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Research Article

Plantain-Tree Rubber Intercropping Systems Improved Productivity in the Tropical Humid Zone of Ghana, West Africa

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A three-year field trial was conducted between 2014 and 2017 in the Ellembelle and Jomoro districts of the Western region of Ghana where rubber production is common to determine the optimum population density of plantain when grown in combination with immature rubber tree crops. The trials were arranged in a Randomized Complete Block Design with 3 replications. The treatments were sole rubber, sole plantain, and three intercrops of one row of plantain in between two rows of rubber, two rows of plantain in between two rows of rubber, and three rows of plantain in between two rows of rubber. The rubber clone used was GT1 while the variety of plantain used was false horn. The results showed that population density of plantain had significant effect on the growth of the associated rubber. Growing plantain at closer spacing of 1.5 m under the high-density plantain treatment significantly increased plantain yield compared to the other cropping systems. There was a significant positive relationship between population density of plantain and the rubber tree growth and development. The optimum population density of plantain when intercropped with rubber was 1,666/ha. The study showed intercropping was advantageous over sole cropping for both crops.

1. Introduction

Rubber tree (*Hevea brasiliensis* [Willd. ex A. Juss.] Müll. Arg.) produces latex used in the manufacture of rubber products. The tree grows best under humid and semi-humid tropical conditions. Areas suitable for natural rubber production in Ghana include the forest zones of the Western, Central, Eastern, and Ashanti regions. The tree requires a minimum rainfall of 1,200 mm per annum and is evenly distributed on lower slopes, uplands, and flatlands.

Rubber plantation development is one of the lucrative farming ventures in the Western and parts of the Central regions of Ghana. Besides cocoa, oil palm, and coconut, rubber cultivation now stands out as one of the most profitable farming activities, despite the long gestation period of six to seven years. Coconut farmers whose farms were affected by the Lethal Yellowing Disease (LYD) as well as those who were not affected are cutting down their coconut trees to make way for the development of rubber plantations in the region [1].

The cultivation of rubber is associated with a long immature period of six years, under good management conditions and possibly longer under low input conditions during which no latex is harvested. The provision of an alternative source of income is particularly important to the smallholder low-income farmers. Similarly, land-poor/landless farmers also have the opportunity to provide labor in rubber plantations by way of intercropping arable crops [2]. Smallholder farmers in Ghana and some of the rubber growing countries like Nigeria, Côte d'Ivoire, and Liberia, amongst others, intercrop rubber with crops with a short gestation period to offer them the most practical means of addressing the gap in income suffered after planting of the rubber. There are varying opinions by smallholder farmers about the benefits of intercropping with some farmers suggesting the associated crop exerts a negative effect whilst others reported a positive effect on the growth of rubber trees [3, 4].

Studies that focused on the evaluation of productivity showed improvement in the growth of rubber trees in the intercrop relative to the sole crop [5–9]. The choice of intercrop by smallholder farmers depends on the local needs, the amount of capital required, market access, and agro-climatic conditions. Rubber cultivation in Ghana is predominantly under smallholder systems. It thus creates employment for a large number of farmers, and it is a sustainable source of income for them when latex production begins after six years of cultivation. However, the primary constraints faced by the farmers who are mostly resourced poor are the nonavailability of dependable income sources prior to latex production. To ameliorate this situation, farmers are advised to intercrop rubber plantations with desirable annual or short-duration cash/food crops to generate income to fill the income gap and also enhance land-use efficiency.

Intercropping in rubber cultivation offers a means of increasing income and land-use efficiency during the unproductive immature phase of rubber [9]. In Ghana, plantain appears to be the most popular intercrop with rubber cultivation. Plantain is a major food crop grown in the Western region of Ghana. It is a very important food crop in Ghana because plantain is eaten in every household in Ghana. Due to the high demand for plantain, cultivating plantain is seen as a sure way to have a regular income for farmers [10, 11].

Also, it is anticipated that the adoption of an appropriate rubber-plantain intercropping system would encourage the unemployed, especially the youth in the plantation areas to acquire spaces in the rubber plantation to intercrop with plantain to earn some revenue [2]. The plantation owner can benefit through savings on weed control and enhanced growth of the rubber trees. Food crops such as plantain, pepper, eggplant, cassava, cocoyam, and maize are important food and cash crops that feature prominently in the farming systems of Ghanaian farmers as sole crops or intercrops in mixed cropping systems. Farmers would be willing to intercrop rubber with crops that are proven to be compatible and profitable, which plantain is considered to be one of the best in Ghana. Good agronomic management for intercropping systems is the possible way by which farmers can be assisted to make maximum use of the lag period to the maturity of the rubber to maximize their profits [12]. Several studies have shown that rubber agroforestry systems improve the soil [13], improve the rate of growth of the rubber [14], as well as reduce the cost of the management of the plantation by ensuring the early generation of revenue to the farmer in the immaturity period of the rubber [15–17]. Thus, rubber agroforestry systems could be a suitable approach in Ghana and could add to the Ghana Poverty Reduction Strategy effort aimed at increasing the production of natural rubber, ensuring food security, reducing rural poverty, and creating employment opportunities for the rural dwellers [18]. However, all the studies pointing to the positive effect of rubber agroforestry were conducted outside Ghana and therefore the need to conduct site-specific studies to validate these claims. The study hypothesizes that intercropping young rubber with plantain at the optimum population density would improve productivity and returns to smallholder farmers during the lag phase to the maturity of the rubber.

