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Impact of Integrated Nutrient Management on Physical Properties of Pineapple Grown in Existing Agroforestry Practice at Madhupur Garh, Bangladesh

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Abstract: This study evaluates the impact of Integrated Nutrient Management (INM) on the physical growth parameters and fruit yield of pineapple (*Ananas comosus* cv. Giant Kew) cultivated under an agroforestry system in Madhupur Garh, Bangladesh. Conducted over a 17-month period (February 2023–July 2024), the field experiment employed a Randomized Complete Block Design (RCBD) with four treatments: T1 (Recommended Fertilizer Dose), T2 (Mulching + 75% FRG), T3 (Mulching + 50% FRG), and T4 (Farmer's Practice). Data on plant height, leaf dimensions, number of leaves and propagules, fruit length, diameter, weight, days to maturity, and number of marketable fruits per plot were collected and analyzed using Statistix 10 software. The results revealed that the T2 treatment (Mulching + 75% FRG) significantly outperformed other treatments across most parameters. T2 plants exhibited the greatest height (94 cm), highest leaf number (55), longest fruit (17.46 cm), and heaviest fruit (1720 g), while also achieving the earliest maturity (121 DAF) and the highest number of marketable fruits per plot (61). In contrast, T4 (control) consistently recorded the lowest performance across most parameters. These findings highlight the synergistic benefits of combining reduced chemical fertilizer inputs with organic practices such as mulching in pineapple-based agroforestry systems. The study underscores INM as a viable and sustainable alternative to conventional fertilization, enhancing both productivity and environmental stewardship. Recommendations derived from this research support improved nutrient use efficiency and practical, farmer-friendly approaches to sustainable pineapple cultivation in Bangladesh's agroforestry contexts.

Keywords: Integrated Nutrient Management; Pineapple cultivation; Agroforestry systems; Soil fertility; Fruit quality.

INTRODUCTION

The global population is increasing rapidly, projected to rise from 7.7 billion in 2019 to 8.6 billion by 2030 and 9.7 billion by 2050, presenting significant challenges to food security worldwide (United Nations, 2019). To meet the growing food demands, agricultural production must increase by over 60% by 2050 (FAO, 2015). Agroforestry, the practice of cultivating woody perennial trees alongside crops—with or without livestock—is a promising sustainable land management strategy. It optimizes spatial and temporal land use, improves biodiversity, and enhances land productivity while delivering economic, social, and environmental benefits, particularly for smallholder farmers relying on limited land resources (FAO, 2015; FAO, 2022).

In Bangladesh, pineapple (*Ananas comosus*) is a key cash crop grown extensively under agroforestry systems in favorable regions such as Madhupur Garh, Tangail, as well as Bandarban, Khagrachari, Sylhet, and Chittagong (Kader et al., 2010). Major varieties cultivated include Giant Kew (locally known as Kalander), Honey Queen (Jaldubi), Red Spanish (Ghorashal), and the late-maturing local variety "Asshini" (Hossain et al., 2016). Pineapple cultivation spans approximately 45,685 hectares nationally, producing nearly 234,865 metric tons annually (Hossain et al., 2016).

Pineapple's importance stems from its desirable physical and organoleptic properties, including unique aroma, sweetness, and acidity, making it the third most produced tropical fruit globally after bananas and mangoes (Mus et al., 2017). It is consumed fresh and in processed forms such as canned fruit, juice, jams, yogurts, pastries, and ice creams, contributing to food security and income generation in tropical regions (Mus et al., 2017).

Nutrient management plays a crucial role in pineapple growth and fruit development. Studies have shown that site-specific nutrient management enhances pineapple yield by 22.9% to 44.9%, along with improved soil fertility and nutrient uptake (Khuong et al., 2024). Integrated Nutrient Management (INM), which combines organic and inorganic fertilizers, has been found to maintain or improve growth and yield parameters compared to conventional fertilizer use, without adversely affecting important fruit qualities (Martínez-Conde et al., 2024).

Physical characteristics such as plant height, leaf length and breadth, leaf number, number of propagules, and fruit attributes including length, diameter, weight, and total yield, are critical indicators of plant vigor and productivity. In agroforestry systems, these traits are influenced by nutrient availability, soil health, and environmental conditions.

