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Effects of Zai Pits on the Growth and Yield of Green Grams in Maragua Subcounty, Murang'a County, Kenya

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***Abstract*: Globally, crop productivity has been hampered by a lack of nutrients and inadequate water availability. In addition to insufficient nutrients, another important factor causing crop yield to decline or stagnate is the restricted amount of soil moisture. In many agricultural locations, soil deterioration continues to be a significant concern. The soil's ability to support healthy crop growth has been further diminished by the depletion of vital nutrients brought on by the overuse of chemical fertilizers and poor soil management techniques. In semi-arid areas, where there is little vegetation cover and rainfall, soil erosion and nutrient loss are increased, making the situation especially grave. Farmers often face challenges in accessing the necessary resources to implement and maintain such techniques, including labor, tools, and technical knowledge. Additionally, the perceived complexity and unfamiliarity of new farming practices may deter farmers from adopting them. Overcoming these barriers requires tailored extension services that can provide farmers with the knowledge and support they need to successfully implement zai pits and other water conservation technologies. Understanding the factors that influence the adoption of these techniques is crucial for designing effective interventions that promote sustainable farming practices in semi-arid and arid regions.**

***Keywords*: Soil moisture, Nutrient loss, Zai pits, Water conservation.**

1. Introduction

A. Background of the Study

Globally, crop productivity has been hampered by a lack of nutrients and inadequate water availability (Hengsdijk & Langeveld, 2019). In addition to insufficient nutrients, another important factor causing crop yield to decline or stagnate is the restricted amount of soil moisture (Garg et al., 2017). Furthermore, Grafton et al. (2015) pointed out that the regular occurrence of prolonged dry spells and water shortages, which are common in rain-dependent farming in Africa as reported by Yazd et al. (2017), poses a serious threat to the country's projected future food needs by 2050. Similarly, the Intergovernmental Panel on Climate Change (IPCC) study from 2007 unequivocally asserts that climate change had a significant impact on agricultural productivity. According to the available information, rain-fed agriculture in Africa is particularly vulnerable to changes in the weather.

Kenya is not the only country in sub-Saharan Africa, where agriculture is heavily reliant on rainfall, to face the problems of water scarcity and low soil fertility. These problems have been made worse by climate change, which has resulted in more frequent droughts and unpredictable rainfall patterns. The necessity for adaptable agricultural methods that might assist farmers in adapting to the changing environment has been emphasized by this variability. In order to guarantee food security and enhance the standard of living for smallholder farmers in these areas, technological interventions such as methods for gathering water and managing soil fertility have become crucial. There has never been a more pressing need for climate change-resilient farming systems, and implementing such systems may be essential to reducing the negative effects of climate variability on crop yields.

Furthermore, in many agricultural locations, soil deterioration continues to be a significant concern. The soil's ability to support healthy crop growth has been further diminished by the depletion of vital nutrients brought on by the overuse of chemical fertilizers and poor soil management techniques. In semi-arid areas, where there is little vegetation cover and rainfall, soil erosion and nutrient loss are increased, making the situation especially grave. Therefore, the effects of soil degradation could be considerably mitigated by including soil conservation practices such as zai pits, which are intended to enhance soil fertility and water retention. When paired with organic inputs that can replace the soil's nutrient reserves, the zai pit method provides a sustainable and affordable way to assist restore the productivity of degraded soils.

Finally, although the zai pit method has demonstrated its effectiveness in improving crop yields in various parts of Africa, its adoption is still limited in certain areas due to various socio-economic and cultural barriers. Farmers often face challenges in accessing the necessary resources to implement and maintain such techniques, including labor, tools, and technical knowledge. Additionally, the perceived complexity and unfamiliarity of new farming practices may deter farmers from adopting them. Overcoming these barriers requires tailored extension services that can provide farmers with the knowledge and support they need to successfully implement zai

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pits and other water conservation technologies. Understanding the factors that influence the adoption of these techniques is crucial for designing effective interventions that promote sustainable farming practices in semi-arid and arid regions.

B. Statement of the Problem

Inadequate soil fertility and water scarcity presented considerable obstacles to rainfed agriculture in the low midland regions of Maragua Subcounty and Mbeere South Subcounty. At that time, there was scant information or published study concerning the effects of integrating zai pits with mulch or manure on green gram yields. While numerous research in Africa have yielded significant insights into the effects of zai pits on cereal crop performance, it was crucial to evaluate their use with alternative soil fertility management amendments.