The specific aim was to determine the optimum population density and productivity of plantain used as intercrop in young rubber plantation.

2. Materials and Methods

2.1. Description of the Study Areas. From 2014 to 2017, field trials were conducted at two different locations in the Western region of Ghana where rubber is mainly cultivated. The study was conducted at the Council for Scientific and Industrial Research–Crops Research Institute (CSIR-CRI), Aiyinasi Station field in the Ellembelle District (2° 05′ W and 4° 40′ N), and Tikobo No. 2 (Ehiamadwen) in the Jomoro District (4° 80′N and 2° 35′ W) (Figure 1).

Ellembelle falls within the wet semi-equatorial climatic zone of the West African subregion and Axim belt where there is rainfall throughout the year. The maximum mean monthly rainfall of 36 mm (ranges between 26.8 mm and 46.6 mm annually) [19]. The average temperature is about 29.40°C with monthly temperature variation between 4°C and 5°C. The relative humidity is about 90% during the night and about 75% during the afternoon, especially in June and July [20] (Figure 2). The soil type is mainly of the Ferric Acrisols and Dysric Fluvisols type [21]. The vegetation is made up of the moist semi-deciduous rain forest.

2.2. Field Preparation and Experimental Design. An old and abandoned rubber plantation with regenerated tree species was cleared and used at Ellembelle. At the Jomoro site, the land was an abandoned regenerated oil-palm plantation.

The field size was 102 m × 102 m for each experimental setup. The treatments were laid out in a Randomized Complete Block Design (RCBD) with three replications. Five treatments, consisting of sole rubber (R), sole plantain (P), and three intercrops consisting of an additive series of one row of plantain between two rows of rubber (i.e., low-density plantain intercropping or PR), two rows of plantain between two rows of rubber (i.e., medium-density plantain intercropping or PPR), and three rows of plantain between two rows of rubber (i.e., high-density plantain intercropping or PPPR). The rubber clone used was GT1 obtained from Ghana Rubber Estates Limited (GREL) while the variety of plantain was false horn. The population density of plantain was 555, 1,111, and 1,666 plants/ha in the low-density, medium-density, and high-density treatments, respectively (Figures 3 and 4). In all intercrop treatments, rubber was planted at a spacing of 3 m and 6 m intra- and inter-rows, respectively. Population densities of 1,666 plants/ha and 555 plants/ha were achieved by planting at inter- and intra-row spacing of

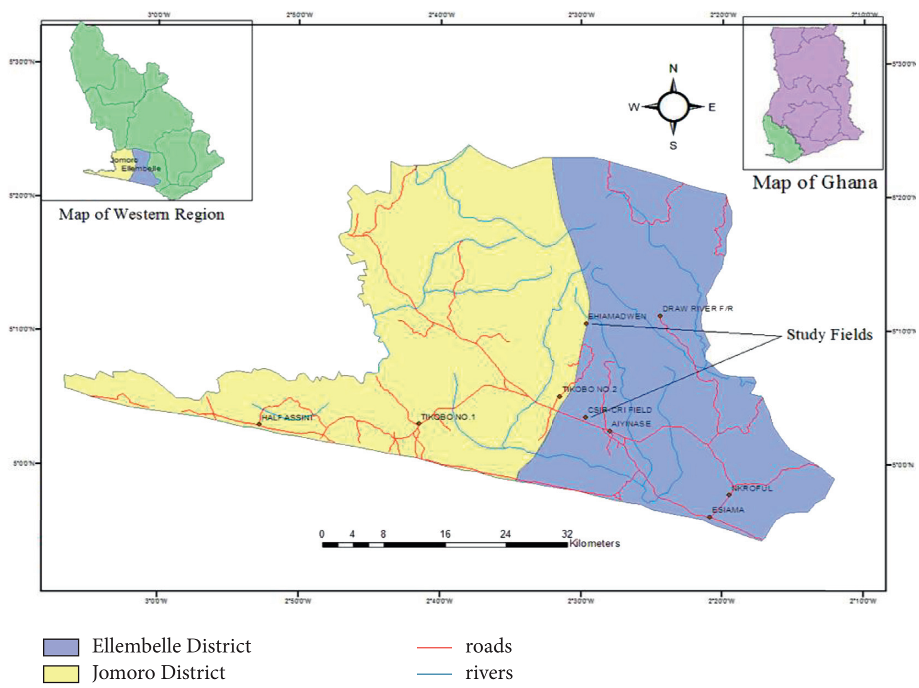

Figure 1: Map of Ellembelle and Jomoro districts showing the research study fields. Source: Ghana districts (2013).

