	448	110.34	61.86	33.75	295.50
Chlorophyll, sixth leaf stage	336	38.26	8.28	19.30	61.50
Chlorophyll, tenth leaf stage	336	39.33	6.97	22.20	57.90
Maize grain yield	448	1.46	1.56	0.00	5.94
Maize stover yield	448	4.45	2.09	0.67	13.00

Note: SD = standard deviation. Values are reported in the original dataset measurement scales; source documentation should be consulted to confirm units.

3.2. Comparison of Plant Height Under Different Agricultural Management Practices
There were significant differences in plant height across the seven soil-input treatments. The RFM treatment gave the highest mean height under D0 (126.29) and the RF gave the highest mean under D15 (126.68). Conversely, control treatment C had relatively low 83.08 and 87.47 under D0 and D15, respectively. The same trends were noted in the course of previous vegetative growth. In general, soil-input measures used had bigger differences in plant height when compared to the use of tillage practices. Figure 1 shows how the mean height of the plants varies according to tillage and soil-input.

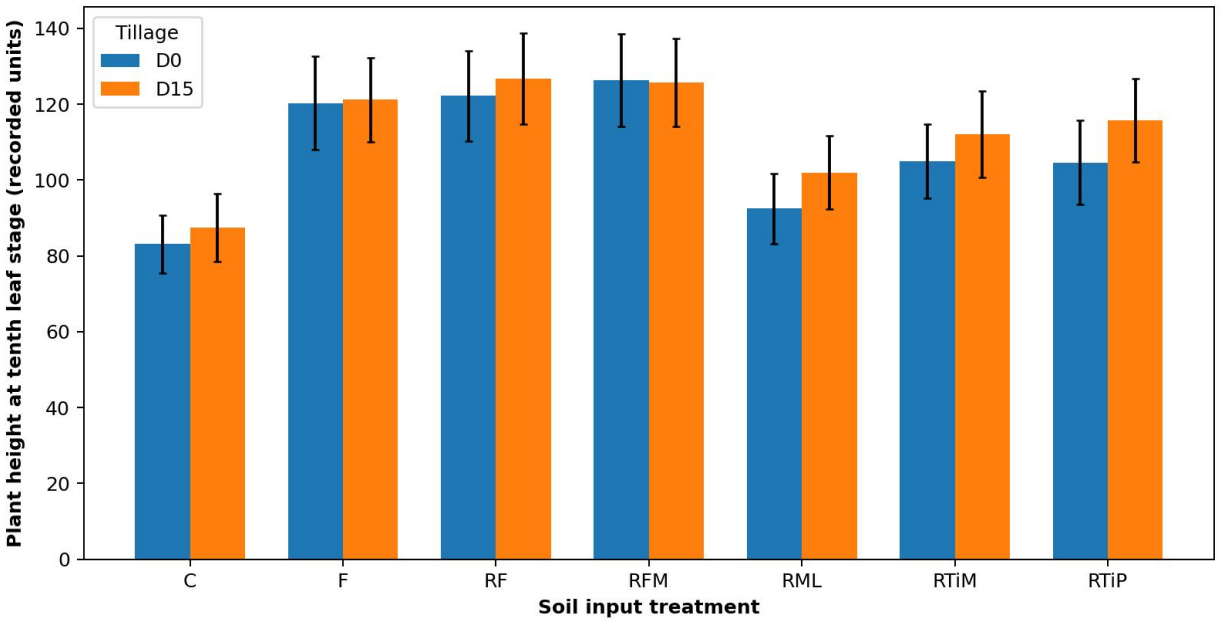


Figure 1. Comparison of Mean Plant Height Across Tillage and Soil Management Treatments
Bars represent mean tenth-stage plant height; error bars indicate standard errors.

3.3. Variations in Chlorophyll Content Across Agricultural Treatments

The content of chlorophyll differed in response to soil-input treatments, suggesting variations in physiological responses of plants. In the sixth leaf stage, the treatment F had the greatest mean chlorophyll (44.71) as compared to RF (43.78) and RFM (42.29). RF had the highest mean at the tenth leaf stage (44.54) as compared to the other two (RML and C) which had the lowest means of 33.70 and 33.80 respectively. There was generally no significant difference in the values of mean chlorophyll between D0 and D15 tillage practices. These observations indicate that the chlorophyll content variation was more related to the soil-input management than the overall tillage category. The summary of the chlorophyll readings of the agricultural management treatments is presented in Table 2.