This study sought to evaluate the impact of employing zai pits with mulch and manure on the production of drought-resistant green grams. The research aimed to examine how the integration of zai pits with mulch and manure improved the crop yield of green grams in semi-arid areas.

The use of integrated soil fertility management strategies, which blended zai pits with organic additions like mulch and manure, was regarded as a potentially sustainable approach to enhancing soil quality and crop productivity in the region. Although individual technologies such as zai pits have demonstrated potential in water capture and moisture retention, the combined impacts of integrating these methods with organic inputs have yet to be thoroughly investigated. The use of mulch and manure not only augmented organic matter in the soil but also enhanced soil structure, facilitated nutrient cycling, and mitigated soil erosion all essential elements for improving crop yields in arid regions. The study offered essential empirical information regarding the synergistic benefits of these activities, enhancing the comprehension of how integrated approaches might tackle the concurrent issues of water scarcity and soil fertility in Maragua Subcounty and Mbeere South Subcounty.

2. Literature Review

A. Green Grams Production

Green grams (Vigna radiata), commonly referred to as mung beans, are highly suited to semi-arid environments and thrive at elevations between sea level to 1600 meters above sea level. These regions are defined by temperate climatic conditions, which are crucial for the effective growth and development of the crop. Green grams thrive on well-drained sandy loam and clayey soils with a pH between 5.5 and 7.5, facilitating nutrient availability and root development (Mucheru-Muna et al., 2010). Their drought-resistant characteristics render them an advantageous option for smallholder farmers in arid and semi-arid lands (ASALs), where annual precipitation varies from 350 mm to 700 mm. increased rainfall beyond this threshold can result in increased vegetative growth, compromising reproductive structures and ultimately impacting pod formation and production (Nderi, 2016).

Effective site preparation is essential for attaining optimal plant density and robust crop establishment. Ploughing during arid periods is strongly advised as it improves soil aeration, inhibits weed proliferation, and exposes soil-dwelling pests to dehydration and predation, hence aiding in pest control (ICRISAT, 2015). The disintegration of soil clods to attain a fine to medium tilth promotes uniform germination and seedling establishment, essential for assuring a consistent crop stand.

B. Use of Zai Pit

The zai pit technique is a traditional water harvesting and soil fertility enhancement strategy that has been adapted and improved in semi-arid regions of Sub-Saharan Africa, including Kenya. It plays a vital role in ensuring food security by improving crop performance in areas that experience unreliable and erratic rainfall. This method supports three core conservation goals: soil fertility maintenance, water retention, and erosion control (Baptista et al., 2015). Zai pits function by concentrating water and nutrients around plant roots, thus creating microenvironments that enable crops to survive and thrive even under harsh conditions.

In Kenya, one of the most effective adaptations of this technology is the "five by nine" zai pit system. This system involves digging pits that measure approximately 0.6 meters in length, 0.6 meters in width, and 0.6 meters in depth a size slightly larger than conventional zai pits used in other parts of Africa Wafula (2022). The term "five by nine" stems from the planting arrangement within the pits, where five maize seeds are planted in arid areas and nine seeds in more humid environments. This configuration maximizes seed utilization while ensuring adequate root spacing for optimal nutrient and moisture uptake (Mati, 2005).

3. Research Methodology

The research was carried out in Maragua Subcounty, Murang'a County, and Mbeere South Subcounty, Embu County, Kenya.

The study adopted Randomized Complete Block Design (RCBD). Three blocks was created with 8 treatments replicated two times. At each site, a total of 48 sub-plots was used. This section highlights the procedures that used for land preparation, the treatments that was used which include Use of Zai Pits and Manure, Use of Zai Pits and Mulch, Use of Zai Pits, Manure, and Mulch, Use of Zai Pits Alone, Conventional Farming Alone, Conventional Farming with Manure, Conventional Farming with Mulch, and Conventional Farming with Mulch and Manure.

The target population in this study was comprised of all the green gram plants across the 48 plots to which the results of the sample analysis was generalized. The size of the target population per experimental site was 864 green gram plants. The data collection involved several key measurements. First, plant height was measured to assess vertical growth over time. Additionally, the stem girth of each plant was recorded to evaluate the thickness and robustness of the plant stems. The number of branches per plant was also counted, providing insight into the plant's overall development and potential for higher yield. Lastly, the grain yield of green gram was measured to determine the productivity and effectiveness of the experimental conditions.

The analysis and data management for the collected data was conducted using SPSS (Statistical Package for the Social Sciences).