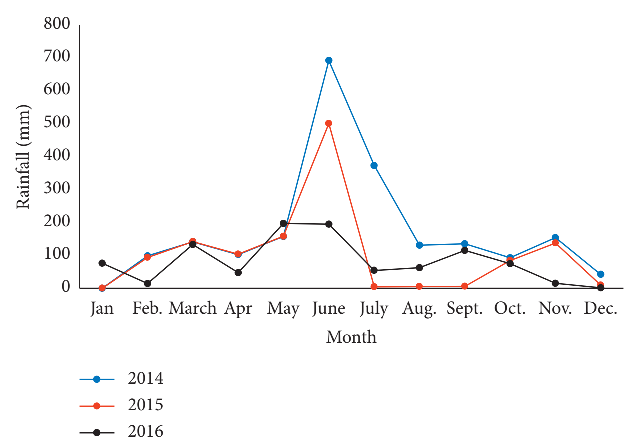

Figure 2: Rainfall data for 2014, 2015, and 2016 at the study sites. Source: Statistical Survey Department, Ellembelle District Assembly (2017).

2 m × 3 m and 6 m × 3 m for sole plantain and sole rubber, respectively. Intra-row spacing for both rubber and plantain was kept constant at 3 m whilst varying the inter-row spacing according to the number of plantain rows, ranging from 3 m in the low density, 2 m in the medium density, to 1.5 m in the high-density treatments (Figures 3 and 4). $N:P_2O_5:K_2O$ 15 : 15 : 15 fertilizer was applied at a rate of 100 and 200 g/plant for plantain and rubber, respectively, after one month and 6 months after planting.

2.3. Data Collection and Analysis

2.3.1. Plantain. Growth data were collected on plant height, the number of leaves, stem girth, months to harvest after flowering for the plantain in each treatment within the central rows. Data were collected on the yield and yield components of plantain at harvest. These included number of functional leaves, number of hands per bunch, number of fingers per hand, number of fingers of second hand per bunch, number of suckers per plant, weight of second hand of bunch, height of tallest sucker, and bunch weight of plantain.

The plant height was measured from the soil level to the latest matured leaf with tape measure. Stem girth was measured with electronic calipers at 0.1 m from the soil level.

The leaf area (a) was determined following the approach described by Obeifuma and Ndubizu, [22] and Potdar and Pawar, [23] as shown below:

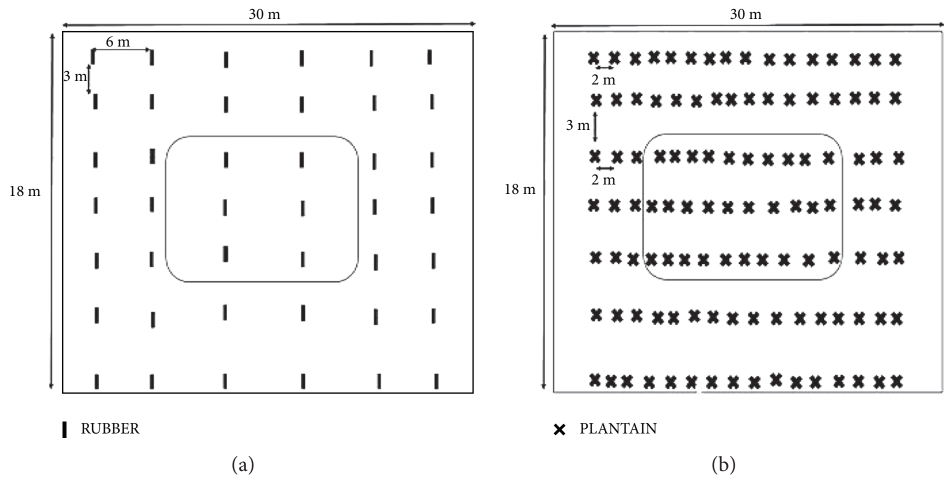

Figure 3: Population of rubber and plantain under the sole cropping systems. The marked plants were the selected plants for the data. (a) Sole rubber. (b) Sole plantain.