Table 2. Comparison of Chlorophyll Content Across Tillage and Soil Management Practices

Management practice	Sixth leaf mean ± SD	Tenth leaf mean ± SD
Tillage treatments		
D0	38.22 ± 8.66	39.08 ± 7.48
D15	38.30 ± 7.90	39.58 ± 6.43
Soil-input treatments		
C	32.87 ± 6.78	33.80 ± 5.25
F	44.71 ± 7.40	43.99 ± 5.49
RF	43.78 ± 6.75	44.54 ± 5.53
RFM	42.29 ± 5.90	44.08 ± 4.74
RML	33.15 ± 6.80	33.70 ± 5.20
RTiM	36.84 ± 6.22	38.07 ± 5.92
RTiP	34.19 ± 7.54	37.14 ± 5.52

Note: Each tillage group contains 168 observations; each soil-input group contains 48 observations. Chlorophyll data cover LR16, SR16, and LR17.

3.4. Effects of Agricultural Management Practices on Maize Yield

There were significant differences in maize grain and stover yield between management treatments. The RFM treatment registered the maximum average yield of the grains in both categories of tillage with the values of 2.06 and 2.11 under D0 and D15, respectively. The control treatment on the other hand yielded fairly low yields of 0.82 and 0.93 grains respectively. The pattern of stover production was quite similar, with the mean of stover production largest (6.17) at the D15RFM combination. These results show that the selection of soil-inputs was linked with significant changes in the production of maize, but the changes between the two tillage types tended to be smaller when it comes to the production of grain. Figure 2 shows the distribution of mean maize grain and stover yields in comparison among management treatments.

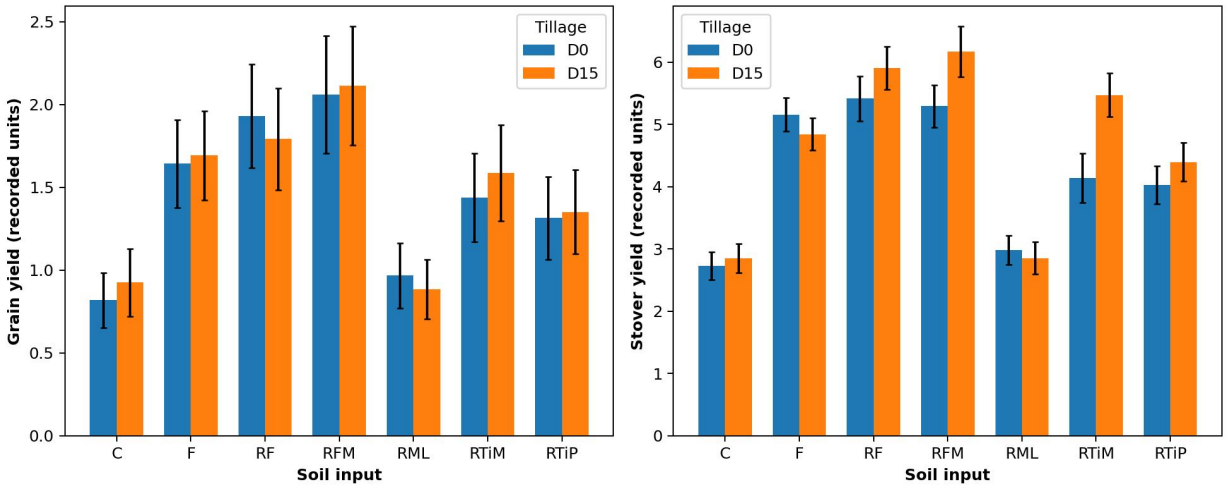


Figure 2. Comparison of Maize Grain and Stover Yield Across Agricultural Management Treatments

Bars show treatment means, with standard-error bars. The grain and stover measurements are displayed on separate panels.

3.5. Statistical Differences and Interaction Effects of Management Practices

Factorial ANOVA revealed significant effects of soil inputs on all the measured growth and productivity measures ($p < .001$). Tillage showed a large primary effect on stover yield ($p = .007$), but none on grain yield or height of the plant. The interactions with tillage and soil at the tenth leaf stage and on stover yield ($p = .036$) and chlorophyll content ($p = .012$) were found to be significant. The experimental conditions were also critical, as site and season were the factors that led to variation in the measured responses. The results of the factorial ANOVA on the growth of the plants, chlorophyll and yield of crops are reported in Table 3, and the factors were controlled by site and season.