4. Results and Discussion

A. Plant Height

Plant height was measured using a meter rule, stem girth using vernier calipers, and the number of leaves by direct counting. The results, as illustrated in Figure 4.1, clearly demonstrate that the tallest plants were recorded under the combined treatment of zai pit, manure, and mulch, while the shortest were observed under the conventional farming method with no amendments. This indicates a positive synergistic effect of integrating zai pits with organic inputs on plant vigor.

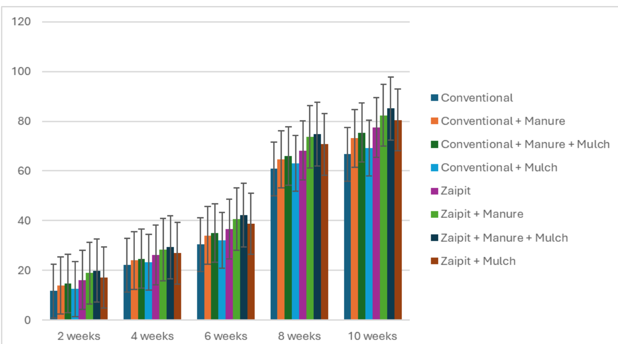

Fig. 1. Plant height at different weeks for Zai pit with or without mulch or manure

Effect of growth was assessed using plant height, girth and number of leaves and different weeks after planting. These parameters were taken every 2 weeks on 5 tagged plants per plot. Plant height was measured using a meter rule; girth diameter was measured using vernier callipers, while number of leaves was determined by counting the leaves. A summary of the data collected is given in Figures 1. for plant height; 4.2 for Girth diameter; and 4.3 for number of leaves.

To statistically assess whether the observed differences in plant height were significant across the different treatments, an ANOVA test was conducted. The results, presented in Table 4.1, revealed that the treatments had a statistically significant effect on plant height ($p < 0.001$), whereas site and block effects were not significant, indicating consistency in the treatment response across the experimental conditions. The high R-squared value (0.991) further confirms that the model explains almost all the variation in plant height due to treatment differences. As can be seen from Table 1, the sites and the blocks did not have significant differences (p values of 0.300 and 0.630 respectively) while the treatments had significant differences (p less than 0.01).

For this reason, the treatment means were compared using posthoc to determine which ones are significantly different and the results are summarized in Table 2.

Table 2
Post Hoc analysis summary for the effect of the treatments on plant height

Treatment	Height (cm)
Conventional	67.280a
Conventional + Mulch	70.048b
Conventional + Manure	72.460c
Conventional + Manure + Mulch	74.973d
Zaipit	77.647e
Zaipit + Mulch	80.135f
Zaipit + Manure	82.355g
Zaipit + Manure + Mulch	84.830h

A post hoc analysis was then carried out to determine which treatment means differed significantly from each other. The results, summarized in Table 2, show a clear gradation in plant height across the treatments. The conventional treatment recorded the lowest mean plant height (67.28 cm), while the highest mean (84.83 cm) was observed under the zai pit + manure + mulch treatment. Intermediate values were recorded for other treatment combinations, with a consistent trend showing that the inclusion of zai pits, either alone or in combination with organic amendments, led to progressively taller plants. Each treatment group was significantly different from the others, as denoted by different letters in the post hoc comparison, reinforcing the conclusion that zai pits and organic inputs significantly enhance green gram growth. These results underscore the importance of integrating zai pits with organic soil fertility amendments for improved crop performance in semi-arid farming systems.

These findings are in agreement with Mati et al. (2006), who found that zai pits enhance soil water availability, leading to improved vegetative growth. Similarly, Yazd et al. (2003) reported that zai pits, when combined with organic inputs, significantly increase plant biomass and height in semi-arid regions by concentrating moisture and nutrients around the root zone.

B. Stem Girth

To determine the growth of green grams the study adopted use of Vanier caliper to measure the girth of the stem at different growth time of the green gram. Measurement was taken at different interval of growth of 2 weeks' time period.