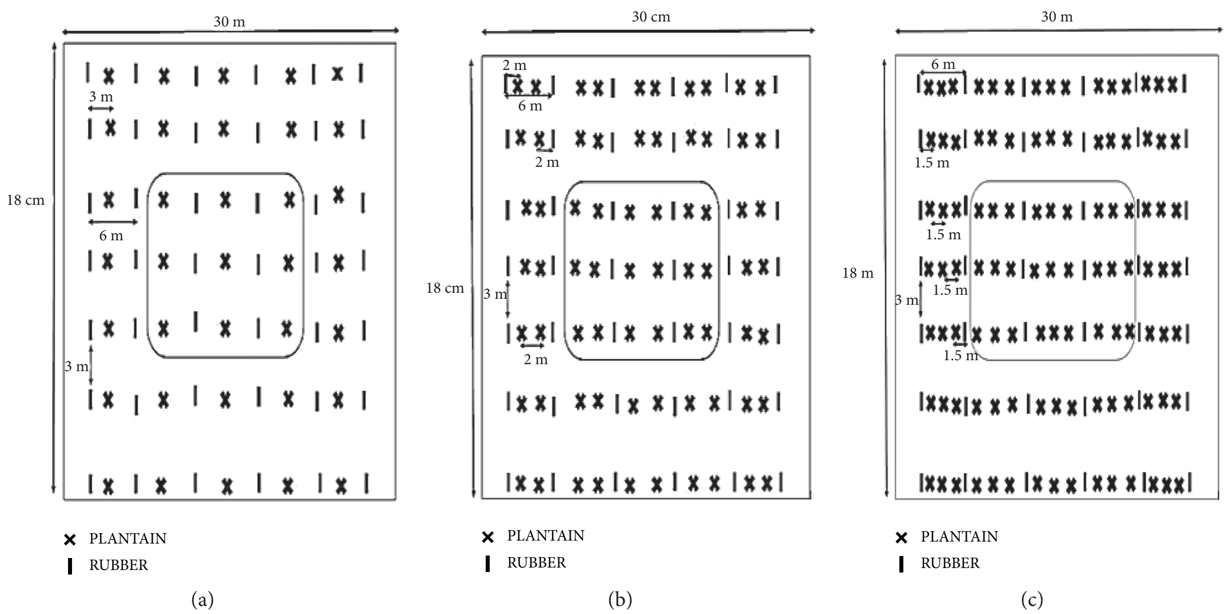

Figure 4: Population of plantain within the rubber-plantain intercropping systems: the marked plants were the selected plants for measurements in each treatment. (a) One row of plantain: two rows of rubber. (b) Two rows of plantain: two rows of rubber. (c) Three rows plantain: two rows of rubber.

$$\text{leaf area } (a) = \text{length } (l) \times \text{maximum width } (w) \text{ of the last matured leaf} \times 0.8. \quad (1)$$

The value 0.8 is a correction factor.

Leaf area index (LAI) is defined as the one-sided green leaf area per unit ground surface area in broadleaf canopies. This was determined by the following equation:

$$\text{LAI} = \frac{\text{mean leaf area of plant}}{\text{area occupied per plant}}. \quad (2)$$

Since the latex yield of the rubber trees were not ready during the experimental period, only the Partial Land Equivalent Ratio (PLER) of the plantain was used to determine the agronomic productivity of the plantain in the various rubber-plantain intercropped systems following the approach of Willey as shown in the following equation: [24]

$$\text{Partial LER of plantain} = \frac{\text{yield of plantain in intercrop}}{\text{yield of plantain in monocrop}}. \quad (3)$$

2.3.2. Rubber. Data were collected on height, stem girth, and leaf area of rubber. The stem girth of the rubber plant was measured with a digital caliper 10 mm above the bud-grafted union of the plant. The height was taken from the bud-grafted union to the tip of the plant using a tape measure. The leaf area of rubber was taken using the area meter AM300 developed by ADC Bio Scientific Limited, SG12 9TA U.K. The leaf area index (LAI) of rubber was derived using (equation 1) above.

The data collected were subjected to analysis of variance (ANOVA) using the GenStat statistical package. Separation of means was done using Standard Error of the Difference between the means (SED) at 5% significant level ($P \leq 0.05$).

3. Results and Discussion

3.1. Effect of Plantain Population Density on the Stem Girth and Height Growth of Rubber. Generally, stem girth and height of rubber increased significantly with increasing population density of plantain in the order of high-density treatment (PPPR) >medium-density treatment (PPR) >low-density treatment (PR) >sole rubber (R) at various stages of the plantain growth (Tables 1–3). At the same age and same intercropping pattern, stem girth of rubber trees at the Jomoro site was consistently higher than that of Ellembelle site. The values of height of the rubber trees at both the Ellembelle and Jomoro sites were significantly higher under the intercrop than the sole crop. At the Jomoro site, the increasing plantain population significantly increased the height of rubber while at the Ellembelle site, the increase was significant only at 4 and 11 months after planting (Table 1). Abdul Razak and Barizan [14] found that rubber agroforestry enhances the growth rate of associated rubber trees. Several other studies have also reported improved growth of rubber when cultivated as an intercrop compared to those that are planted as sole crops [4, 25, 26]. These are consistent with the enhanced girth and height of rubber trees under the intercrop relative to the sole rubber.

