

Evaluation of Farmer Practices in High Density Banana Production Agronomic Aspects in Taveta County Kenya

*Wasilwa, L.W.¹, Ndungu, JM.¹, Rono S.², Gathambiri C.W.¹, Karani J.², Njuguna J.K.¹, Mwiti E.², Moseti P.², Amukhoye R.², Kinaga P.¹ and Rayani J.³

¹Kenya Agricultural and Livestock Research Organization KALRO

²Micro Enterprises Support Programme Trust (MESPT)

³Taita Taveta County Agriculture Livestock Fisheries and Irrigation Department

*Corresponding Author

DOI: <https://doi.org/10.51244/IJRSI.2025.120600130>

Received: 17 June 2025; Accepted: 25 June 2025; Published: 15 July 2025

ABSTRACT

The most significant fruit crop in Kenya is the banana, which accounts for 35 percent of total volume (1.08 MT), followed by the mango (17 percent). Recently, Taita Taveta County designated this crop as a priority value chain. In Taita Taveta County's Taveta Sub-County, banana is becoming more and more popular as a result of market-driven horticultural production intensification and land pressure. This study assesses how well farmer agronomic practices with four spacings of interest (2by 2M, 3 by 4, 3by 3M and 4by4M) adhere to suggested best practices under HDP systems. Data was gathered from 329 farms chosen through the MPEST banana project, secondary data collection, focus groups, direct field observations, and a structured questionnaire. Data was analyzed using SPSS Version 17 to draw up descriptive statistics, (frequency tables, means, and percentages). The results showed that Grand Nain to be frequently grown by farmers in the study subcounty at high planting densities. Significant yield differences were found between high-density planting (2m × 2m) and wider (4m × 4m and 3m × 3m) spacing. During planting, farmyard manure application was significantly (94.7%) higher for the HDP systems compared with the wider spacing (86.1%-90.8%). Irrigation (flood or drip) water was inconsistently scheduled and not correlated to crop evapotranspiration demands under 2m x 2m, 3m x 3m, 4m x 3m, and 4m x 4m as 96.5%, 67.8%, 71.7%, and 90.8%, respectively. Canopy management and desuckering were irregular, with limited understanding of their influence on light interception and plant vigor. In the 2m x 2m, 3m x 3m, 4m x 3m and 4m x 4m spacing's farmers maintained about 2, 3, 4 and 3 suckers per stool, respectively. The diseases of economic importance are Fusarium wilt and Sigatoka leaf streak disease. The frequent incidence of banana weevil was due to poor field sanitation and inadequate monitoring. Farmers practicing HDP realized higher productivity associated with an increased number of plants and this should be encouraged for spreading to others areas outside the county. The study recommends a strategy to intensify banana production using high-density production systems and in particular with reference to land use efficiency.

Keywords: Banana, High density spacing, farmer agronomic practices

INTRODUCTION

Banana (*Musasp*) is an important source of income and food security among smallholders and large-scale farmers (GoK, 2011, KALRO, 2019). This crop is also ranked 1st in production, hectares and value among the fruits sub-sector and is considered as a major food and cash crop (AFA, 2024). In 2023, banana constituted 35% of fruits component, is grown on 75,184 hectares producing 1.88 million tons valued at KES 35.9 billion (AFA, 2024). Challenges in banana production are poor adoption of appropriate production technologies, prevalence of insect pests and diseases (panama disease and bacteria wilt disease); poor marketing channels and market structure. Interventions such as provision of clean planting material through the tissue culture technology and capacity building in crop husbandry to reduce losses attributed to pests and diseases (KARI, 2012). Use of appropriate plant spacing of banana addresses challenges of low production and productivity.

Value addition technologies such as ripening chambers, processing of crisps, wine, beer and flour for increased income. Reliablerainwater or access of water for irrigation, adoption of superior varieties, availability of clean planting materials, exposure of farmers to modern agronomic practices will contribute to increased yields as recorded in Kisii (45tons ha⁻¹), Meru (40tons ha⁻¹), Taita Taveta (31.2 tons ha⁻¹), Muranga (22 tons ha⁻¹), Kirinyaga (20.7 tons ha⁻¹) counties (AFA 2024).

Most (80%) banana is consumed locally, with minimal exports to international markets like Europe and the Middle East (KNBS,2022; OECD/FAO, 2022). Currently, Kenya has approximately 2,139,421 households growing bananas (2019 Census; GoK, 2024) cultivated in 75,184 ha (AFA, 2024; KNBS, 2024). Each farmer is estimated to have an average of 40 stools in a 0.075-acre, which translates to a yield of 0.6MT. Nationally, the average annual production is about 1.88 billion MT with an annual value of KES 35.9 billion with a national per capita consumption of about 34.3 kgs per year (FAO, 2021). The area under banana increased from 71,800 Ha in 2022 to 75,184 Hain 2023, a 4.7% increase. Banana production stabilized from 1.9 million MT in 2022 to 1.88 billion MT in 2023, this was attributed to poor rainfall and low adoption of production technologies. The value increased by 2 percent from KES 27.5 billion in 2022 to KES 35 billion in 2022 which was not commensurate to the increase in production as a result of depressed farm gate prices in the main growing areas of Meru, Murang'a and Taita Taveta Counties.

The average production per acre in Kenya 11.8 metric tons compared to the potential of 35 metric tons (KNBS, 2024). Constraints limiting banana production and productivity include ecological durability of intensified cultivation systems, lack of rapid and reliable disease diagnostics, insufficient technologies to control pests (e.g. banana weevil, thrips) and diseases (e.g. Fusarium wilt/Black and Yellow Sigatoka disease and Banana Xanthomonas Wilt), weak seed systems resulting in insufficient quality planting materials, inadequate water resources for irrigation, limited genetic improvement of varieties, developing and enforcing phytosanitary standards to enable cross-border trade, limited adoption of pre-and-post-harvest technologies, high input costs, limited access to credit and low levels of adoption of technologies, innovations and management practices (Beed and Markham, 2008; GoK, 2024).

The common spacing recommended for banana production for some time now in Kenya is 4m x 4m and 4m x 3m (Nyaga et al., 2021). These spacing's are used for all banana varieties i.e. tall or short types. In the past decade, High Density Production (HDP) has been adopted for banana production in Taita Taveta, Meru, and Embu Counties of Kenya. The HDP spacing's' are used in different production systems, using different banana varieties and with no justification or validation of their use. The luck of information has resulted to poor agronomic management, in low yields and poor-quality fruit (Sarrwy et al., 2012; Patel and Patel, 2018). Several constraints are bottlenecks in banana production systems including varieties, temperature, soil health, nutrient management, water availability, pests and diseases, mechanization and market access (Mustaffa and Kumar, 2012; Sanjit et al., 2021). Different plant spacing's influence bunch access and handling, pre-and-post-harvest management, quality and yield (Sarrwy et al., 2012; Patel and Patel, 2018; Haque and Sakimin, 2022). They report that bunch size increases with decreasing planting density, while total yield increases with an increasing plant density. In HDP light penetration into the canopy decreases thus reduces weed seed germination and growth (Mashingaidze et al., 2009), whereas supplemental water and nutrients must be added to nourish this crop. Thus, it is recommended to use the appropriate plant density as detected by variety and best management practices for optimal yields.

To better understand the farmer agronomic management in Taveta county, the Micro-Enterprises Support Programme Trust (MESPT) had been working on promoting banana production in Taveta Sub-County in the period 2022-2024. The farmers had taken up banana production using the HDP spacings (2m x 2m, 3m x 4m, 3m x 3m and 4m x 4m) targeting bridging the banana production gap and generating alternative source of revenue for the farming households in Taveta sub-county. The banana value chain was also one of the Taita Taveta county priority value chains for promotion and development. Thus, the objective of the study was to examine the agronomic practices of different banana spacing's being used by farmers in Taveta sub-County, Kenya. The banana agronomy aspects of study interest under different spacings were banana varieties in study areas, fertilizer management, sucker management, pest and disease incidences and control, pruning methods used, irrigation management, propping support techniques used and harvesting methods.

MATERIALS AND METHODS

Description of the study area and data

This study was conducted in Taveta Sub-County, Taita Taveta County, Kenya where banana is a major value chain. Taveta sub-County has a population of 91,222 persons and an area of 6,399Km² (KNBS, Census 2019). Taveta Sub-County has five wards including Challa, Mahoo, Bomani, Mboghoni and Mata (Table 1; Figure 1).

Table 1: Wards in Taveta Sub-County

County	Sub-county	Wards	Population	Households
Taita Taveta 340,671 Households (HH) 96,429	Taveta 91,222 HH 24,115	Challa	22,910	5,876
		Mahoo	6,823	1,730
		Bomani	50,531	13,347
		Mboghoni	6,328	1,526
		Mata	6,524	1,541