Table 1
Anova summary for the effect of the treatments on plant height

Tests of Between-Subjects Effects
Dependent Variable: Height (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Treatment	1577.026	7	225.289	607.868	.000
Block	.922	2	.461	1.244	.300
Site	.088	1	.088	.236	.630
Error	13.713	37	.371		
Total	**1591.748**	**47**			

a. R Squared = .991 (Adjusted R Squared = .989)

Table 3
Anova summary for the effect of the treatments on plant girth

Tests of Between-Subjects Effects
Dependent Variable: Girth (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Treatment	113.655	1	113.655	351.819	.000
Block	2.178	7	0.311	0.963	.459
Site	74.947	232	0.323		
Error	190.780	240			
Total	**77.126**	**239**			

a. R Squared = .028 (Adjusted R Squared = -.001)

Stem girth followed a similar upward trend, albeit with less statistical clarity. According to the post-treatment means, zai pit + manure + mulch recorded the highest mean girth (0.833 cm), while the conventional treatment had the lowest (0.543 cm). This suggests that while moisture and nutrient conservation promote stem thickening, the differences were not as stark as with plant height.

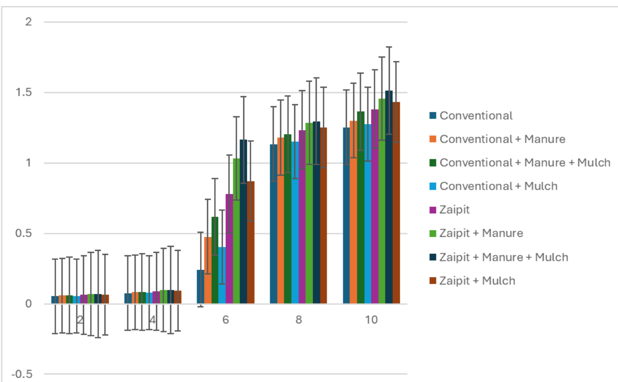

Fig. 2. Plant girth at different weeks for Zai Pit with or without mulch or manure

However, ANOVA analysis revealed that the differences in stem girth due to block effects were not statistically significant (F = 0.963, p = 0.459), and the adjusted R^2 was -0.001, indicating that the model had virtually no explanatory power for stem girth variation. In contrast, the treatment effect was highly significant (F = 351.819, p = 0.000), suggesting that treatment had a strong influence on stem girth. This implies that while blocking did not account for much variation, the applied treatments themselves played a substantial role in determining stem girth differences.

Table 4
Post Hoc analysis summary for the effect of the treatments on plant girth

Treatment	Subset 1
Conventional	.54301a
Conventional + Mulch	.58607b
Conventional + Manure	.62373c
Conventional + Manure + Mulch	.66513d
Zaipit	.71064e
Zaipit + Mulch	.75031f
Zaipit + Manure	.79309g
Zaipit + Manure + Mulch	.83329h
Sig.	.094

Despite the lack of statistical significance, the biological trend is notable and aligns with the findings of Ouedraogo et al. (2001), who reported improved stem robustness in legumes when organic inputs were integrated with zai pits. The combination of organic matter and better water infiltration likely enhanced the structural support of the plants, even if these effects were not strong enough to be statistically validated in this study.

C. Number of Leaves Per Plant

The number of leaves were determined to assess the growth of the green gram. It was done by counting the number of leaves at different interval of 2 weeks on the growth period of the green gram.

A substantial increase in the number of leaves per plant was observed with the application of zai pits and organic amendments. As shown in the treatment means, the conventional plot had the fewest leaves (28.53), while the zai pit + manure + mulch treatment produced the most (45.63), followed closely by zai pit + manure (43.20) and zai pit + mulch (40.70). This trend reflects improved vegetative development under integrated soil fertility and water conservation measures.

ANOVA analysis showed that the treatments had a statistically significant effect on the number of leaves (F = 4.316, p = .000). This indicates that at least one of the treatment groups had a significantly different number of leaves compared to others. The R^2 value of 0.115 suggests that about 11.5% of the variation in the number of leaves can be explained by the treatment. Although this effect is statistically significant, the adjusted R^2 of 0.089 indicates a relatively modest explanatory power, implying that other factors not included in the model may also contribute to the variability in leaf number.