The growth parameters of the rubber tree especially the stem girth is very important because the latex tapping begins only when the rubber tree has attained a stem girth of 50 cm and above. The beginning of tapping is evaluated by the percentage of the rubber trees which have attained a stem girth of 50 cm at a height of 90 cm from the bud-grafted union upwards [26, 27].

The use of above and below ground resources in intercropping systems could facilitate (positive effect) or result in competition (negative effect) between the crops involved [28]. The negative effect of competition in rubber intercropping systems reported by others [3, 20, 29, 30] was contrary to the results of this study. In Sri Lanka, 50% of smallholders practice intercropping during the immature phase of the rubber and farmers were generally positive about intercropping [4]. Improved performance of the associated rubber in rubber-banana [4, 9, 25] and rubber-sugarcane [31] intercropping system are consistent with this study. The rubber crop could have benefit from the microclimatic condition created by the associated plantain which could have reduced weed competition and soil moisture loss in the cropping system to facilitate resource use [4, 9, 31–33].

The stem girth and height of rubber at harvest of plantain was better in the intercrops relative to the sole rubber (Figures 5 and 6, Tables 2 and 3) and this trend could be maintained till the attainment of the tappable stem girth of 50 cm. This stem girth increment could be due to a positive carry-over effect which has been proved by many scientific outputs. Rodrigo et al. [4] observed that an increase in stem girth of intercropped rubber was maintained throughout the immature phase resulting in an earlier onset of tapping in the intercrop than in the sole rubber.

The improved rubber growth with the increasing plantain densities in the intercrops shown in the correlation analysis suggests the stem girth of rubber trees in the high-density plantain intercropping systems could attain earlier tappable stem girth of 50 cm faster than when rubber is planted as sole rubber (Figures 5 and 6).

There is intercropping advantage over sole rubber planting [9, 26]. Rodrigo et al. [4] found out that after 5½ years of growth, the high-density banana intercrops, double banana rows between two rubber rows, and triple banana rows between two rubber rows showed an increase in tappable number of rubber trees of 69% and 72%, respectively, compared to sole rubber.

Other studies have reported the positive effect of intercropping on rubber latex production even at mature phase [19, 26]. This is very important to the plantation sector such as the Ghana Rubber Estates Limited (GREL) as well as the numerous smallholder rubber farmers in other parts of the world where rubber is cultivated.

3.2. Effect of Population Density on the Stem Girth and Height Growth of Plantain. The growth in stem girth and height of plantain was monitored on a monthly basis three months after planting till harvest of the plantain. This was to ascertain the influence of the intercropping systems on the growth of the plantain. At Ellembelle, the plantain population significantly influenced plantain stem girth from 4 MAP to 7 MAP, while the differences observed from 8 to 11 MAP were not significant. At Jomoro, the increasing plantain population significantly increased plantain stem girth throughout the 15 months (Table 4). The stem girth of plantain ranged from 48.34 cm (PR) to 55.27 cm (P) at Ellembelle. The ranking order for girth was PPPR (64.33 cm) >PPR (61.33 cm) >PR (55.67 cm) >P (54.88 cm) at Jomoro. Similarly, increasing plantain density resulted in significant growth in plantain height at both sites except 4 and 7 MAP at Ellembelle. Height of plantain ranged from 167.70 cm (P) to 238.10 cm (PPPR) at Ellembelle, and 219 cm (P) to 254.89 cm (PPPR) at Jomoro (Table 4).

Table 1: Stem girth and height growth of rubber tree at Ellembelle and Jomoro.