Source: 2019 Kenya Population and Housing Census

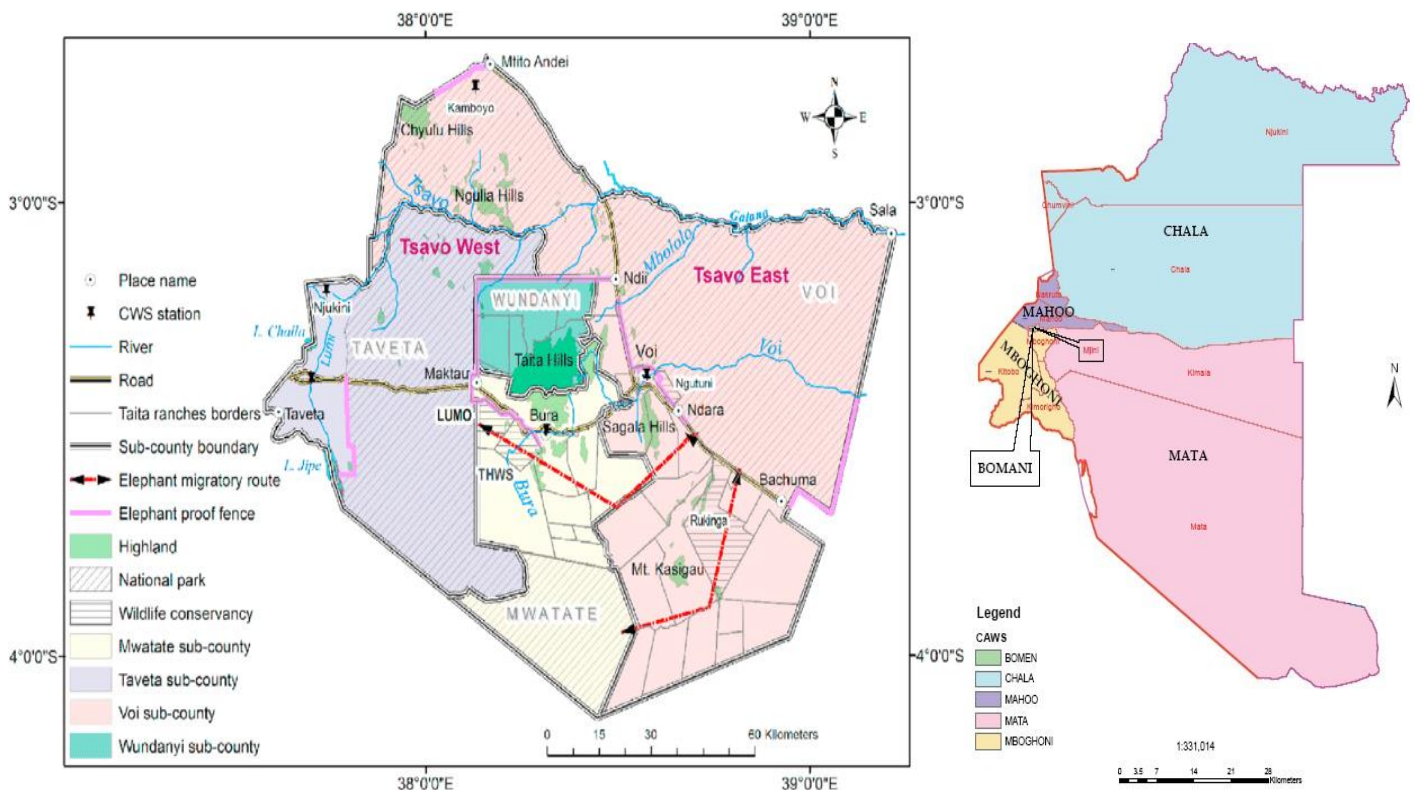


Figure 1. Map of Taita Taveta County Taveta Sub-County (study area)

The long rains are usually experienced between March and May – where on average, highlands record 265 mm as opposed to the 157 mm in lowlands. Short rains are anticipated between October and December, with annual rainfall being recorded at 1,200 mm (highlands) and 341 mm (lowlands). Rainfall distribution is usually uneven, with higher rainfall amounts being recorded in highland areas as compared to the lowlands. Annually, mean rainfall is 650 mm (Jaetzold et al., 2007). The main food crops are maize, beans, rice, green grams and bananas while the main cash crops are macadamia nuts, avocado, assorted vegetables, mango, sisal and French beans.

Primary data collection was based on the information provided by the Micro-Enterprises Support Programme Trust (MESPT) Taveta Sub-County team in the period 2022-2024. The different banana crop spacing used by farmers is as listed in Table 2. The total number of farmers used in this study were 966 and grouped in 10 clusters (Table 2).

Table 2: Distribution of farmers for different banana spacing's

Cluster	2mx2m	3mx4m	3mx3m	4mx4m	Total
Chala	5	12	12	5	34
Kasokoni	15	33	28	31	108
Kitobo	1	16	14	54	85
Kitogotho	1		2	84	87
Mata	30	6	30	2	68
Mboghoni	15	58	103	36	212
Mrabani Moyamoya	4	33	49	57	143
Ngutini		4	6	42	52
Njukini		17	5	31	53
Timbila	3	33	38	50	124
Total	74	212	287	392	966

Sample size: Each farmer had an equal chance of being selected and the sample size was randomly selected using the equation below:

$$n = \frac{N}{1 + N(e)^2} \quad \text{Yamane (1967)}$$

n= Sample Size

N= Population Size

e= Margin of Error

$$n = \frac{966}{1 + 966 (0.05)^2}$$

$$n \approx 283$$

Also, taking a 10% Margin of error/Level of significance was applied (due to unforeseen likelihoods of dropouts, incomplete filling of the questionnaires and data cleaning measures be taken into considerations according to Mugenda and Mugenda (2019) the sample size was adjusted by 10% to have 293 farmers as the minimum sample size. The sample size was distributed among the wards where the banana project was being implemented. Additional farmers were identified using the snowball effect to maximize and reach the targets numbers where a shortfall occurred.

Structure questionnaire programmed in Kobo Collect was used during the farmer interviews. The data collected was on banana production under different banana spacing and the farmer agronomic practices for each spacings. The specific areas of interest in the study were:

Banan varieties being commonly grown, yields, land sizes under banana.

Fertilizer management- what fertilizer to apply, when to apply, how often and what aspects to consider under each spacing.

Sucker management –when to do desuckering, how often and what aspects to consider under each spacing, how many suckers to maintain in each spacing.

Pest and disease control- how to manage pests and disease attack based on the closeness of the banana trees under each spacing.

Pruning techniques- when to do pruning, how often and what aspects to consider under each spacing, how many leaves to be left.

Irrigation management- how often should one water, what quantities and when to do watering under each spacing.

Propping support management- when to do this and how often and what tools to use on the various spacings.

Harvesting techniques- how best to ensure the banana quality is not compromised considering all the various banana spacings

Additionally, since there were four spacing of interest (2m x 2m, 3m x 4m, 3m x 3m and 4m x 4m) in the study a total of 329 famers were interviewed. A break down for 2 x 2m spacing 57 farmers were interviewed, for 3m x 4m, spacing 115 farmers, 3m x 3m spacing 92 farmers and 4m x 4m spacing 65 farmers were interviewed (Table 3).

Table 3: Number of farmers interviewed for each spacing in Taveta sub-county per ward

Spacing	Bomani	Chala	Mahoo	Mata	Mboghoni	Total
2mx2m	3	22	3	15	14	57
3mx3m	22	5	23	2	63	115
4mx3m	5	15	21	4	47	92
4mx4m	2	14	13	2	34	65
Total	32	56	60	23	158	329

In each of the banana spacing the authors have taken a land size of one acre and the plant population per acre (number of banana stools per acre) calculated (Coder, 2023). According to Coder, Kim D. 2023 the number of plants for each spacing per acre are estimated as indicated in Table 4.

Table 4: Spacing type and plant population

Spacing type (m)	Spacing type (feet)	Plants population per acre
2mx2m	6.5 x 6.5	1,000
3mx3m	9.8 x 9.8	444
4mx3m	9.8 x 13.1	333
4mx4m	13.1 x 13.1	250

Method of data analysis

Version 17 of Statistical Package for Social Sciences (SPSS) software was used for data entry and analysis. Descriptive statistics, such as totals, averages, percentages, etc., were used to illustrate the message (Mugenda and Mugenda, 2019). In addition, average comparison techniques such as ANOVA and independent sample t-tests were used to compare different banana growing areas and the plant spacings as suggested by various authors (Beed and Markham, 2008; Mustaffa and Kumar, 2012; Nyaga et al., 2021; Sanjit et al., 2021).

RESULTS AND DISCUSSIONS

Farmers land sizes and land size under banana production

Farmers owned a minimum of 0.25 acre of land to a maximum of 30 acres of land. Depending on the farmers' ability (capital, labour,), they were able to increase the land size for banana production. The banana spacing's of 2m x 2m, 3m x 3m, 4m x 3m and 4m x 4m had on average land size of 1.15, 1.28, 0.97 and 1.13 acres, respectively under banana production (Table 5).

Table 5: Minimum, maximum, average, farm land size and average land under banana production for each banana spacing

Spacing	Minimum land size (acre)	Maximum land size acre)	Average land size (acre)	Average land under banana (acre)
2mx2m	0.08	22.00	4.40	1.15
3mx3m	0.50	8.00	1.91	1.28

4mx3m	0.25	30.00	1.97	0.97
4mx4m	0.50	7.00	1.98	1.13
Grand Total	0.08	30.00	2.33	1.14

For the socio-economic characteristics of the farmers in the study area, the age of the farmer in years, the level of education, the main source of income, land ownership/own and land ownership/leased and acreage under bananas were statistically significant for the different spacing at between 90 and 95%. (Mugenda & Mugenda 2019).

Banana varieties grown in Taveta Sub-County

In Taveta Sub-County three types of bananas - dessert, cooking and plantain bananas are grown for the local market. Muingi (2023) reports varieties in Taita Taveta include Grand Nain, FHIA 17, William hybrid and Giant Cavendish. Other include Kinguruwe, Valarie, Matoke, Mshale, Kisii, Mkono wa Tembo, Iimage and Bokoboko (Mkojozi) (Muingi, 2019).

In all the three data collection methods used (the farmer interviews, farmer group discussions and key informant interviews), tissue culture (TC) banana seedlings were the most commonly used. The fully hardened banana tissue culture seedlings were obtained from Jomo Kenyatta University of Agricultural Technology (JKUAT) nursery at KES 130 Stockman Rozen from Naivasha at KES 90, or banana seedlings not hardened at KES 15 charged for transportation from Mimea International in Kitengela at KES 65 plus those seedlings not hardened, from Maua Mazuri at KES 130. Some lead farmers are also engaged in hardening of the young seedlings and then sell to other farmers at KES 150 per fully hardened banana seedling. The common TC banana seedling farmers growing were Grand Nain, Cross-bandia, Kimalindi, Kingurue and Giant Cavendish (Figure 2).