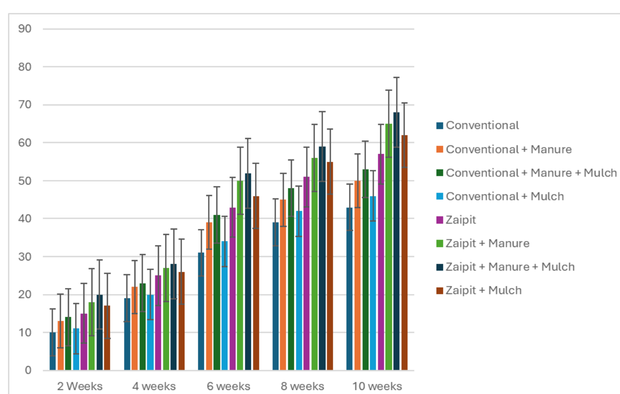

Fig. 3. Plant number of leaves at different weeks for zai pit with or without mulch or manure

Post hoc Duncan tests revealed a consistent gradation in leaf number, with significant differences among treatments. These results are consistent with findings by Kang et al. (1999), who

Table 5
Anova summary for the effect of the treatments on plant number of leaves

Tests of Between-Subjects Effects Dependent Variable: Number of Leaves					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Treatment	7,583.250	7	1,083.321	4.316	.000
Error	58,228.333	232	250.984		
Total	**395,112.000**	**240**			

a. R Squared = .115 (Adjusted R Squared = .089)

showed that combining organic matter with moisture-retaining structures enhances leaf production due to better soil aeration, nutrient availability, and microbial activity. Furthermore, Ngigi (2003) emphasized that increased leaf number is often an early indicator of higher biomass and productivity in legumes grown in moisture-stressed areas.

Table 6
Post Hoc analysis summary for the effect of the treatments on plant number of leaves

Treatment	Mean
Conventional	28.533a
Conventional + Manure	33.367b
Conventional + Manure + Mulch	35.767c
Conventional + Mulch	30.833d
Zaipit	38.300e
Zaipit + Manure	43.200f
Zaipit + Manure + Mulch	45.633g
Zaipit + Mulch	40.700h

Table 7
Duncan's multiple range test analysis: number of leaves

Treatment		Mean
Conventional	30	28.53a
Conventional + Mulch	30	30.83b
Conventional + Manure	30	33.37c
Conventional + Manure + Mulch	30	35.77d
Zaipit	30	38.30e
Zaipit + Mulch	30	40.70f
Zaipit + Manure	30	43.20g
Zaipit + Manure + Mulch	30	45.63h
Sig.		.108

Duncan's post hoc test results for the number of leaves per plant provide a nuanced view of how different treatments influenced vegetative growth in green grams. The table categorizes treatments into overlapping subsets based on statistical similarity at a significance level of α = 0.05.

The conventional treatment recorded the lowest mean number of leaves (28.53) and stood alone in the first subset, indicating it was significantly different from all other treatments. This underscores the limited vegetative performance of green grams when grown under traditional practices without any soil amendments or water conservation techniques. The conventional + mulch treatment had a slightly higher mean (30.83 leaves) and was grouped in Subset 2, sharing statistical similarity with the conventional and conventional + manure treatments. Although it showed some improvement, the differences were not large enough to establish a distinct grouping from conventional methods. This suggests that mulch alone provides only marginal benefits in terms of leaf development.

The conventional + manure treatment (33.37 leaves) appeared across Subsets 2, 3, and 4, indicating its intermediate status—better than the conventional and mulch-only treatments, but still statistically overlapping with both. The integration of manure begins to show a noticeable improvement in leaf number, confirming findings by Palm et al. (2001), who noted enhanced vegetative growth with the addition of organic nutrients. The turning point is seen with conventional + manure + mulch (35.77 leaves) and zai pit (38.30 leaves), which appear in Subsets 3 and 4, now firmly distinguishing themselves from all conventional-only treatments. These combinations show that either organic inputs alone or zai pits alone can enhance leaf growth, but their impact is stronger when used together.

The highest values were observed in the zai pit + mulch (40.70), zai pit + manure (43.20), and zai pit + manure + mulch (45.63) treatments. These were grouped progressively into the upper subsets, with the zai pit + manure + mulch treatment standing alone at the top, indicating it was significantly superior to all others. This confirms the synergistic effect of combining moisture conservation (zai pits) and soil fertility enhancement (manure and mulch) in promoting vegetative growth. Similar findings were reported by Yazd et al. (2003), who showed that integrating soil fertility with in-situ water harvesting significantly boosts biomass production. The significance values (ranging from 0.097 to 0.108) for the subsets are slightly above the conventional alpha level of 0.05, which suggests that while there are notable trends and gradations, the strict statistical separations between groups are moderate, allowing some overlap in interpretation.

Duncan's test confirms that leaf number increases progressively with the introduction and combination of mulch, manure, and zai pits. The highest vegetative performance was achieved under zai pit + manure + mulch, which was significantly different from the conventional baseline. These results emphasize the importance of integrated soil and water management practices in enhancing green gram productivity under semi-arid conditions.