Treatments											
	Girth (mm) Ellembelle										
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	11 MAP				
R	5.25	6.08	6.99	8.64	10.27	11.73	14.76				
PR	5.78	6.88	8.00	9.32	10.56	12.57	16.24				
PPR	6.33	7.36	8.53	10.18	11.07	12.92	17.49				
PPPR	6.93	8.00	9.17	11.30	13.21	14.39	18.22				
SED (5%)	0.19	0.13	0.21	0.55	0.60	0.44	0.42				
CV (%)	3.90	2.30	3.10	6.80	6.50	6.90	3.10				
Treatments	Girth (mm) Jomoro										
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP	13 MAP	15 MAP
R	12.30	19.77	23.63	25.57	27.95	32.40	35.54	38.59	41.96	45.34	54.88
PR	14.28	21.22	25.12	28.73	32.85	35.50	38.42	41.10	44.40	47.39	55.67
PPR	16.32	22.57	28.94	31.89	36.40	39.34	43.48	44.64	47.43	50.72	61.33
PPPR	17.72	25.58	32.05	36.08	39.66	41.88	45.08	47.71	50.16	52.41	64.33
SED (5%)	0.50	0.59	0.21	0.31	0.65	0.47	0.78	0.28	0.45	0.41	0.47
CV (%)	4.10	3.20	1.00	1.20	2.30	1.50	2.40	0.80	1.20	1.00	1.00
Treatments	Height (cm) Ellembelle										
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	11 MAP				
R	27.60	32.30	34.60	40.80	54.00	61.40	81.90				
PR	26.60	29.40	36.70	38.70	54.60	65.30	98.10				
PPR	28.20	32.80	38.80	49.10	57.90	67.80	103.60				
PPPR	41.20	48.20	45.00	56.40	69.20	83.60	120.50				
SED (5%)	5.76	NS	NS	NS	NS	NS	3.55				
CV (%)	22.90	26.70	14.60	20.30	15.90	13.40	4.30				
Treatments	Height (cm) Jomoro										
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP	13 MAP	15 MAP
R	37.78	42.78	58.84	72.19	81.91	115.30	138.50	161.67	203.67	236.80	305.90
PR	42.65	47.65	60.52	79.67	87.56	129.44	150.49	176.78	227.06	252.60	335.40
PPR	48.67	56.08	66.50	86.50	95.89	139.06	161.29	197.44	242.57	282.60	351.80
PPPR	52.78	61.33	69.30	100.11	109.43	154.72	181.33	207.54	259.41	317.90	371.70
SED (5%)	0.53	0.43	0.56	1.01	1.47	1.20	1.11	1.48	1.82	3.24	3.73
CV (%)	1.40	1.00	1.10	1.50	1.90	1.10	1.00	1.00	1.00	1.50	1.30

MAP = months after planting; R = sole rubber; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; NS = not significant; SED = standard error of the difference; CV = coefficient of variation.

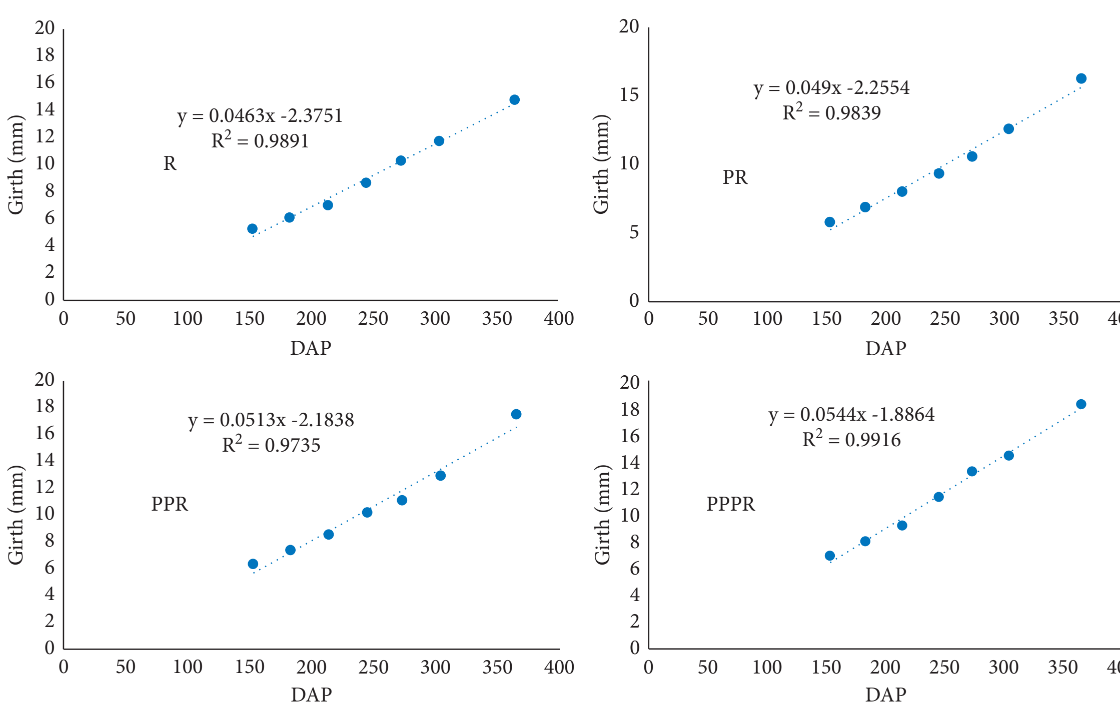

Figure 5: Correlation between girth and days after planting (DAP) of rubber in the rubber-plantain intercropping systems at Ellembelle study site, Western region, Ghana. R = sole rubber; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain.