Research in Madhupur Garh has demonstrated that INM treatments, particularly mulching combined with 75% of the recommended fertilizer dose, significantly improve physical growth parameters of pineapple (Senapati et al., 2020). These integrated approaches optimize nutrient use efficiency, resulting in taller plants with more leaves and propagules, and larger, heavier fruits with higher total yield.

Previous experiments conducted at Bangladesh Agricultural University on pineapple maturity stages also indicated that physical fruit properties, such as size and weight, vary with maturity and storage conditions, impacting shelf life and market quality (Dhar et al., 2008). The highest physical quality was recorded at optimal harvest maturity, emphasizing the importance of managing growth stages in pineapple production.

Agroforestry systems contribute positively to physical crop attributes by creating favorable microclimates, enhancing soil moisture retention, and encouraging biodiversity that reduces pest pressure, thereby supporting healthier plant growth (Wadud et al., 2011). Pineapple's compact growth form and efficient water use make it well-suited for integration in these systems, where physical properties can be improved through balanced nutrient management.

Despite the recognized benefits of INM and agroforestry in enhancing crop production, limited research has focused on their combined impact on the physical properties of pineapple in Bangladesh, particularly in Madhupur Garh. Addressing this gap, the current study aims to evaluate how INM influences physical parameters, providing practical recommendations for sustainable pineapple cultivation under agroforestry.

MATERIALS AND METHODS

Study area

The study was conducted in the Madhupur Sal Forest consisting of Tangail and Mymensingh districts of Bangladesh. Data were collected from Magontinagar village (Figure 1). The village under research were located in the Madhupur Tract Agroecological zones (Islam et al., 2015).

Geographical description of the study area

The research was conducted within the Madhupur Tract, also known as Madhupur Garh, covering a large part of the Tangail district and a smaller portion of the Mymensingh district in Bangladesh (Islam et al., 2015). Geographically, the Madhupur Tract is located between latitudes 23.050° to 24.050° north and longitudes 89.054° to 90.050° east. The soil belongs to the bio-ecological zone of the Madhupur Sal Tract, with the top layer comprising well-drained, crumbly clay loam to clay, overlaying a similarly structured clay subsoil, and varying gully formations. Presently, more than 50,000 farmers, including approximately 20,000 individuals from tribal communities, engage in agroforestry practices involving tree-crop cultivation in the Madhupur Tract (Islam et al., 2015). Currently 18-20 % of the original Sal Forest cover remains in the Madhupur Tract due to extensive deforestation, land conversion for agriculture and settlements, and encroachment over the past several decades (Ratul et al., 2021). In response to deforestation, agroforestry was introduced on previously forested land with active local participation.

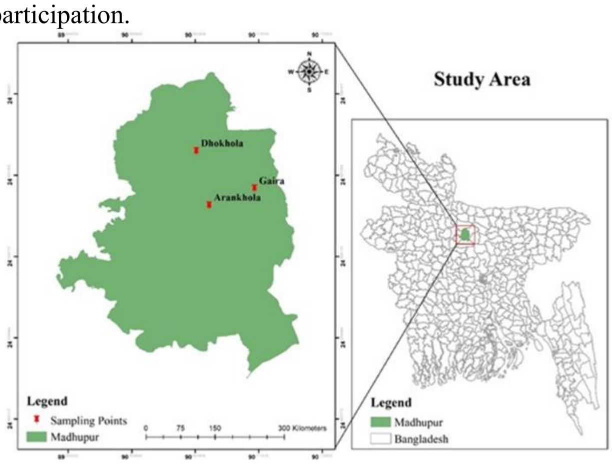

Figure 1. Study area map showing Magontinagar village, Madhupur

Soil fertility status

The soils of the Madhupur Tract are highly acidic, with pH values ranging from 3.96 to 5.11, which can limit nutrient availability. Organic carbon content is low to medium (0.50% to 1.27%), affecting soil structure and nutrient retention. Nutrient levels are generally low, with total nitrogen ranging from 0.07% to 0.16%, available phosphorus from 2.45 to 16.62 ppm, and potassium from 16.09 to 98.41

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ppm. These deficiencies hinder plant growth, emphasizing the need for lime application to reduce acidity and fertilization to replenish nitrogen, phosphorus, and potassium for improved soil fertility and crop productivity (Ratul et al., 2021).