5. Discussion

A. Plant Height

The progressive increase in plant height from conventional to zai pit + manure + mulch reflects the synergistic benefits of combining in-situ water harvesting (zai pits) with soil fertility enhancements (manure and mulch). These practices likely improve soil moisture retention, increase nutrient availability, and create favorable root zone conditions for vigorous growth.

This agrees with the findings of Mati et al. (2006), who emphasized the moisture-retention advantage of zai pits, and Yazd et al. (2003), who noted increased biomass and plant height when zai pits were combined with organic inputs in semi-arid areas. Thus, the integration of zai technology with organic matter significantly contributes to plant vigor and height in resource-constrained environments.

B. Stem Girth

However, the gradation observed in Table 4, where each treatment combination showed a marginal improvement over the previous, still indicates a consistent trend. This aligns with the findings of Ouedraogo et al. (2001), who observed increased stem robustness in legumes when zai pits were used in combination with organic matter.

The lack of statistical significance could be attributed to greater measurement variability or the possibility that stem girth responds more slowly to soil and water management interventions compared to plant height. Nevertheless, the visible trend supports the idea that integrated management improves structural plant traits.

C. Number of Leaves Per Plant

The post hoc analysis (Table 6) confirmed that treatments significantly affected leaf production, with zai pit + manure + mulch resulting in the highest number of leaves (45.63), followed by zai pit + manure (43.20) and zai pit + mulch (40.70). The conventional method had the lowest count (28.53). This trend suggests enhanced photosynthetic surface area and biomass accumulation under integrated soil and water management. The presence of mulch helps regulate soil temperature and moisture, while manure supplies essential nutrients that stimulate vegetative growth.

The Duncan test (Table 7) further supported these findings by grouping treatments into statistically distinct subsets. These results agree with Kang et al. (1999) and Ngigi (2003), who highlighted the role of soil fertility and water conservation in boosting leaf production and plant performance in moisture-stressed areas.

Although the significance values for the Duncan subsets were slightly above 0.05, the biological consistency of results validates the effectiveness of combining zai pits with manure and mulch in improving leaf development.

Overall, the study confirms that the combination of zai pits with organic amendments significantly enhances the vegetative performance of green grams in semi-arid environments. While plant height and number of leaves showed strong statistical significance and clear treatment trends, stem girth exhibited a biological but non-significant response.

These results collectively reinforce the agronomic importance of integrated soil fertility and water management practices for improving crop growth parameters. The application of zai pits alongside manure and mulch can be recommended as a sustainable strategy for increasing green gram productivity under dryland farming conditions.

6. Summary, Conclusions and Recommendations

A. Summary

The study assessed the effects of zai pits, mulch, and manure on the growth and yield of green grams using key growth parameters such as plant height, stem girth, and number of leaves. Measurements taken biweekly revealed that the combined treatment of zai pits, manure, and mulch significantly enhanced plant growth compared to conventional methods, with the tallest plants and highest leaf numbers recorded under this treatment. ANOVA results confirmed significant treatment effects on plant height and leaf number, though differences in stem girth were not statistically significant. These findings demonstrate a positive synergistic impact of integrating soil fertility amendments with water conservation practices on vegetative growth, consistent with previous research.

Yield data further supported these results, showing progressive increases from conventional farming to combined zai pit, manure, and mulch treatments. The conventional treatment recorded the lowest yields, while zai pit-based treatments, especially when combined with manure and mulch, produced the highest yields. Duncan's multiple range test revealed seven distinct subsets, illustrating incremental and statistically significant yield improvements with each added treatment component. This highlights the critical role of integrated soil and water management in optimizing green gram production in semi-arid environments.

B. Conclusion

The study concludes that the integration of zai pits with organic soil amendments like manure and mulch significantly improves green gram growth and yield under semi-arid conditions. The combined use of these practices enhances soil moisture retention, nutrient availability, and overall plant vigor, resulting in superior vegetative development and maximum yields. These findings reinforce the importance of adopting holistic soil fertility and water conservation strategies for sustainable and productive legume farming in dryland regions.

C. Recommendations

The study recommends the following

1. There is need for smallholder farmers in semi-arid regions should adopt integrated zai pit technology combined with organic amendments such as manure and mulch to maximize green gram productivity and improve resilience to moisture stress.
2. Agricultural extension services should promote training and awareness programs that emphasize the benefits and implementation of combined soil fertility and water conservation techniques to enhance crop growth and yields sustainably.

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