Table 3. Factorial ANOVA Results for Plant Growth and Yield Parameters

Response variable	Tillage F (p)	Soil input F (p)	Interaction F (p)
Plant height, sixth leaf	0.60 (.439)	45.09 (<.001)	0.81 (.560)
Plant height, tenth leaf	3.74 (.054)	17.42 (<.001)	0.35 (.909)
Chlorophyll, sixth leaf	0.02 (.878)	50.79 (<.001)	1.82 (.095)
Chlorophyll, tenth leaf	0.78 (.379)	41.94 (<.001)	2.76 (.012)
Grain yield	0.06 (.808)	11.60 (<.001)	0.14 (.990)
Stover yield	7.42 (.007)	39.90 (<.001)	2.28 (.036)

Note: ANOVA models included tillage, soil input, their interaction, site, and season. These are ordinary least-squares factorial ANOVA results and should be interpreted provisionally until experimental independence and model assumptions are verified.

Figure 3 also explains the interactive effects of tillage and soil-input treatments on tenth-stage height of plants. The patterns of response in both tillage types were generally similar, but the level of plant height varied across the treatments of soil inputs. The treatment lines were relatively parallel, which was consistent with the non-significant interaction effect obtained with the tenth-stage height of plants.

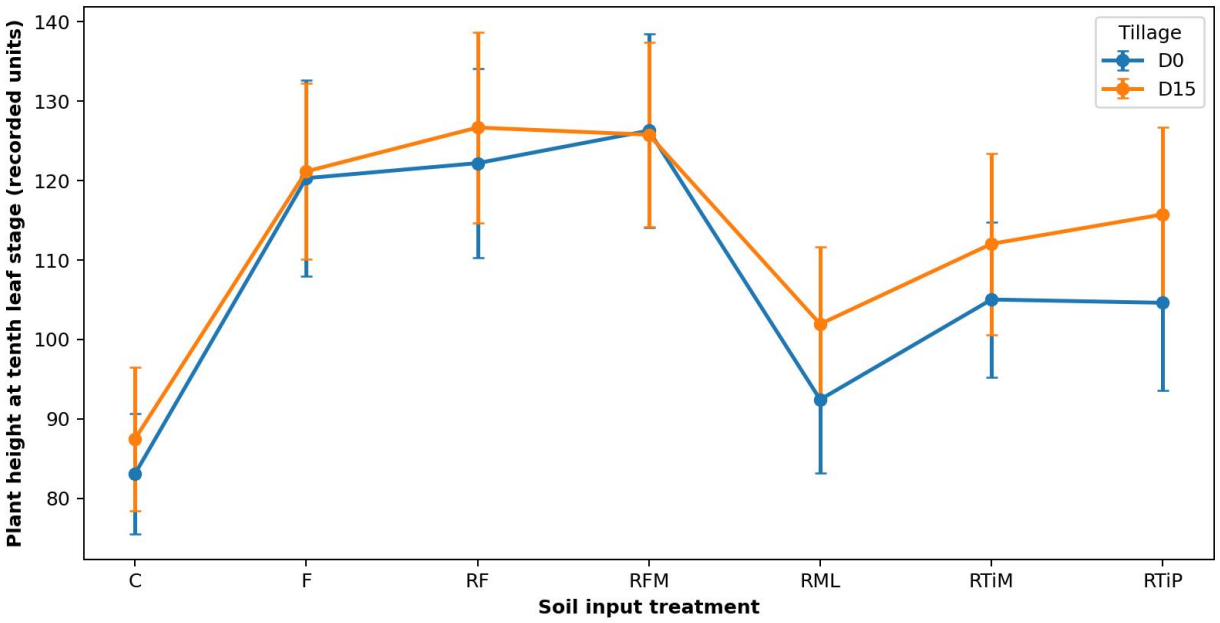


Figure 3. Interaction Effects of Tillage and Soil Management on Plant Growth Responses

Points represent treatment means for tenth-stage plant height; error bars indicate standard errors.