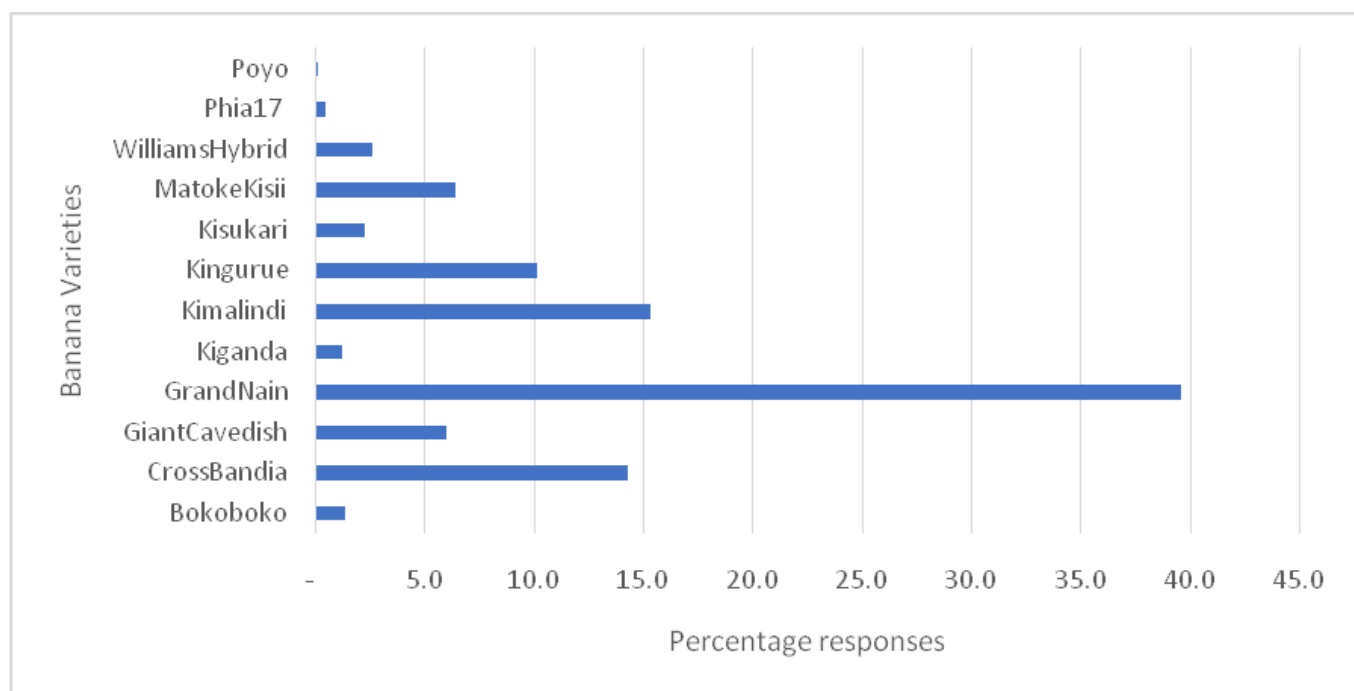


Figure 2: Percentage of respondents growing different banana varieties in Taveta Sub-county

Fifty-four percent of farmers planted multiple varieties while 45.9 % grew only one variety and the common grown single varieties were Grand Nain, Giant Cavendish, Cross-Bandia, Kimalindi and Kingurue.

Planting holes, fertilizer and manure application

Banana is a heavy nutrient feeder to support pseudostem and fruit bunch health (Singh, 2022). Nutrient management for this crop begins at hole preparation. In Taveta Sub-County, farmers dig holes of 60cm wide, 60cm long and 60cm deep. For effective nutrient management, the top soil is separated from the subsoil and

well decomposed manure or compost is mixed with it at the rate of 10kgs per hole. The mixture is returned to the hole and filled to the brim and planting done at the top of the hole just covering the level of the seedling where the media in the polybags reached, about ½ft deep. Nutrients from this mixture will adequately feed the banana plant for six months. Farmers use the sub-soil to make basins that hold water with 2-4 banana seedlings per basin. This is done to reduce labour cost for making basins.

Farmers that practiced inorganic farming added 200gms NPK, and a nematicide (Mocap) at the rate of 5-10gms per hole during planting. A few farmers practicing organic production use vermiculture practices where by vermi-liquids applied as a foliar fertilizer (ratio of 1:10) on young banana seedlings and vegetable intercrops. Farmers either make the vermi-liquid or purchase at one litre at KES 200 (\$ 1.5). During irrigation, the basins were opened to let in water and closed to prevent out flow. Most farmers did not use herbicides (97.8-100%) or agro-chemicals (98.2%-100%) in banana growing (Table 6). However, 83.7%-94.7% of the farmers used farm yard manure from cattle for banana growing. It has been reported that farmers practicing both organic and inorganic production systems realized higher yields due to synergistic and biological properties (Singh, 2022)

Table 6: Herbicide, chemical and manure use for the different banana planting spacing

Spacing	Non herbicide use (%)	Non chemical use (%)	Use of farm yard manure (%)
2mx2m	100	98.2	94.7
3mx3m	100	100	86.1
4mx3m	97.8	98.9	83.7
4mx4m	100	100	90.8

Sucker management

De-suckering:

In banana production, Singh (2022) stresses on the importance of maintaining the most vigorous suckers for the next generation. Sucker management allows for appropriate light penetration in the canopy allowing for good bunch colour (Singh, 2022). In this study, farmers de-suckered maintaining 2-4 suckers per plant/stool depending plant spacing. The farmers identified suckers for removal as those closely attached to the mother or were constrained by the weight of fruit bunch. Farmers typically de-suckered every 2-3 months or when required. Farmers with a few acres under banana production used household labour to desucker whereas those practicing large-scale production engaged a labourer (s) on a daily or task basis at costs between KES 350 - 400 (about \$3). Most farmers de-suckered at 84.2%, 94.8%, 98.9% and 86.2% of the respondents, using 2m x 2m, 3m x 3m, 4m x 3m and 4m x 4m spacing's, respectively (Figure 8).

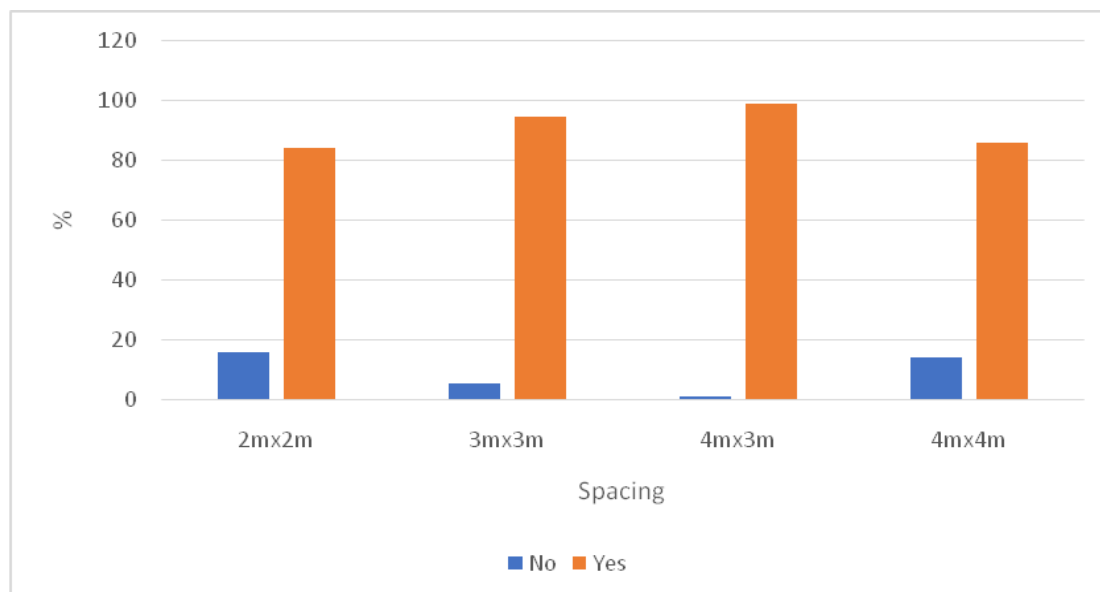


Figure 2: Percentage of farmers de-suckering in different banana spacing

For each banana spacing and varieties, farmers maintained different number of suckers per stools. This has also been reported in other countries (Ad  laide, 2023; Haque and Sakimin 2022). For Grand Nain, farmers left an average 2 suckers in the 2m x 2m, 3 suckers in 3m by 3m, 4m by 3m and 4m by 4m spacing's (Table 7). On average for the 2m x 2m spacing farmers maintained 2 suckers, 3m x 3m spacing 3 suckers, 4m x 3m spacing 4 suckers while the 4m x 4m spacing 3 suckers per stool. The 4mx4m spacing is commonly used in Kenya whereby farmers are trained to leave only 3 suckers (Araya et al., 2009; KALRO 2019). It was observed that the stages at which the farmers left the suckers varied widely. The number of suckers per stool depends on banana variety and plant spacing. According to Omondi (2012) dwarf varieties such as Dwarf Cavendish were recommended for 2m x 2m spacing while the tall and medium varieties such as Williams and Grand Nain are planted at 3m x 3m and above. At 2m x 2m the number of suckers per stool are retained between 2-3 while at 3m x 3m and above should be 3-4 per stool (Omondi, 2012).

Desuckering results in a vigorous second cycle, homogeneity and increased production and productivity. A homogeneous layout of the mother and selected daughter involves removal of excess sword and all water suckers. Desuckering is undertaken in two stages at a two-month intervals whereby doubtful suckers (first series) are removed and then subsequent suckers are selected from the second series. Additionally, four to six weeks after the first operation, the second series suckers are red and markedly elongated, displaying strong growth. Desuckering is performed when they are 30 cm tall, thus preventing competition between daughter and mother. It is recommended to maintain vigorous suckers with roots. (Nyaga et al., 2021).

Table 7: Number of suckers per stool

Variety	2mx2m	3mx3m	4mx3m	4mx4m
Bokoboko		2.33 (3)	2.75 (4)	4 (2)
CrossBandia	2 (2)	3.23 (43)	3.91 (34)	3.21(14)
Giant Cavendish	2.5 (2)	3.3 (23)	4.5 (10)	2.75 (4)
GrandNain	2.14 (54)	2.9 (88)	3.3 (67)	3.3 (50)
Kiganda		3.3 (3)	2.67 (3)	4.5 (2)
Kimalindi	1.67 (2)	3.12 (42)	3.51 (3.7)	3.28 (18)
Kingurue	2 (3)	3.3 (37)	3.89 (18)	3.33 (9)
Kisukari		3.3 (6)	3.5 (4)	3 (5)
MatokeKisii	3 (1)	3 (15)	3.13(15)	3.9(10)
Williams Hybrid		2.57 (7)	3.3 (6)	3.5(4)
FHIA 17		3 (1)	3 (1)	2 (1)
Poyo				2 (1)
Average	2.14	3.09	3.54	3.325
Average	2	3	4	3

Note: Numbers in brackets is the frequency while the other is the average number of suckers maintained per stool



Plates 1: 2m x 2m - two suckers Plates 2: 3m x 3m - 3 suckers maintained



Plates 3: Poor sucker management in some farms in Taveta Sub-County

In this study, it was observed that farmers are not very sure when to de-sucker, the method of de-suckering (cut down the sucker at the base and leave it at that or cut down the sucker and destroy the apical meristem), the number of suckers to retain and which sucker to retain or remove (water sucker or sword-shaped sucker). The desuckering should be done at 1-2 month intervals by selecting the most actively growing sword sucker and cutting the others (Nyaga et al., 2018; Okoko et al., 2019). At spacing of 2m x 2m, 2-3 suckers should be left per stool while 3m x 3m spacing and above, 3-5 suckers are retained.