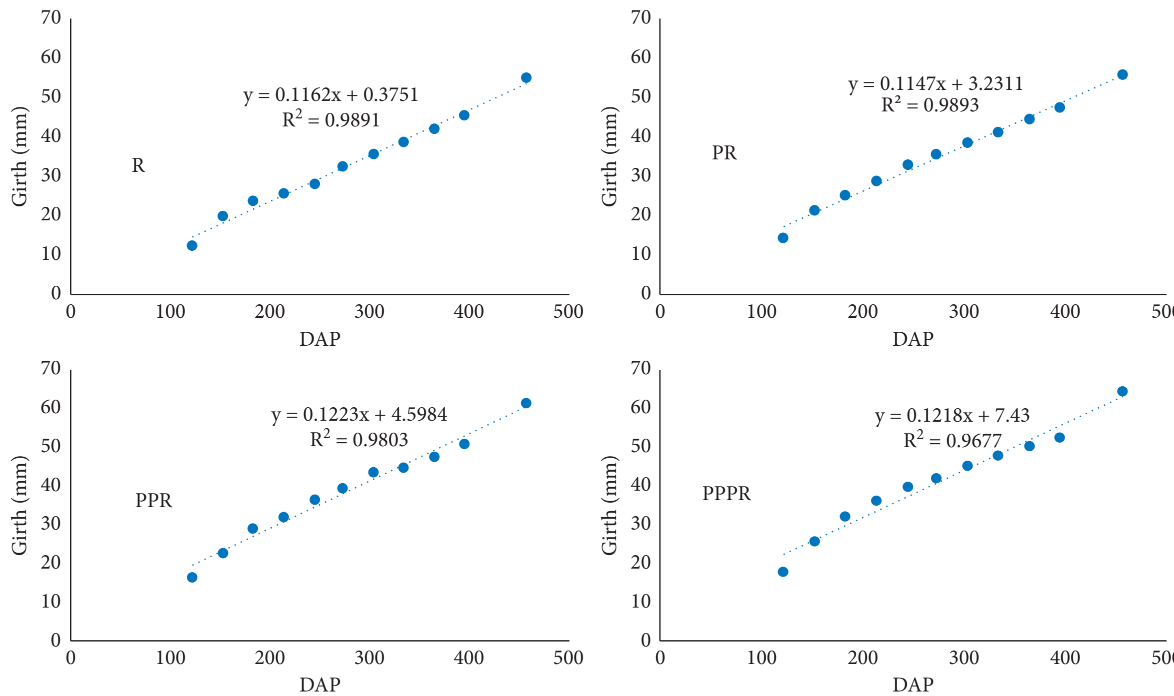

Figure 6: Correlation between girth and days after planting (DAP) of rubber in the rubber-plantain intercropping systems at Jomoro study site, Western region, Ghana. R = sole rubber; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain.

Table 2: Stem girth and height growth of rubber tree at flowering of plantain at Ellembelle and Jomoro.

Treatments	Ellembelle	
	Stem girth (mm)	Height (cm)
R	15.50	93.50
PR	16.29	107.61
PPR	16.94	114.20
PPPR	19.58	130.31
SED (5%)	0.36	1.73
CV (%)	2.60	1.90
Treatments	Jomoro	
R	33.29	305.4
PR	31.96	305.2
PPR	36.55	363.2
PPPR	38.67	369.0
SED (5%)	0.96	19.20
CV (%)	3.30	7.00

R = sole rubber; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; SED = standard error of the difference; CV = coefficient of variation.

Table 3: Stem girth, height, and leaf area growth of rubber tree at harvest of plantain at Ellembelle and Jomoro.

Treatments	Stem girth (mm)	Height (cm)	Leaf area (cm^2)
		Ellembelle	
R	20.41	117.70	240.4
PR	21.67	138.30	281.5
PPR	24.04	150.900	394.3
PPPR	26.44	170.90	434.0
SED (5%)	0.76	4.77	23.38
CV (%)	4.00	4.00	8.50
		Jomoro	
R	54.88	305.90	193.00
PR	55.67	335.40	310.00
PPR	61.33	351.80	412.00
PPPR	64.33	371.70	480.00
SED (5%)	0.47	3.73	36.30
CV (%)	1.00	1.30	12.70

R = sole rubber; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; SED = standard error of the difference; CV = coefficient of variation.

The umbrella formed by the leaves of the high-density plantain intercropping system (PPPR) could have reduced the extent of water loss from the cropping system. This could have led to high moisture retention under the high-density plantain intercropping systems, thereby enhancing stem and height growth of the plantain. High-density banana intercrops conserved more soil moisture relative to the low-density banana intercrop [4].