Participatory agroforestry improves soil quality by increasing organic matter, soil carbon, and nutrient availability. By integrating trees with crops, it enhances organic material through tree litter and root systems, improving soil structure and water retention. Trees also capture and store carbon, contributing to soil fertility. Additionally, certain tree species fix nitrogen, enriching the soil with this essential nutrient, while deep-root systems make nutrients available to surface crops. Overall, participatory agroforestry mitigates soil degradation and boosts agricultural productivity, benefiting local communities (Islam et al., 2024).

Development of pineapple based agroforestry practices

The potential for pineapple-based agroforestry systems in Madhupur Garh, Bangladesh, has been increasingly recognized as a sustainable land-use strategy that harmonizes ecological preservation with economic benefits for local farming communities. Situated within the region's tropical moist deciduous forest ecosystem characterized by nutrient-deficient sandy loam soils, pineapple (*Ananas comosus*) cultivation has demonstrated remarkable adaptability when integrated with native tree species such as sal and mahogany integrated systems not only enhanced soil fertility through improved organic matter content and nutrient cycling but also provided farmers with crucial supplementary income during the early years of tree establishment (Rahman et al. 2020).

Complementary research by Islam et al., (2015) further reinforced these findings by documenting a 25-30% increase in overall land productivity when pineapple was intercropped with jackfruit (*Artocarpus heterophyllus*) stands, while simultaneously addressing soil conservation challenges through the pineapple plant's dense leaf cover that effectively reduced erosion rates in the region's sloping agricultural lands. Beyond these agronomic advantages, pineapple-based agroforestry systems in Madhupur Garh have shown significant potential for climate change adaptation, offering improved microclimate regulation and enhanced carbon sequestration capacity compared to traditional monoculture practices.

The research site was established seven years ago, with pineapple suckers being planted in the first week of February 2023 and harvested in the last week of June. The site accommodates around 200-250 Acacia trees per hectare, strategically spaced to allow optimal growth. Thinning and pruning are integral components of the site's silvicultural management. These practices support tree growth by reducing competition for crucial resources such as sunlight, water, and nutrients. Enhancing air circulation and sunlight penetration fosters healthier development for both trees and crops. The wood obtained from thinning is versatile, serving as timber, fuelwood, or a source of additional income when sold in local markets. Moreover, pruned branches and leaves are commonly used as mulch or organic compost, enriching soil fertility and minimizing the dependence on chemical fertilizers. Some farmers also repurpose pruning materials as livestock fodder. These sustainable approaches enable nutrient recycling within the soil, thereby boosting both productivity and sustainability in agroforestry systems. Typically, 50% of the thinning is carried out within the first seven years, while the remaining trees are harvested after completing a 10-year cycle.

Duration of the experiment

The experiment was carried out in an existing pineapple-based agroforestry system. The field experiment was conducted from February 2023 to July 2024. Field data were collected, and fresh samples for laboratory testing were taken on June, 2024. The samples were sent to the laboratory as soon as possible. Chemical analyses of the pineapple samples were conducted at the Biochemistry and Molecular Biology Laboratory and Horticulture laboratory of Bangladesh Agricultural University. The laboratory tests were conducted between June 23 to July 10, 2024.

Design of the experiment and Treatment

The study was conducted by Randomized Complete Block Design with three replications. The study had four treatments (T) and each treatment had three replications (R). So, there were 12 plots in farmer's field. Each plot size was 5m×5m.

T1= Recommended Fertilizer dose (FRG) for pineapple
T2=Mulching+75% FRG for pineapple
T3= Mulching+50% FRG for pineapple
T4= Control (Farmer's practice)

R1T1	R2T3	R3T4
R1T4	R2T1	R3T2
R1T3	R2T2	R3T1
R1T2	R2T4	R3T3

Figure 2. Experimental layout

Planting material and sucker establishment

Pineapple sucker is used as planting material. Pineapple variety is Kalender (Giant Kew) which is popular variety. Flesh of the ripe pineapple is yellow color, eye pointed and developed, leaf with thorn, very tasty. Suckers are one of the primary vegetative propagules used for pineapple cultivation, emerging from the leaf axils near the base of the mother plant. For successful establishment, it is important to select healthy, disease-free, medium-sized suckers weighing between 300 to 450 grams. Once selected, the suckers should be cured by drying them in a shaded area for 3 to 5 days, which helps reduce the risk of fungal infections. Before planting, treating the suckers with a fungicide such as Bordeaux mixture or Captan is recommended to prevent disease.