3.6. Relationships Between Plant Growth, Chlorophyll Content, and Crop Yield

The correlation analysis indicated positive significant relationships between various growth indicators of plants and the maize grain yield. The highest correlation coefficient between grain yield and plant height was at the tenth stage ($r = .767$, $p < .001$), followed by stover yield ($r = .509$, $p < .001$), and sixth-stage plant height ($r = .383$, $p < .001$). There was less positive correlation between chlorophyll content, specifically at the tenth leaf stage ($r = .115$, $p = .035$). Approximately 70.1% of variability in grain yield was explained using multiple regression analysis, which included plant growth indicators and categorical management, site, and seasonal factors ($R^2 = .701$). Plant height in the tenth stage was an important positive predictor after adjustment. The correlation coefficients and adjusted regression estimates of the plant growth indicators and maize yield are given in Table 4.

Table 4. Correlation and Regression Analysis of Plant Growth and Yield Variables

Predictor	N	Pearson's r	Correlation p	Adjusted β	Regression p
Plant height, sixth leaf	448	.383	<.001	0.0107	.145
Plant height, tenth leaf	448	.767	<.001	0.0198	<.001
Chlorophyll, sixth leaf	336	.248	<.001	0.0225	.042
Chlorophyll, tenth leaf	336	.115	.035	0.0087	.403
Stover yield	448	.509	<.001	—	—

Note: Regression used 336 complete observations ($R^2 = .701$; adjusted $R^2 = .688$). β represents unstandardized regression coefficients, adjusted for the other four plant-growth indicators and tillage, soil input, site, and season. Stover yield was included in correlation analysis only.

Figure 4 shows the correlations among tenth-stage height of plants, chlorophyll content, and yield of maize grains. The scatterplots show that there is a relatively good positive correlation between the plant height and the grain yield, whereas the correlation between the chlorophyll content and the yield is much weaker. These results indicate that the tenth leaf stage vegetative growth was a useful predictor of maize productivity under the experimental conditions that were observed.

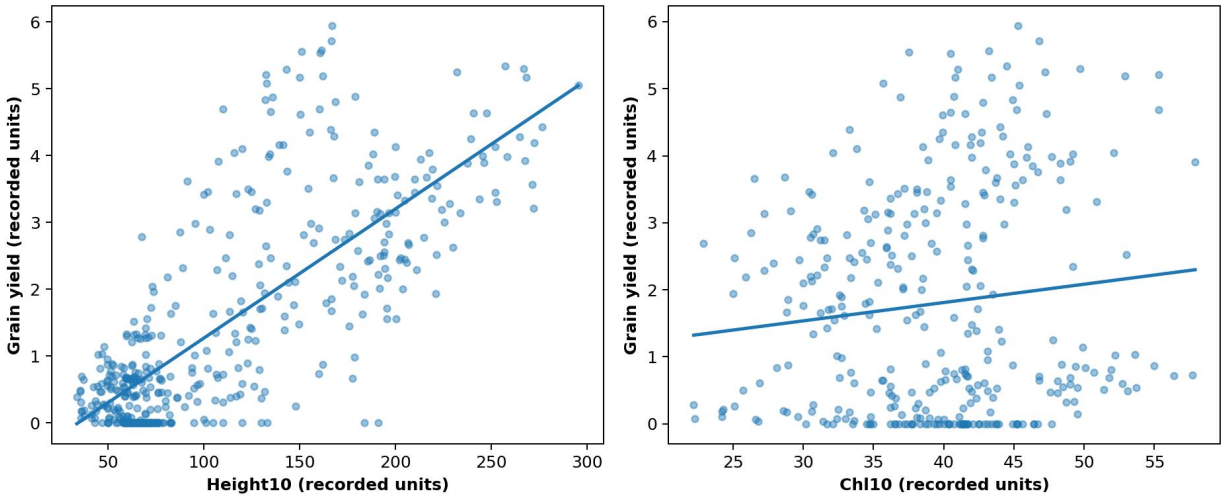


Figure 4. Relationships Between Plant Growth Indicators and Maize Grain Yield

Scatterplots display observed values and unadjusted linear trend lines for tenth-stage plant height and chlorophyll content against grain yield.

4. Discussion

The present study showed high variability in maize growth, chlorophyll content and productivity with different agricultural management practices. The soil-input treatments showed significant differences for all growth and yield parameters ($p < .001$), while the tillage treatments had limited comparisons. The plant height and grain yield of the crop under the RFM treatment were always higher than those under the other treatments, which means that the crop responded well to the RFM treatment. In addition, a strong positive correlation ($r = .767$) was obtained between 10th stage plant height and grain yield, indicating possible use of plant height as a productivity indicator. The results reinforce the role of nutrient availability interactions and their management on crop development, aligning with the research that focused on the role of integrated farming systems on maize performance (Liu et al., 2023; Qi et al., 2025).