Diseases and pest incidences and control

Diseases

Diseases of economic importance in banana production systems of Kenya include bacterial wilt (Banana Xanthomonas Wilt [BXW], causes up to 100% yield losses), Panama wilt disease (or Fusarium wilt - Fusarium oxysporum f. sp. cubense, causes 70-100% yield losses), Black Sigatoka disease of banana (Mycosphaerella fijiensis causes 40-50% yield losses) and Yellow Sigatoka disease of banana (Mycosphaerella musicola causes 40-50% losses), cigar end rot disease (Verticillium theobromae and Trachysphaera fructigena causes 30-40% losses), crown rot (anthracnose – Colletotrichum musae causes 10-30% yield losses) and banana streak disease (banana streak viruses (BSV) cause 20-30% yield losses) (Geberewold, 2019; Nyaga et al., 2021; Amata et al., 2024). In Taveta Sub-County, most farmers were unable to identify or control diseases. After pruning, it was observed that leaves with black sigatoka disease were used as mulch thus increasing the spread of this disease. Farmers commonly reported diseases as bacterial wilt (BXW), banana streak disease (or banana streak virus [BSV]), Panama wilt disease and yellow Sigatoka disease. Disease incidences were low with Fusarium wilt and yellow sigatoka disease being severe in very few farms (Table 8). Farmers were advised to manage these diseases by uprooting/rogueing symptomatic plants, removal and destruction of infected leaves, field sanitation and use of clean farm tools. Data on banana postharvest diseases were not collected in this study. In previous studies, postharvest diseases such as crown rot caused by anthracnose (Colletotrichum musae) or Fusarium (Fusarium spp) have been reported to cause major losses in banana production systems (Nyaga et al., 2021; Singh, 2022).

Table 8: Level of disease incidence in the banana farms in Taveta Sub-county

Level of infestation	Minor	Moderate	Severe
Bacterial wilt (BXW)*	3		
Banana streak disease		1	
Panama disease/Fusarium Wilt	4	2	1
Yellow sigatoka disease	4	6	2

*BXW =Banana Xanthomonas Wilt

Farmers who reported disease incidence were few for all banana production spacing's 2m x 2m, 3m x 3m, 4 m x 3m and 4m x 4m with 7%, 11.3%, 7.6% and 4.6% of the respondents, respectively (Figure 14).

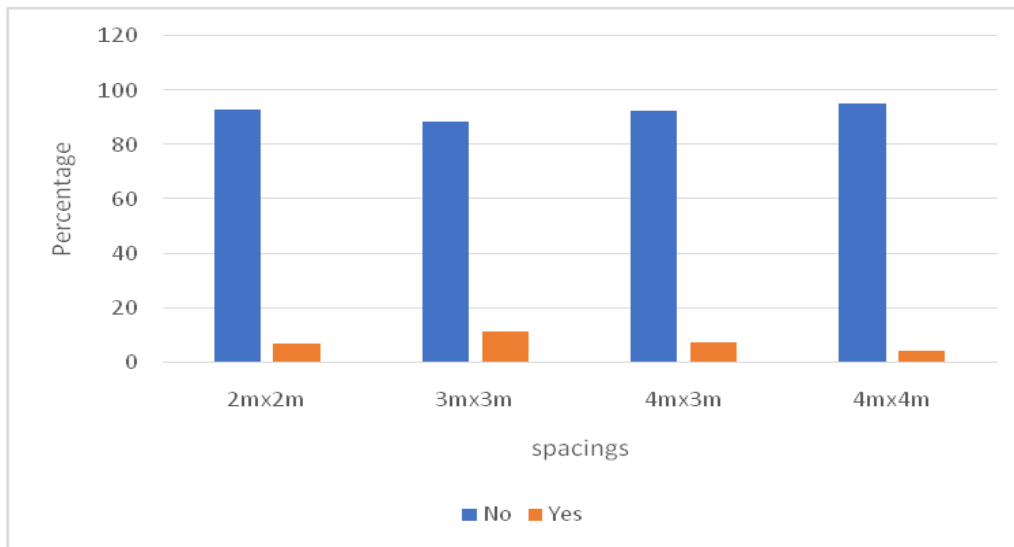


Figure 3: Percentage of disease in different banana spacing's

Pests

In Kenya pests of economic importance on banana include banana weevil (*Cosmopolites sordidus* Germar), banana rusty thrips (*Chaetanaphothripssignipennis*), banana aphids (*Pentalonianigranervosa*) and nematodes that cause up to 40-50% losses (Nyaga et al., 2021; Kathuri, 2022). They report that important nematodes are root lesion nematode (*Pratylenchusspp*), root knot nematodes (*Meloidogyne spp.*), and burrowing nematodes (*Radopholussimilis*). Nematodes are controlled using nematicides and bio-pesticides. Banana weevils predispose banana plants to *Fusarium* wilt and Banana *Xanthomonas* Wilt (BXW). In Kenya, thrips and banana weevil are controlled using biological controls such as neem based biopesticides (Achook 0.15% EC3, Neemraj Super and Nimbecidine) and inorganic chemical pesticides (JICA, 2019; Nyaga et al., 2021).

The number of farmers who reported arthropod pests and nematodes were few for each spacing 2mx 2m, 3m x 3m, 4m x 3m and 4m x 4m with 7%, 3.5%, 5.4% and 6.3% of the respondents, respectively (Figure 15).

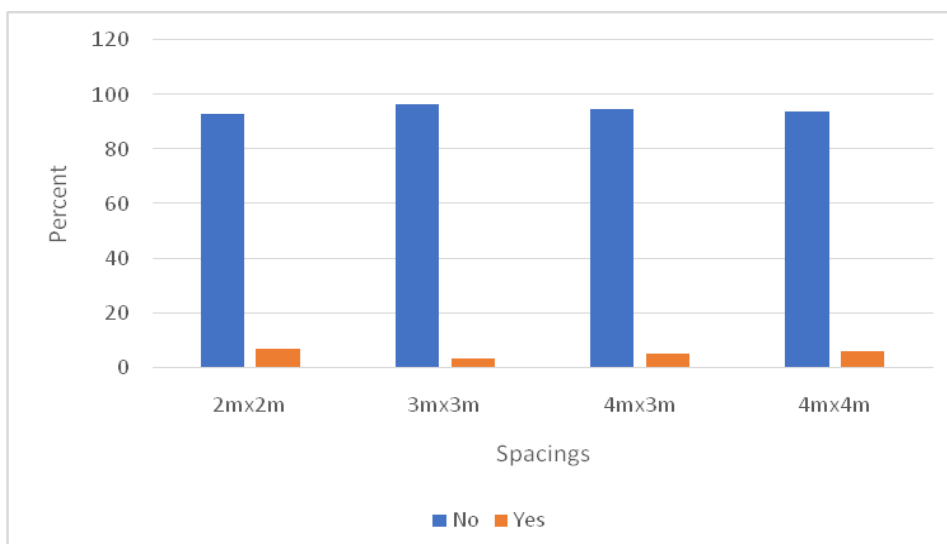


Figure 4: Percentage respondent noted pest in different banana spacing

The pests identified by the farmers were banana nematodes, banana weevil, fruit fly and thrips (Table 9). The level of infestation was minor to moderate for the different pests. Control methods used include use of blue sticky traps, farm hygiene, use of traps, uprooting infested plants, and pseudostem trapping (for banana weevil). To manage banana weevil, it was recommended field hygiene while for thrips the male bud is cut-off immediately the fruits are properly formed (at a 90° angle to the male flower) and for nematodes farmers used nematicides during planting.

Table 9: Level of pest infestation in Taveta Sub-County

Level of infestation	Minor	Moderate
Nematodes		1
Banana weevil	2	3
Fruit fly	1	
Thrips	4	1

Pruning (Canopy management)

Canopy management in banana orchards is highly recommended to ensure appropriate light penetration, adequate air flow and reduce bunch injury/scaring (Singh, 2022). Consequently, Singh (2022) and Patel and Patel (2018) report that plant population is an important factor affecting fruit quality. Farmers in Taveta Sub-County prune their banana plants and use cut leaves as mulch. In other parts of Kenya, banana farmers seldom prune leaves (Muthee et al., 2019). In this study majority of the farmers pruned at 89.4%, 100%, 98.9% and 98.4% of the respondents for the different spacing's of 2m x 2m, 3m x 3m, 4m x 3m and 4m x 4m, respectively (Figure 9). The main challenges were the number of leaves retained; disposal of diseased leaves and low light intensity observed in HDP banana fields. In addition, pruning was undertaken to remove disease infested, dry and excess banana leaves. It is recommended to remove the pruned plant debris the field, burn or bury. It is reported that number of leaves retained on a plant do not affect banana quality (Patel and Patel, 2018; Araya et al., 2009). According to Ramirez et al., (2008) in tropical commercial banana plantations and producing for international markets, it is possible to defoliate the banana plants to seven leaves at flowering without causing a reduction on the green and yellow life and quality of fruit. Increasing leaf pruning intensity led to improved flowering in the first, second and third ratoon crop (Araya et al., 2009).

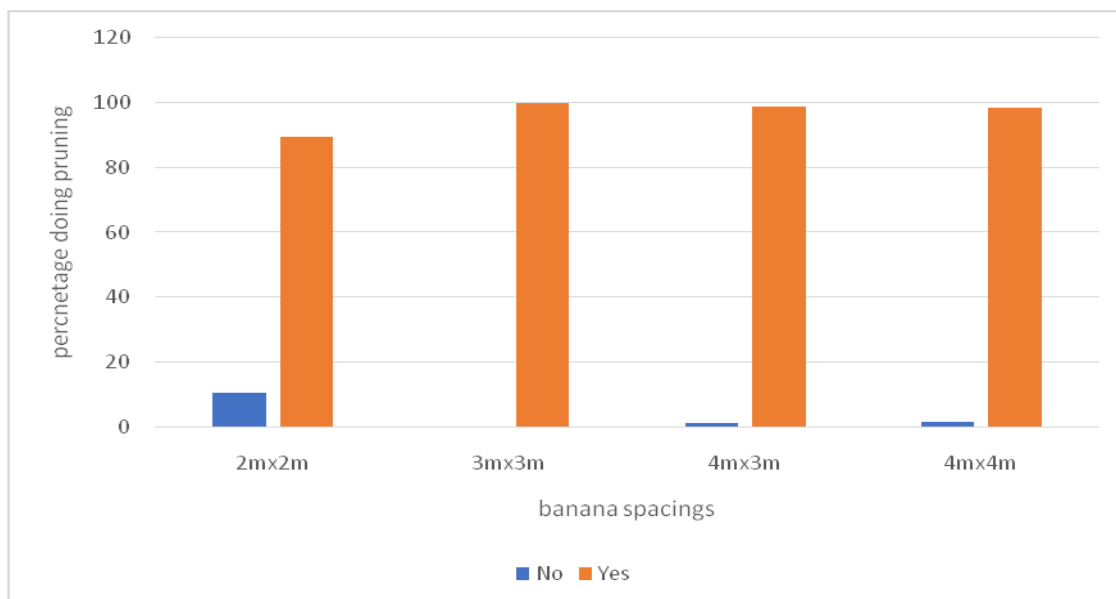


Figure 5: Percentage of farmers pruning at different banana spacing

Irrigation

Bananas are very susceptible to moisture stress (Hegde and Srinivas, 1989; Khalifa, 2012; Mustaffa and Kumar, 2012) necessitating the use of irrigation as an option to increase production and productivity. Numerous researchers have established that low water availability can lead to a decline in fruit yield and quality (Das et al., 2018). However, Hasan and Sirohi (2006) reported that drip irrigation is one of the contemporary techniques for conserving water and controls its amount for plants with high water efficiency levels.