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Land preparation and transplanting of sucker

The respective farmer's land was first cleared and soil was tilth well and the study followed minimum tillage (one time) with less disturbance of soil. After weeding, the soil was then mix with fertilizers as per the below rate. Except urea, all fertilizers together with 3 ton/ha cow dung were applied during land preparation and well mixed with soil. The pineapple suckers were transplanted during the first week of April, 2023. Only 50% of urea was applied after 30 days of transplanting pineapple suckers and rest of 50% was applied after 4 months of first application to the respective plot. Besides, we left farmer to applied fertilizers as per their rate. The pineapple suckers were transplanted at the rate of 52000 sucker/ha for Giant Kew variety with existing agroforestry trees. The spacing was 20 cm for plant to plant and 40 cm for row to row, after every two rows there was 80 cm distance.

Application of fertilizer

In this study, varying doses of fertilizer were applied to the experimental plots to assess their impact on crop growth and yield.

Table 1. Recommended of fertilizer doses

Fertilizer	FRG (Kg/100m2/year) T1	75% T2	50% T3	Control T4
N	0.6	0.45	0.3	2.47
P	0.25	0.1875	0.125	1.2
K	0.6	0.45	0.3	1.2
S	0.07	0.0525	0.035	0.2

Intercultural operations

Earthing Up

Due to its shallow root system pineapple plants are prone to lodging. Lodging of plants during fruit development results in lopsided growth and uneven development of fruits. Hence earthing up is an important operation in pineapple cultivation, as it helps in promoting good anchorage to plants. It involves pushing soil into the trench from the ridge, where trench planting is common.

Weeding

Weed Control Hariyali and nutgrass are the common weeds in pineapple plantations. Weeding is important from the economic point of view

Mulching

Mulching is one of the cultural practices aimed at weed control and soil-moisture conservation. It is essential when pineapple is gown as a rainfed crop and is feasible where flatbed planting is followed. In South India, mulch of leaves or straw is spread on soil between the plants. However, use of black polythene film as mulch is equally beneficial.

Removal of Suckers, Slips and Crowns

Suckers begin to grow when the inflorescence emerges, while slips develop alongside the fruit. Only one or two suckers are kept on the plant for ratooning, while any additional suckers and all slips are removed. This practice is crucial, as their growth can weaken the plant and hinder fruit development. Desuckering can be postponed as much as possible since studies show that fruit weight increases with a higher number of suckers per plant. However, a greater number of slips delays fruit maturity, so they are removed once they reach the appropriate size for planting.

Procedure for measurement of data collected parameter

Plant height

The average height of the three sample plants was calculated by measuring the distance between the ground and the top of the plant in centimeters. A measuring tape was used to determine the height.

Leaf length

Using a measuring tape, the length of each leaf was measured in centimeters from base to apex, and the average was calculated.

Leaf width

Leaf width was measured in centimeter at the widest point of the leaf and we used measuring tape.

Leaf number

The total number of leaves on selected plants was counted, and their average was recorded as the leaf number.

Number of propagules

The suckers (emerging from below the soil with roots) and slips (growing at the base of the fruits) from the selected plant were counted, and their average value was taken.

Days to fruit maturity

The estimation was based on the number of days required for the pineapple to reach maturity (ready for harvest but not necessarily ripe) and be suitable for marketing. Fruit color serves as a reliable indicator of maturity, as the outer shell gradually transitions from green to yellow, and the pineapple's spines become flat as it matures.

Fruit length

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Three mature ripen pineapple were harvested from each treatment. Total twelve mature ripen were harvested from all treatments. Then collected pineapple was sent to the Biochemistry Laboratory of BAU. Then Fresh fruit's lengths were weighted individually using digital balance.

Fruit diameter

Three mature ripen pineapple were harvested from each treatment. Total twelve mature ripen were harvested from all treatments. The collected pineapples were then sent to the Biochemistry Laboratory at BAU. Each fruit's diameter was individually measured using slide calipers, with the measurements recorded in centimeters.