Tillage methods had varying impacts on maize growth and productivity. The main effect of tillage was not significant ($p = .808$) for grain yield; however, stover yield was significant ($p = .007$). This separation implies that changing tillage practices affect vegetative biomass production but not necessarily grain yield. It has been shown in previous studies that tillage management influences the dry matter production and its distribution in maize plants (L.-Q. Wang et al., 2024). Likewise, conservation tillage has the potential to increase the storage of soil moisture and efficiency of resource use, but effects on yield vary with rainfall distribution and the environment (K. Zhang et al., 2022). The results here suggest that several indicators of crop performance should be used to assess the effectiveness of tillage.

Significant variation was recorded in the plant height, Maize yield and chlorophyll content between soil-input treatments. The higher chlorophyll values in F, RF and RFM treatments indicated comparatively good physiological conditions, and the highest mean grain yield was obtained for RFM treatment under both tillage systems. The nutrient availability and soil conditions are possible causes of these differences, but the present analysis did not identify them. Earlier, it was found that the application of integrated organic and inorganic fertilizer increased soil properties and maize productivity (Singh et al., 2024; L. Wang et al., 2024). Likewise, organic amendments have proven to be beneficial for maize growth under difficult soil conditions (Y. Wang et al., 2023). The observed treatment differences thus warrant the use of soil-input combinations in addition to physiological and productivity parameters.

The observed differences among agricultural treatments are consistent with previous studies that highlighted the need for integrated soil and nutrient management. Studies have found that biochar and nitrogen fertilization can enhance crop production and resource use efficiency under specific management scenarios (L. Wang, Yu, et al., 2023). Analyses of straw incorporation have also revealed connections between the placement of residue and maize production and the environment (J. Wang et al., 2024). Furthermore, there is robust evidence that the success of conservation tillage depends on production conditions and management factors (Q. Zhang et al., 2022). The present findings support these investigations by showing that soil-input treatments were more closely linked with differences in maize growth and yield than tillage alone.

Results demonstrate the value of choosing agricultural management practices based on crop response, not just on single practices. Improved vegetative development and grain production may present opportunities to increase agricultural productivity through soil-input treatments. In addition to yield, though, nutrient use efficiency, soil health, and environmental effects must be considered for sustainability. It is important to balance productivity with nutrient loss in the long-term management of nitrogen (L. Wang, Ma, et al., 2023). Likewise, research incorporating biochar, straw return, and fertilizer management highlights the importance of holistic strategies for soil enhancement and productivity (Wei et al., 2025). Therefore, site-specific conditions and resources should be taken into account when making management recommendations.

In addition, the data on rainfall and soil water were not always recorded for each experimental combination. The definitions of treatments and measures also need to be verified with reference to the experimental documentation. While

factorial ANOVA showed significant treatment differences, the results are still subject to experimental independence and model assumptions verification. Long-term treatment responses in a range of agroecological conditions; inclusion of further soil fertility indicators; and mixed-effects models for repeated plot-level observations should be used in future investigations. This kind of research would help build knowledge about the links between agricultural management, plant physiology, and crop productivity.

5. Conclusion

The present study investigated plant growth response to the contrasting agricultural management practices highlighting plant height, chlorophyll content and maize productivity differences under tillage and soil-input treatments. Results showed that soil-input management had a significantly greater effect on all the growth and yield variables measured, compared with the tillage practices. Of the treatments tested, RFM always resulted in greater grain yield and plant height, which suggests that it can be a useful tool to facilitate the development and productivity of maize. A higher chlorophyll content in one of the treatments also showed that soil management is an important factor affecting physiological response of crop plants. The tenth stage plant height was strongly correlated with plant grain yield, indicating that advanced vegetative growth a good indicator of crop productivity. Some interactions between tillage and soil-input treatments for selected parameters were significant as seen in factorial ANOVA results, especially for stover yield and tenth-stage chlorophyll content. The results highlight the need to analyze the combined agricultural management practices and not consider individual interventions alone. It was also found that crop responses were different between experimental sites and growing seasons, thus emphasising the importance of the environmental conditions. The overall results indicate a possibility to design site specific agricultural management plans seeking to enhance crop performance. Increased field observations and detailed soil data and environmental assessments over the long-term are recommended to enhance management recommendations and ensure sustainable production in agriculture.

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