Because they are vegetative, bananas require a lot of water, a minimum of 25 mm per week is needed for maximum growth. In areas growing banana, a well-distributed yearly average rainfall of 1,500–2,500 mm is thought to be ideal. However, bananas can even grow in places with mean annual rainfall below 1,200 mm, if

available water is managed well (Robinson and Saúco, 2010). Insufficient sunlight, waterlogging conditions, and drought lead to crop damage and reduced crop output.

In Taveta Sub-County, the amount of water used to irrigate banana has not been quantified. Farmers use either flood or drip irrigation. Flood irrigation is typically used because of minimal investment in infrastructure and the amount of labour required. Recently, Taita Taveta County government has been promoting drip irrigation because of precise application of water to root zone, amount used and application in banana orchards (Dengiz, 2006; Yira, 2011; Khalifa, 2012). Khalifa (2012) reports that Grand Nain plants under drip irrigation were slightly taller, had a wider pseudostem, a larger leaf area, more green leaves and plants mature earlier. In this study more data should be collected over time to validate these results.

Most farmers in Taveta Sub-County irrigated banana as indicated by data as 96.5%, 67.8%, 71.7% and 90.8% of the respondents for all banana spacing's including 2m x 2m, 3m x 3m, 4m x 3m and 4m x 4m, respectively (Figure 10). The data however supports that in HDP, most farmers using 2mx2m and 4mx4m irrigated the crop regularly. The amount of water required to irrigate banana varies based on climate, soil types, irrigation system and evapotranspiration (Mahmoud, 2013).

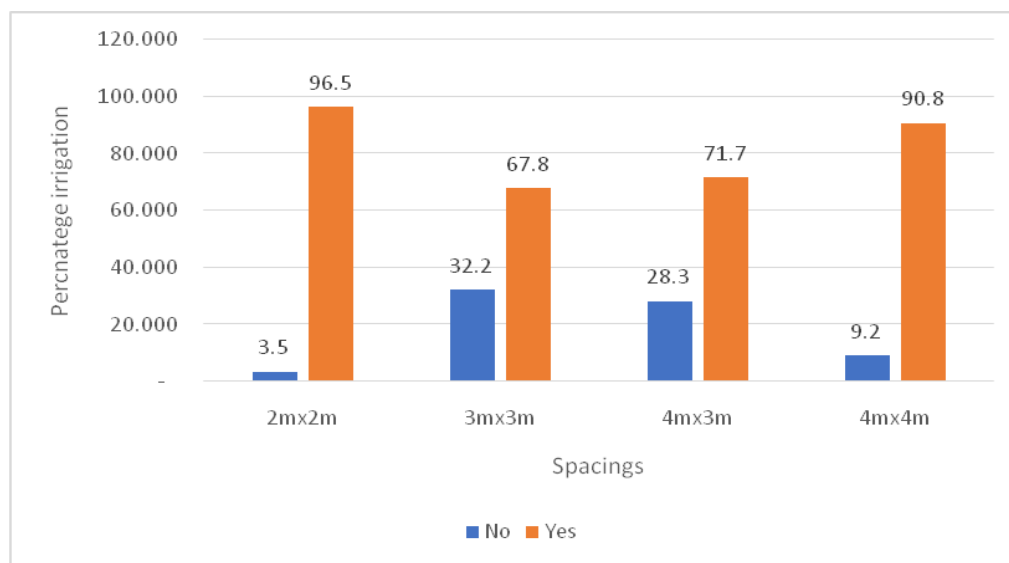


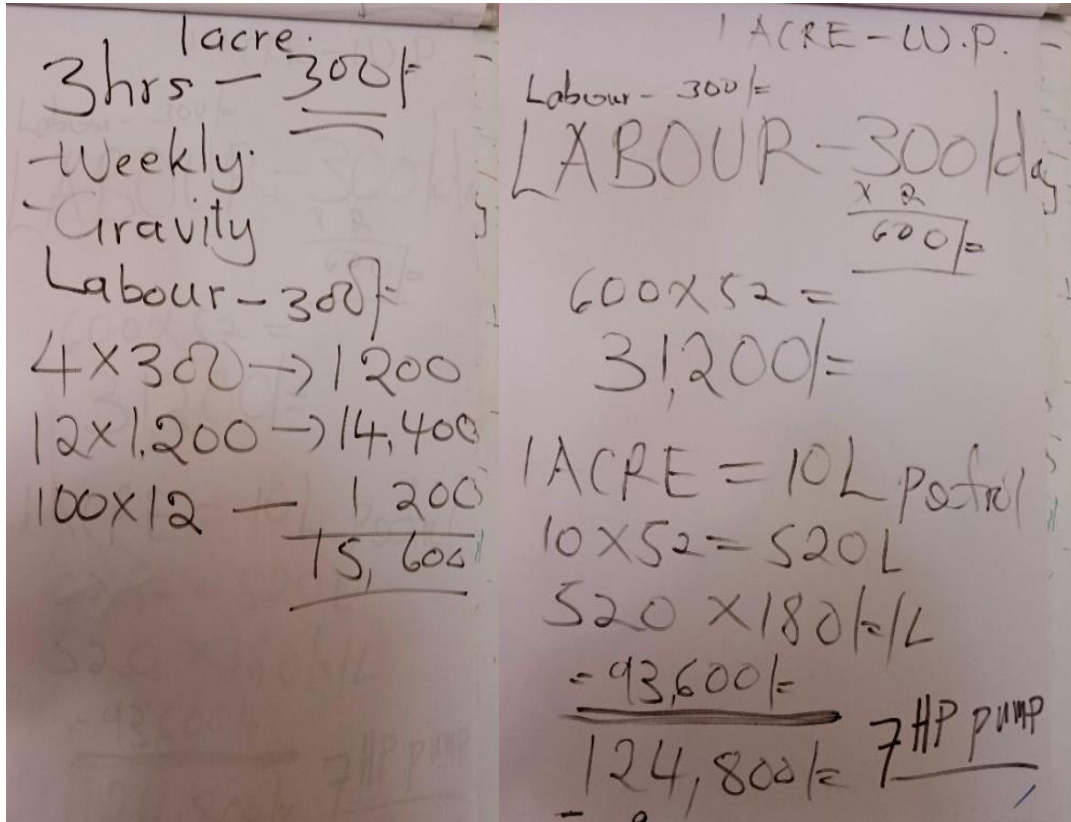
Figure 6: Percentage of farmers who irrigate banana under different spacing's

Flooding was the most commonly used irrigation method in the study area. The farmers pay about KES 100 per week for watering on a specific day of the week. In this study, farmers tend to overwater banana plants which results to nutrient leaching.



Plates 4: and Plates 5: Flooding system in banana plantations

The preferred method of irrigation in Taveta Sub-County was use of flood irrigation. The amount of water used in this irrigation system is not easy to assess as most farmers do not keep daily itemized records for water use. Moreover, farmers spend various amounts for water costs as shown in the two different scenarios shown in Plate 6.



Plates 6: Two farmers calculations on the cost of water used in banana farming

Few farmers used mechanization/pumps for irrigation whereby only 45.5%, 15.4%, 20% and 20.3% of the respondents for 2m x 2m, 3m x 3m, 4m x 3m and 4m x 4m, respectively banana production systems (Figure 11).

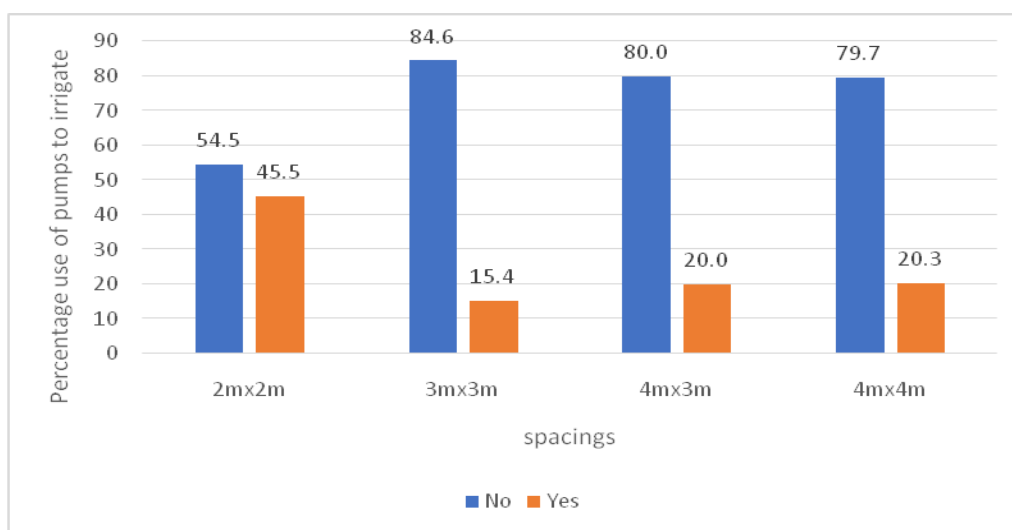


Figure 7: Percentage of farmers who use mechanization/pumps for irrigation under different banana spacing

Weeding

It was observed that farmers in Taveta Sub-County keep their fields weed-free with help from casual labourers in all spacing's of 2m x 2m, 3m x 3m, 4m x 3m and 4m x 4m weeding at 75.4%, 89.6%, 73.9% and 75.4% of

the respondents, respectively (Figure 12). In previous reports, hand weeding is recommended for weed management in banana orchards, because of stool and root injury (Ramirez et al., 2008; Nyaga, et al., 2018).