Fruit weight

Three mature ripen pineapple were harvested from each treatment. Total twelve mature ripen were harvested from all treatments. The collected pineapples were then sent to the Biochemistry Laboratory at BAU. Each fresh fruit was individually weighed using a digital balance, with the weight recorded in grams (g).

Number of fruits per plot

The total number of marketable fruits in each plot was manually counted.

Data analysis

All of the relevant data were collected in Excel and then analyzed using the Randomized Complete Block Design (RCBD) method to ascertain the experimental results' statistical significance. Using the Statistix 10 software tool, the means of all the data gathered on physical parameters were computed and statistically assessed in order to ascertain the experimental results' statistical significance. The Least Significant Difference (LSD) test was used to evaluate the mean differences at a 5% level of significance. Ultimately, the findings were organized into pivot tables, and the results chapter will include graphical representations.

RESULTS AND DISCUSSION

Plant Height (cm)

The analysis of variance (ANOVA) results indicated a highly significant effect of treatments on plant height ($F = 33.36$, $P < 0.01$). Therefore, plant height highly significantly influenced by different fertilizer treatment. The coefficient of variation (CV) was 7.59% suggesting moderate experimental variability. The tallest plant (94 cm) was recorded in T2 treatment (Mulching + 75% FRG - Recommended Fertilizer dose) and second tallest plant (70 cm) was also recorded in T1 treatment and shortest plant was recorded in T4 treatment.

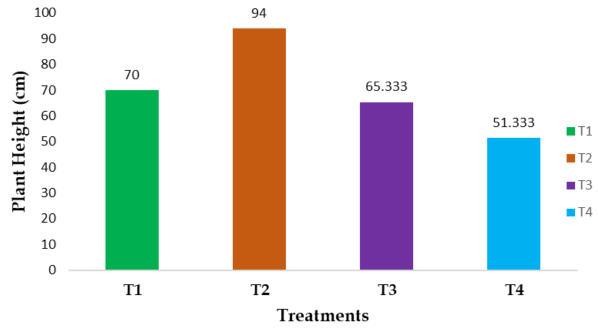

Figure 3. Effect of different treatments on plant height (cm) of pineapple

Leaf length (cm)

The analysis of variance (ANOVA) results indicated significant effect of treatments on leaf length ($F = 8.98$, $0.01 < P < 0.05$) with CV of 4.29%. The highest leaf length (67 cm) was recorded in T2 treatment (Mulching + 75% FRG - Recommended Fertilizer dose) and the lowest leaf length (56 cm) was recorded in T4 (control) treatment.

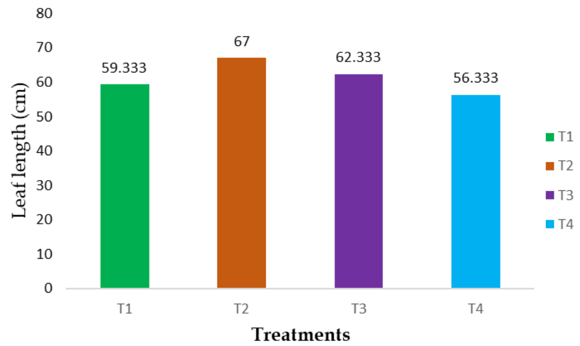

Figure 4. Effect of different treatments on leaf length (cm) of pineapple

Leaf width (cm)

Leaf breadth across treatments also showed a Non Significant variation ($F = 2.16$, $P > 0.05$). The coefficient of variation (CV) was 8.55% suggesting minimal experimental variability. The maximum leaf width (4.3667 cm) was found in T1 treatment (FRG - Recommended Fertilizer dose) while the smallest leaf width (3.6667 cm) was recorded in T4 (control) treatment.

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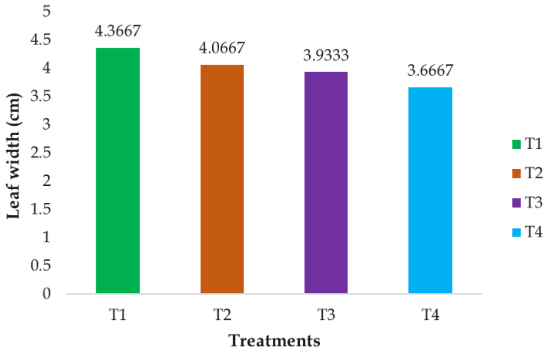

Figure 5. Effect of different treatments on leaf breadth (cm) of pineapple

Number of leaves

Leaf number across different treatments showed a highly significant variation (F = 46.42, P<0.01). Coefficient of variation (CV) was 9.62% suggesting minimal experimental variability. The maximum leaf number (55) was found in T2 treatment (Mulching + 75% FRG - Recommended Fertilizer dose), second highest leaf number (48.667) was also on T1 treatment (FRG - Recommended Fertilizer dose), while the minimum leaf number (20.667) was recorded in T3 treatment (Mulching + 75% FRG - Recommended Fertilizer dose).

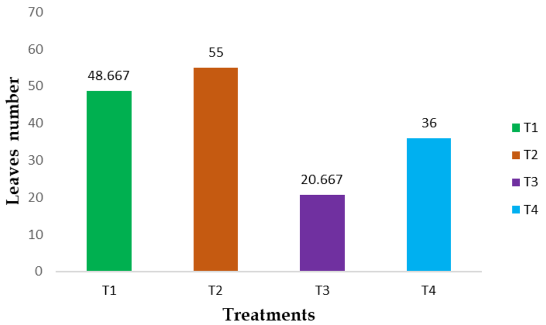

Figure 6. Effect of different treatments on number of leaves of pineapple

Number of propagules

Number of propagule across different treatments showed a significant variation (F = 7.71, P<0.01< 0.05). Coefficient of variation (CV) was 22.29% suggesting moderate experimental variability.The highest number of propagule (4.3333) was recorded in T2 (Mulching + 75% FRG - Recommended Fertilizer dose) and second highest number of fruit (3.3333) was also recorded in T1 treatment (Recommended Fertilizer dose) while the lowest number of fruit (1.6667) was recorded in T4 (control) treatment.

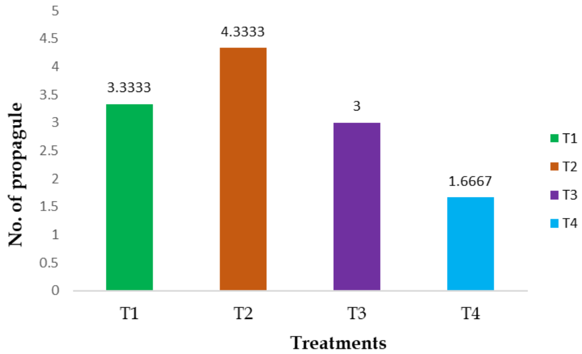

Figure 7. Effect of different treatments on number of propagules of pineapple

Fruit Parameters

Significant differences (p < 0.01) were observed among treatments for all measured fruit traits. Treatment T2 produced the earliest maturing fruits (121 DAF), along with the highest fruit length (17.46 cm), diameter (41.43 cm), fruit weight (1720 g), and fruit number per plot (61). In contrast, T3 had the latest maturity (149 DAF) and the lowest values across all fruit parameters. T1 and T4 showed intermediate performance.

Table 2. Yield and yield contributing parameters of Giant Kew pineapple at different treatments

Treatments	Days to fruit maturity (DAF)	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Fruit number per plot
T1	124 bc	16.6 ab	38.53 a	1560 b	49 AB
T2	121 c	17.46 a	41.43 b	1720 a	61 A
T3	149 a	13.70 c	30 c	1100 d	26 C
T4	130 b	15.30 b	36.33 b	1413 c	39 B
CV (%)	2.86	4.52	4.77	4.8	13.98
LSD (5%)	7.47	1.42	3.48	138.9	12.22
Level of Significance	**	**	**	**	**

CV = Co-efficient of Variation, LSD = Least Significant Difference; ** means significant at 1% level of probability and * means significant at 5% level of probability.