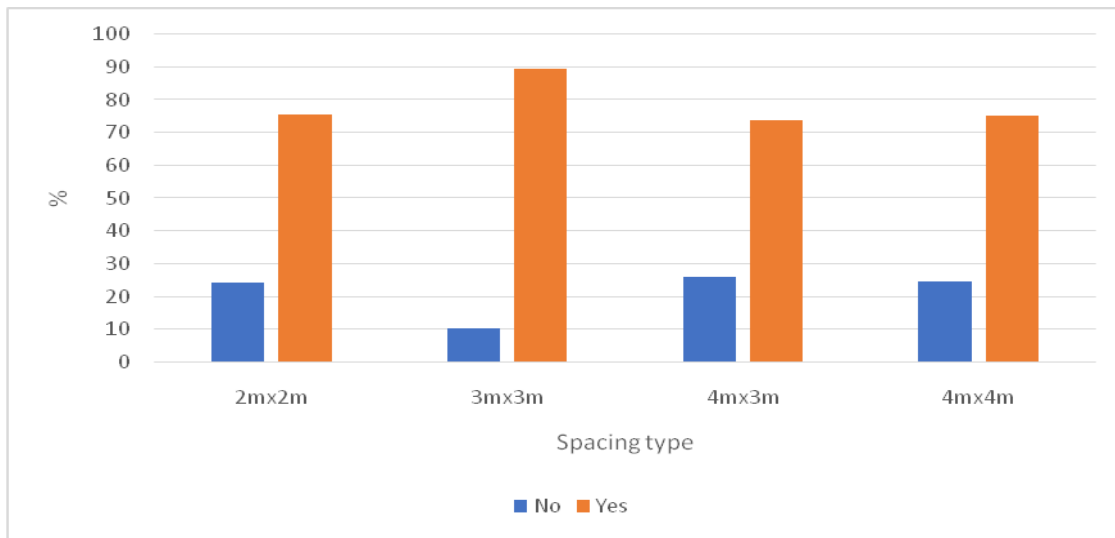


Figure 8: Percentage of farmers interviewed who weeded their fields under different banana spacing's

The 2m x 2m spacing had little challenge on weeds since the canopy suppressed the weeds as the crop matured. When the banana was young some farmers intercropped with legumes or local African indigenous vegetables to suppress weeds (Plate 8).

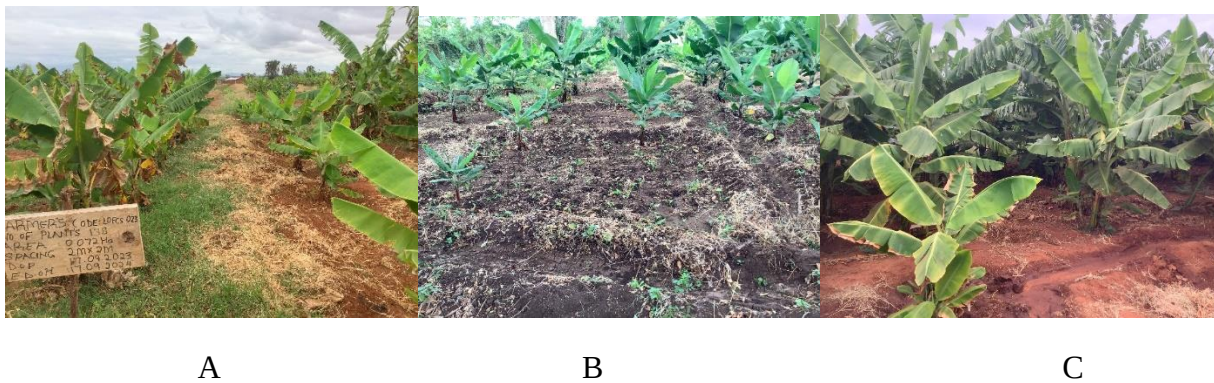


Plate 7: Weeding required in farms A and B whereas no weeding required in C



Plate 8: Intercropping with African



Plate 9: Pruned banana leaves used as much indigenous vegetables

Use propping support

In all spacing's, 2m x 2m, 3m x 3m, 4m x 3m and 4m x 4m farmers propped their bananas with sticks at 33.3%, 79.1%, 72.8% and 49.2% of the respondents, respectively (Figure 13). In this study those farmers using 2m x 2m spacing seldom propped their bananas compared to other spacing's. Propping of banana was done mostly in tall and medium varieties, therefore for 2m x 2m spacing which is recommended for short varieties, propping is not mainly done as also was observed in this study.

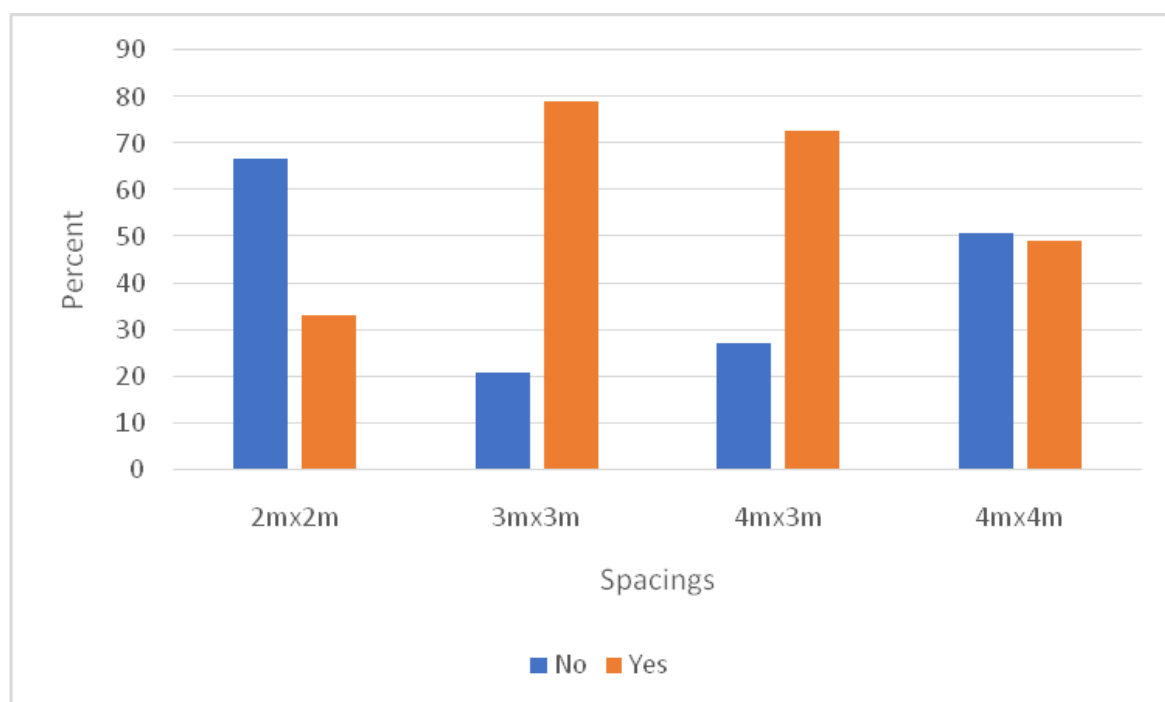


Figure 9: Percentage of farmers using propping support under different banana spacing's



Plates 8: No propping used in this farm



Plates 9: Propping used in other farms

Harvesting

It has been reported that immature bunch harvest negatively impacts on banana quality (Singh, 2022). Singh (2022) reports that farmers should use maturity indices to ensure harvest of mature banana and hence optimal quality and flavour of banana. Farmers in Taveta Sub-County are aware of the appropriate date to harvest banana bunches to meet market standards. They typically observed the roundness of fingers and also used bunch colour (lighter green) as maturity indices. Thus, banana bunches were harvested at full maturity and fingers let to ripen naturally. Farmers in Taveta Sub-County seldom used days after flowering to determine maturity compared with previous reports that recommended 80-90days after flowering (Singh, 2022). During harvesting, good postharvest practices were observed whereby farmers took good care not to bruise the banana fingers. To ensure this, leaves were spread on the ground and pseudostem slowly bent towards them, the bunch

detached and slowly placed down. The banana bunches were carried on padded shoulders by men or on the head by women to the collecting/aggregation sites where the co-operatives or brokers collected them.

Cutting down pseudostem after harvesting

The pseudostem stumps were left on the plants to release stored water back to the stool and cut later when dry. It is recommended to cut down the pseudostem and apply soil to accelerate rotting (Ramirez et al., 2008; Nyaga, et al., 2018) which reduces banana weevil infestation (Ramirez et al., 2008; Nyaga, et al., 2018). In this study, there were no significant differences for the four spacing's investigated on removal of pseudostem. It was observed that most farmers cut down pseudostems after harvesting 2m x 2m, 3m x 3m, 4m x 3m and 4m x 4m at 80.7%, 93%, 91.3% and 86.2% of the respondents, respectively (Figure 16).