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Discussion

Growth parameters are important traits that indicate the vigor of the plant. In this present study, the growth parameters of pineapple as influenced by different level of fertilizer treatments with mulch have been elucidated through plant height, leaf length, number of leaves, number of propagules, fruit length, fruit diameter etc. From the analysis, among the treatments T2 treatment (75% FRG + mulch) led to the tallest plants at 94 cm, longest leaf length at 67 cm, highest number of leaves at 55, leaf width at 4.0667. T1 treatment (FRG) resulted in intermediate values with a plant height of 70 cm, leaf length of 59.33 cm, number of leaves of 48.667, highest leaf width of 4.366. T3 treatment (50% FRG + mulch) resulted in intermediate values with a plant height of 65.333 cm, leaf length of 62.333 cm, number of leaves of 20.667, leaf width of 3.9333. The control treatment T4 treatment (Farmers control) produced the shortest plants, shortest leaves and the shortest leaf width. These findings agree with Patnaik (2022). The pineapple plant has a low demand for N and K in the first three months after planting, after which the need increases up to the time of flowering (Malézieux and Bartholomew, 2003). The height of the pineapple plant is an important growth characteristic directly linked with productive potential in term of fruit yield. In pineapple plant, 75% FRG + mulch registered the highest plant height against FRG treatment without mulching. The number of leaves at flower induction is also crucial for determining the yield potential. It is the vegetative variables that best expresses the ability of pineapple plant to support productivity at the time of floral induction (Barker et al., 2020). Pineapple plants grown on soil with polythene mulch present a larger leaf area, with higher leaf dry mass production and are photosynthetically more efficient by showing higher relative growth rate and unit leaf rate (Martinez et al., 2005). In a similar way, T2 treatment exhibited the highest number of leaves than other treatment.

The nutrient treatment with FRG recommended fertilizer and mulching was also reflected in the yield attributes and yield of pineapple fruit. The yield attributes like fruit length, fruit diameter, number of propagules, Fruit weight, fruit number per plot and fruit yield are considered to be important factors in the pineapple crop. Number of propagules, fruit number per plot, fruit weight, fruit diameter, fruit length and yield were recorded significantly highest in the plants under the treatment T2 {mulching + 75% FRG Recommended fertilizer dose). These findings also agree with Patnaik (2022). There is a positive association between vigor at flower induction and fruit weight at the time of harvest (Fassinou Hotegni et al, 2014). The size of fruits and yield is the cumulative effect of various attributes affected by macronutrients through a higher rate of cell division and cell enlargement, photosynthetic rate and increase in enzymatic activities. The adequate availability of nutrients might have helped for better flower bud differentiation, primordial development and ultimately quality fruit production in pineapple. Comparing the performance of fertilizer treatment with mulching and with farmer's control, it was noticed that the treatments given through 75% FRG with mulching have given excellent result which might be due to the boosting of overall vegetative growth and higher biological efficiency of plants. Pineapple is a nutrient demanding crop. Ayoola and Makinde (2007) have reported that both nitrogen and phosphorus are necessary for root initiation, root elongation and an increase in fruit length, fruit diameter and fruit yield in pineapple. Days to fruit maturity are an important parameter for pineapple yield. The minimum days for fruit maturity was 121 days, recorded in T2 treatment (Mulching +75% FRG - Recommended Fertilizer dose). But maximum days for fruit maturity was 149 days recorded in T3 treatment (Mulching +50 % FRG - Recommended Fertilizer dose). (Hossain et al, 2016) reported that more than three months are necessary from flowering to fruit maturity in pineapple.

It is likely that an optimal balance of NPK fertilizers contributed to better assimilation of nutrients, ultimately enhancing fruit quality. Overall, improvements in fruit quality were closely linked to nutrient use efficiency and timely application of nutrients directly into the crop's root zone.

CONCLUSION

This study assessed the effects of integrated nutrient management (INM) on pineapple cultivation in an existing agroforestry system in Madhupur Garh, Bangladesh, focusing on plant physical and fruit yield. Among the treatments, T2 (mulching + 75% of the recommended fertilizer dose) proved most effective, significantly improving plant growth traits. This research provides valuable insights into sustainable pineapple cultivation by demonstrating the benefits of integrating organic inputs with reduced chemical fertilizers. It offers a practical guideline for farmers to improve yield and fruit quality while maintaining soil health in agroforestry systems. The findings support environmentally friendly nutrient management practices, contributing to long-term agricultural sustainability in regions like Madhupur Garh.

Conflict of Interest

The authors declare no conflicts of interest.

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