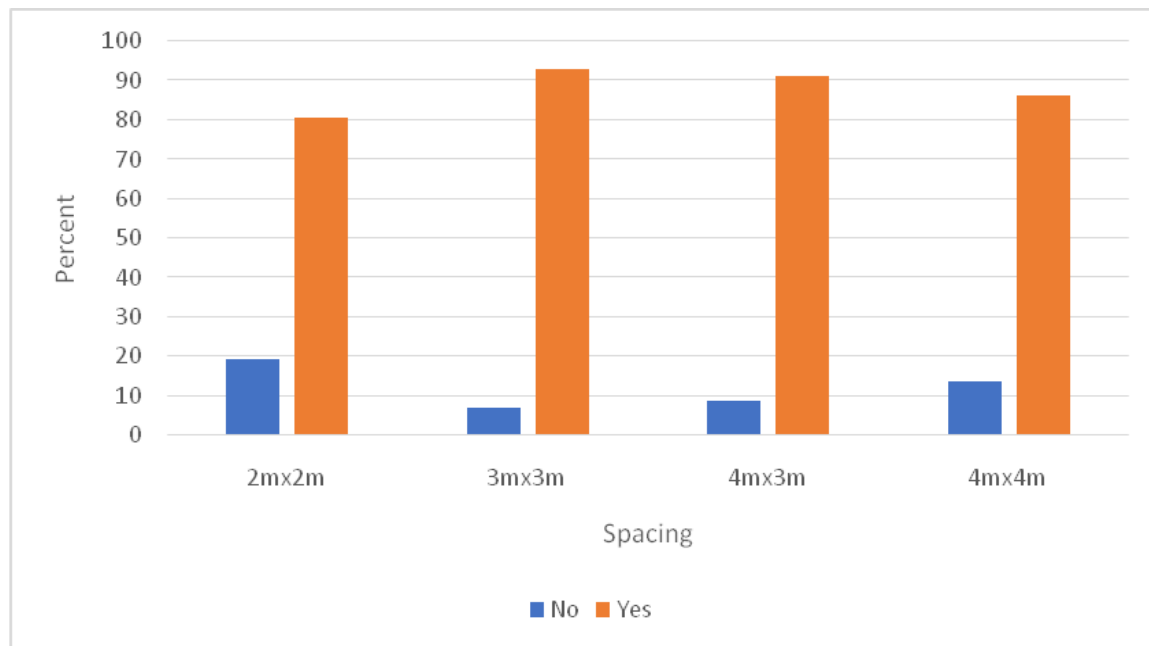


Figure 10: Percentage of farmers that cut down the pseudo-stem after harvesting for the different spacing's

CONCLUSIONS

In Taveta Sub-County, the average productivity increased by shifting from 4m x 4m and 4m x 3m spacing to HDP 2m x 2m and 3m x 3m banana spacing's, by using short tissue culture varieties (Grand Nain, FHIA 17, Williams Hybrid etc.), drip irrigation, and good production practices. Moreover, the higher yields realized under HDP attracted more farmers to adopt this production system. Socio economic factors including market access and market price also influenced adoption.

Several banana varieties are commonly grown under high density planting in Taita Taveta County including Grand Nain, Giant Cavendish, Cross-Bandia, Kimalindi and Kingurue. Grand Nain, Williams hybrid and FHIA were the most commonly grown varieties. Results from this study show that Taveta Sub-County farmers should grow more commercial short-type banana varieties that are suited to the high density planting. Several varieties can be introduced on demonstration farms in Taveta Sub-County obtained from the Kenya Agricultural & Livestock Research Organization (KALRO) genebanks located in KALRO-Kisii and the KALRO Horticulture Research Institute, Thika.

More detailed studies on the impact of fertilizer (organic and inorganic) and type of irrigation (drip or flood irrigation) in HDP banana production systems should be undertaken in Taveta Sub-County. These studies should include other agronomic treatments such as leaf pruning, bunch thinning and crop spatial arrangement on yield and fruit quality to quantify the threshold.

Results from this study show that the level of arthropod pests and diseases infestations was minor to moderate in the study site. This could also be a result of the low capacity of farmers to identify biotic constraints. Efforts

should be undertaken to build farmer capacity on pest and disease identification and control and also provide extension providers that are conversant in crop health. The county should develop banana agronomy extension guide with pest and disease management options to guide farmers.

Implementing policies that will raise banana productivity and encourage social adaptation to a future scenario of climate change is therefore extremely necessary and essential. Proper irrigation and manure application, which is vital for raising this type of banana spacing, needs a well-structured irrigation system over a longer period of time. The shift from flooding the fields to the drip pattern of irrigation required for increasing productivity of high-density banana production also need further research. Water use requirement for banana is still a major gap in banana farming as is for the different banana spacings

RECOMMENDATIONS

Optimizing spacing and orchard management depend on banana variety type, climatic conditions and labour costs. High Density Planting (HDP) is recommended for short varieties such as Dwarf Cavendish. In addition, the final number of suckers per stool depends on the banana variety. For instance, for dwarf varieties such as Dwarf Cavendish, should have 2-3 suckers per stool, consisting of a bearing mother plant, a large daughter and a small granddaughter sucker. De-suckering should be done after every 1-2 months where the unwanted suckers (slow growth) should be cut near ground level making and ensure the remaining sucker is not injured. Pruning of banana should be done in such way that it does not affect the quality of fruits. In 2m x 2m plant spacing, pruning should be carried out regularly to manage diseases that occur due to high crop density and dampness such as cigar end rot and sigatoka. In addition, high field hygiene should be observed to reduce infestation of banana weevil and thrips. In High Density Planting (HDP), the yield per unit plant reduces but the total yield per unit area is increased as the number of plants per unit area are more in case of high-density planting. Propping of banana is done mostly in tall and medium varieties, therefore for 2m x 2m spacing which is recommended for short varieties, propping is not mainly done as also was observed in Taveta Sub-County. Further research is required on water requirement for banana under different banana spacing's and surface irrigation or drip irrigation. Though HDP results in significant yield increase and optimization of costs leading to higher profitability appropriate agronomic practices should be observed. On the agronomic practices under different banana spacing's more research is required to confirm specific recommendations for each spacing's in different agro-ecological conditions. More-so with changing climatic conditions and farmer capabilities and capacity to adopt and customize research recommendations tailored to their needs is encouraged.

SPECIFIC RECOMMENDATIONS

Fertilizer management Research recommends that to maintain the soil fertility while ensuring the bananas are well nourished, organic fertilizers such as well decomposed manure, compost or tithonia leaves should be applied every six months. Applying fertilizer and irrigation water simultaneously is a relatively new technological advancement. In addition to improving nutrient use efficiency, it also delivers necessary components straight to the active root zone, reducing costly nutrient losses and eventually enhancing banana crop output and quality. Future research should prioritize precision input management and adaptive agronomic models to enhance the sustainability and profitability of HDP banana systems in Taveta Sub-County.

Suckers per stool In banana, the adoption of optimum density is very important for bridging the gap between the actual yield and the potential yield of banana from a unit area. Under this technology, with the adoption of three suckers per pit at a spacing of 1.8 x 3.6m about 4,600 plants/ha or two suckers per pit at 2.1m x 2.4m or 2.1m x 2.7m about 3,525 plants and 3,960 plants/ha were accommodated, respectively.

Pest and diseases To reduce the chances of pest and diseases due to the closeness of the banana trees as was observed where the leaves interlocked recommendation is to cutting down any severe affected leaves, pruning the affected leaves, trimming the infected leaves, destroying all plants showing symptoms, removal if infected plant, and ensuring farm tools are clean.

Pruning should be done to a level of just allowing sunlight after removal of dry, diseased and interlocking leaves. Farm scouting is encouraged to know the frequency of pruning. Regardless of the spacing pruning is a

requirement in banana farming and no distinct specification necessary for different spacing's. All dry/dead leaves which hang down the sides of the pseudo-stem need to be removed at least twice a year (each pseudostem should have 7 leaves at any one time).

Irrigation management is usually to supplement rain-fed farming where it is inadequate. Investing in irrigation system in banana farming should be considered as a way of increasing yields as reduce operational costs. Irrigate bananas when it is necessary and not as a routine to avoid dampness that is conducive for root rot disease. Further studies necessary to determine the amount of water required and actual water costs under different spacing's under surface irrigation.

Propping The major varieties which require propping are: Grand Nain, Williams, Valery, Giant Cavendish, FHIA series etc. Propping of banana is done mostly in tall and medium varieties, therefore for 2m x 2m spacing which is recommended for short varieties. Where the banana plant hole at planting has been left at $\frac{3}{4}$ the banana will not require propping for some years but where the banana is planted at the same level with the ground chances are high that it will require propping at first to subsequent bunch maturity.

Harvesting For local market, dessert banana fruit can be harvested when fully mature for immediate ripening and marketing. Dessert bananas for distant markets should be harvested when between 75% mature when fingers are $\frac{3}{4}$ round and 90% mature, to avoid ripening on the way to the markets. Cooking bananas should be harvested when between 75% mature and fingers are $\frac{3}{4}$ round and 90% mature to avoid ripening before use.

ACKNOWLEDGEMENT

We would like to acknowledge the entire farm households, business service providers and the Micro Enterprises Support Programme Trust (MESPT) Taveta team in the study site for their cooperation and support in field of study. Micro Enterprises Support Programme Trust (MESPT) are highly acknowledged for providing relevant information. Grateful to the Director General KALRO granting support during the study and Micro Enterprises Support Programme Trust (MESPT) for the financial support in the study.

REFERENCES

1. Abdallah, M. and Roshdy, K.A. (2010). Effect of plant density on growth, flowering, fruiting and yield of grand nain banana in sandy soil. Alexandria Sci. Exch. J. 31, 380–385.
2. Adélaïde N, Olivier AGJ, N'goran A, Siaka T, Muriel KDL and Cyrille KKG, 2023. Assessment of agronomic traits of plantain cultivars and hybrids cultivated at high-density planting. Int J Agri Biosci, 12(1): 22-26. <https://doi.org/10.47278/journal.ijab/2022.038>
3. AFA (2022). Year Book of Statistics Agriculture and Food Authority Nairobi, Kenya
4. AFA (2024). Year Book of Statistics Agriculture and Food Authority Nairobi, Kenya
5. AFA 2023 Year Book of Statistics Agriculture and Food Authority Nairobi, Kenya
6. Amata R., Thurania D. and Wasilwa L. (2024). Cigar end rot disease (*Verticillium theobromae* and *Trachysphaera fructigena*). KALRO/NAVCDP Programme Factsheet No.069/2024. Kenya Agricultural & Livestock Research Organization, Kaptagat Road, Loresho Nairobi Kenya
7. Apshara, S. E and S. Sathiamoorthy. (1999). Effect of planting density and spacing on growth and yield of banana cv. Nendran (AAB). South Indian Horticulture. 47 (1-6): 1-3.
8. Araya M. and Vargas A., (2009). Effect of leaf pruning at flower emergence of banana plants (*Musa AAA*) on fruit yield and black Sigatoka (*Mycosphaerella fijiensis*) disease. International Journal of Pest Management 55(1):19-25 DOI:10.1080/09670870802450219
9. Beed F. and Markham R. (2008). Strategy elements to transform the banana sector in Africa. An output of the international conference: banana 2008 Mombasa, Kenya, 5-9 October 2008 www.banana2008.com
10. Benfica, Rui; Hossain, Marup; Davis, Kristin E.; Boukaka, Sedi Anne; and Azzarri, Carlo. 2024. The true costs of food production in Kenya and Viet Nam. IFPRI Discussion Paper 2269. Washington, DC: International Food Policy Research Institute. <https://hdl.handle.net/10568/152074>
11. Coder, Kim D. 2023. Number of trees per acre by spacing distance. University of Georgia, Warnell School of Forestry & Natural Resources Outreach Publication WSFNR23-02C. Pp.6.

12. Das, T., Banerjee, A. 2018 Distribution, molecular characterization and diversity of banana bunchy top virus in Tripura, India. *VirusDis.* 29, 157–166 <https://doi.org/10.1007/s13337-018-0451-7>
13. Dengiz, O. (2006). A Comparison of different irrigation methods based on the parametric evaluation approach. *Turkish Journal of Agriculture and Forestry.* (30): 21-29.
14. FAO 2017 Methodology for Estimation of Crop Area and Crop Yield under Mixed and Continuous Cropping framework of the Global Strategy to improve Agricultural and Rural Statistics Rome Italy
15. FAO 2021 banana water requirements accessed at <https://www.fao.org/land-water/databases-and-software/crop-information/banana/en/#:~:text=Water%20requirements%2Dper%20year%20vary,often%20grows%20under%20less%20rainfall>. Accessed on may 2025
16. FAO. 2021. FAOSTAT: Production, Crop Primary Database. Accessed on 04 June 2025. <https://www.fao.org/faostat/en/#data/QCL>
17. Geberewold, A. Z. (2019). Review on impact of banana bacterial wilt (*Xanthomonas campestris* pv. *Musacerum*) in East and Central Africa. *Cogent Food & Agriculture*, 5(1). <https://doi.org/10.1080/23311932.2019.1586075>
18. Ghimire S, Koirala B, Devkota S and Basnet G (2019), Economic analysis of commercial banana cultivation and supply chain analysis in Chitwan, Nepal *Journal of Pharmacognosy and Phytochemistry* 2019; SP5: 190-195
19. GoK, (2011), Ministry of Agriculture Validated Report 2011, Karuri Ventures, Nairobi
20. GoK (2013). National Banana Development Strategy - 2013-2016
21. GoK (2019). 2019 Kenya Population and Housing Census
22. GoK (2024). National Value Chain Development Strategy. Ministry of Agriculture and Livestock Development. www.kilimo.go.ke
23. Gowri MU, Shanmugam TR. 2015 An economic analysis of production and marketing of banana in India. *American International Journal of Research in Humanities, Arts and Social Sciences*;9(3):234-240.
24. Haque M. A. and Sakimin S. Z. (2022). Planting Arrangement and Effects of Planting Density on Tropical Fruit Crops-A Review. *Horticulturae*, 8, 485. <https://doi.org/10.3390/horticulturae8060485>
25. Hasan, M.A. and Sirohi, N.P.S. (2006). Drip Irrigation and Fertigation Technology for Improving water Productivity of horticultural crops National Seminar on Technological Options for Improving Water Productivity in Agriculture. JNKVV, Jabalpur. Nov. 15-17.
26. Hegde D. M., and Srinivas K. (1989). Irrigation and nitrogen fertility influences on plant water relations, biomass, and nutrient accumulation and distribution in banana cv. Robusta. *Journal of Horticultural Science.* 64:91-98
27. Jaetzold, R., Schmidt, H., Hornez, D., & Shisanya, C. (2006) Farm Management Handbook of Kenya Vol 2 Natural Conditions and Farm Management Information Part B, Central Kenya 2nd Ed, Ministry of Agriculture Publisher, Nairobi.
28. JICA (2019). Banana production. www.jica.go.jp
29. Kenya Agricultural and Livestock Research Organization (KALRO). (2019). Inventory of climate smart agriculture banana technologies, innovations and management practices.
30. KALRO 2024, KALRO TIMPS. <https://kalrotimps.com/timps/42>.
31. Kumar, N., & Jeyakumar, P. (2001). Influence of micronutrients on growth and yield of banana (*Musa* sp.) cv. Robusta (AAA). In *Plant Nutrition* (pp. 354-355). Springer, Dordrecht.
32. Kathuri D. N. (2022). Adoption of Recommended Technologies Along Banana Value Chain and its Effects on Productivity in Embu West Sub-County, Kenya. Thesis. University of Embu
33. Khalifa, A. B. A. (2012). Comparison of Surface and Drip Irrigation Regimes for Banana (*Musa* AAA) cv. Grand Nain in Gezira, Sudan. Thesis. University of Khartoum
34. Kenya National Bureau of Statistics. (2020). The 2019 Kenya population and housing census report.
35. KNBS 2024a National agricultural production report 2023-2024, Nairobi Kenya
36. Mahmoud, H.H. (2013). Effect of different levels of planting distances, irrigation and fertigation on quality characters of main & ratoon banana crop cv. Grand Naine. *Glob. J. Plant Ecophysiol.* 3, 110–114.

37. Maricruz Ramírez, Marco Vinicio Sáenz, Alfonso Vargas, Mario Ar (2008) Leaf pruning intensities at flowering of banana (Musa AAA, cv. Grande Naine) did not influence fruit green and yellow life and quality' *Scientia Horticulturae*, Volume 115, Issue 4, 21 Pages 319-322
38. Mashingaidze, A.B.; Van Der Werf, W.; Lotz, L.A.P.; Chipomho, J.; Kropff, M.J. (2009). Narrow rows reduce biomass and seed production of weeds and increase maize yield. *Ann. Appl. Biol.*, 155, 207–218.
39. Mishra, A., Kumar, A., Joshi, P., D'Souza, A., & Tripathi, G. (2018). Contract farming, productivity, and fertilizer usage: Empirical evidence from specialty crop production. IFPRI. International Food Policy Research Institute (IFPRI).
40. Mugenda O., & Mugenda A. (2019). *Research methods: Quantitative and qualitative approaches*. 3rd. Rev. Ed. Nairobi.
41. Muingi S. (2019). Taita banana farmers to get value addition plant. TEFNET News. <https://www.itfnet.org/v1/2019/05/kenya-taita-banana-farmers-to-get-value-addition-plant/#:~:text=The%20banana%20variety%20in%20Taveta%20ranges%20from%20tissue,Bokoboko%20commonly%20referred%20to%20as%20Mkojozi%20among%20others>
42. Muingi S. (2023). Taita Taveta starts banana multiplication to boost production. *The Star Newspaper*. <https://www.the-star.co.ke/sports/2023-09-24-taita-taveta-starts-banana-multiplication-to-boost-production>
43. Murigi Michael, Ngui Dianah & Ogada Maurice Juma (2024) Impact of smallholder banana contract farming on farm productivity and income in Kenya, *Cogent Economics & Finance*, 12:1, 2364353, DOI: 10.1080/23322039.2024.2364353
44. Mustaffa M. M. and Kumar V. (2012). Banana production and productivity enhancement through spatial, water and nutrient management. *J. Hortl. Sci.* Vol. 7(1):1-28
45. Muthee, A. I., Gichimu B. M. and Nthakanio P. N. (2019). Analysis of banana production practices and constraints in Embu County, Kenya. *Asian Journal of Agricultural and. Rural Development*. 9(1): 123-132.
46. Nofal, O.A., and Rezk, A.I. (2021). Some factors affecting the yield and quality of banana: a review. *Science Archives*, Vol. 2 (3), 206-211. <http://dx.doi.org/10.47587/SA.2021.2309>
47. Nyaga, A.J.N, Okoko E.N., Gatambia E., Gathambiri C., Amata R., Barare M., Mogaka, J. Njuguna J.K., Ndubi, J., Mwangi M., Wandera F. W., Owino, W., Esilaba, A. Muriithi, C., Martim, J., Too. A., Wayua, F.O., Orayo, M., Ndambuki, J., Ndungu B.W., Muriuki, S.J.N., Mwangi, H., Momanyi, V., Mutuma, E., Wanyama, J.M., Wambua, J., Nasirembe, W.W., Kirigua, V.O., and Wasilwa, L. (2021). Inventory of Climate Smart Agriculture Technologies, Innovations and Management practices for Banana value chain. Kenya Agricultural and Livestock Research Organization 2021. www.kalro.org
48. Obaga, B., & Mwaura, F. (2018). Impact of farmers' participation in banana value addition in household welfare in Kisii central sub-county. *International Academic Journal of Social Sciences and Education*, 2(1), 25–46.
49. OECD/FAO (2022), *OECD-FAO Agricultural Outlook 2022-2031*, OECD Publishing, Paris, <https://doi.org/10.1787/f1b0b29c-en>.
50. Okoko, N., Nyaga A.N., Mogaka J., Gatambia E., Gathambiri C., Amata R., Wandera F.M., Wanyama J., Kirigua V.O and Wasilwa L.A. 2024, *Banana agronomy*, KALRO/NAV CDP/BANANA/Pamphlet No. 115/2024.
51. Omondi H and Mutisya J (2012). Managing banana stools to maximize production, factsheets for farmers plantwise CABI Nairobi
52. Patel, M.J.; Sitapara, H.H.; Shah, N.I.; Patel, H.R. (2018). Effect of different levels of planting distance and fertilizers on growth, yield and quality of banana cv. Grand Naine. *Journal of Pharmacognosy and Phytochemistry*. 7, 649–653
53. Republic of Kenya. (2019). *Agricultural sector transformation and growth strategy (2019–2029)*.
54. Robinson, J. C., and Saúco, V. G. (2010). Bananas and plantains (Vol. 19). Cabi. Sarker, M, Alam, K., and Gow, J (2012), Exploring the relationship between climate change and rice yield in Bangladesh: An analysis of time series data, *Agriculture System* 112: 11–16, <http://dx.doi.org/10.1016/j.agry.2012.06.004>.
55. Sanjit, Debnath; Bauri, F.K; Swain, S; Patel, A.N; Patel, A.R.; Shaikh, N.B.; Bhalerao, V.P.; Baruah, K; Manju, P.R.; Suma, A; Menon, R; Gutam, S. (2021), Studies on high density planting and nutrient

- requirement of banana in different states of India *Journal of Horticultural Sciences*, vol. 16, núm. 2, Society for Promotion of Horticulture, India <https://www.redalyc.org/articulo.oa?id=577074107004>
56. Sarrwy S. M. A., Mostafa E. A. M., and Hassan H. S. A. (2012). Growth, yield and fruit quality of Williams banana as affected by different planting distances. *Int. J. Agric. Res.*, 7, 266–275
57. Singh R. (2022). Eco-friendly post-harvest technologies of banana: A review. *The Pharma Innovation Journal* 2022; SP-11(7): 4375-4381
58. SPSS, I. (2012). IBM SPSS statistics version 21. Boston, Mass: International Business Machines Corp, 126.
59. Yira Y. (2011). Design of a Drip Irrigation System for the Production of Bananas on the Plain of Bagré (Burkina Faso). *Istituto Agronomico per l'Oltremare*.