At the flowering stage of plantain, the stem girths recorded for plantain were 50.4 cm for sole plantain, 51.7 cm for low-density treatment, 58.1 cm for medium-density treatment, and 61.3 cm for high-density treatment, while the recorded heights were 226.5 cm for sole plantain, 230.9 cm for low-density treatment, 241.3 cm for medium-density treatment, and 260.8 cm for high-density treatment. At plantain harvest, plantains had attained stem girth of 55.3 cm for sole plantain, 55.6 cm for low-density treatment, 62.7 cm medium-density treatment, and 65.4 cm for high-density plantain. This finding is consistent with the report that intercropping, even at high densities, resulted in improved growth of both the component crops of banana and rubber [9].

Table 4: Stem girth and height of plantain at Ellembelle and Jomoro sites.

Treatment	Girth (cm) Ellembelle						
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	11 MAP
P	32.04	33.61	43.00	49.56	49.70	51.84	55.27
PR	22.29	28.39	34.39	39.55	42.28	43.44	48.34
PPR	25.54	31.72	36.50	41.99	44.47	45.68	49.98
PPPR	27.61	33.61	39.28	43.90	46.34	48.87	54.03
SED (5%)	1.79	1.41	0.83	0.80	NS	NS	NS
CV (%)	8.20	5.20	2.60	2.20	2.80	2.00	3.10

Treatment	Girth (cm) Jomoro										
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP	13 MAP	15 MAP
P	12.30	19.77	23.63	25.57	27.95	32.40	35.54	38.59	41.96	45.34	54.88
PR	14.28	21.22	25.12	28.73	32.85	35.50	38.42	41.10	44.40	47.39	55.67
PPR	16.32	22.57	28.94	31.89	36.40	39.34	43.48	44.64	47.43	50.72	61.33
PPPR	17.72	25.58	32.05	36.08	39.66	41.88	45.08	47.71	50.16	52.41	64.33
SED (5%)	0.50	0.59	0.21	0.31	0.65	0.47	0.78	0.28	0.45	0.41	0.47
CV (%)	4.10	3.20	1.00	1.20	2.30	1.50	2.40	0.80	1.20	1.00	1.00

Treatment	Height (cm) Ellembelle						
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	11 MAP
P	73.60	82.20	93.60	113.10	122.20	132.40	167.70
PR	83.00	95.30	110.10	134.10	143.40	157.40	194.60
PPR	91.70	102.80	119.50	140.10	132.50	170.90	209.60
PPPR	97.20	119.50	126.80	134.10	172.20	194.30	238.10
SED (5%)	NS	8.31	9.30	NS	12.64	12.12	8.41
CV (%)	13.20	10.20	8.52	10.60	10.90	9.10	5.10

Treatment	Height (cm) Jomoro										
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP	13 MAP	15 MAP
P	39.31	64.58	74.28	87.22	97.26	106.91	115.83	137.02	172.10	206.00	219.33
PR	45.45	75.02	82.93	100.10	108.67	121.86	126.67	156.84	188.80	226.20	235.17
PPR	51.78	81.06	100.67	112.22	124.52	130.78	143.27	167.95	203.10	233.50	243.50
PPPR	59.28	92.83	113.79	121.01	128.52	139.61	149.17	181.36	214.40	236.80	254.89
SED (5%)	1.52	0.64	2.63	1.14	1.94	2.05	1.70	2.52	3.12	5.05	2.04
CV (%)	3.80	1.00	3.50	1.30	2.10	2.00	1.60	1.70	2.00	2.70	1.00

MAP = months after planting; P = sole plantain; R = sole rubber; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; SED = standard error of the difference; CV = coefficient of variation.

3.3. Population Density Effect on the Number of Leaves and Functional Leaves of Plantain. The number of leaves and functional leaves of plantain were monitored at both Ellembelle and Jomoro trials till flowering and harvest of plantain (Tables 5 and 6). This was to determine how the intercropping systems influence leaves and canopy formation of the plantain. At flowering of plantain, the number of functional leaves obtained at Ellembelle was highest under the PPPR system. At flowering and harvest at Jomoro, there was no significant difference in the number of functional leaves among the treatments. Generally, the number of leaves fluctuated monthly with the PPPR (high-density treatment) recording significantly higher values at 4, 5, and 11 MAP at Ellembelle and throughout the growth period at Jomoro (Table 6).

The number of functional leaves of plantain obtained at flowering in both trials was consistent with the required functional leaves for a good bunch yield. According to Banful [11], at good vegetative growth, 8 functional leaves are required at flowering to produce a good bunch yield. The number of functional leaves obtained at flowering at Ellembelle (9–12) and Jomoro (8–9) for the various treatments (Table 5) were within the number of functional leaves required for a good bunch yield.

3.4. Effect of Plantain Population Density on the Yield and Yield Components of Plantain. The population density of plantain generally had a significant effect on the plantain yield in the rubber-plantain intercropping system (Table 7). The yield of plantain recorded at the Ellembelle site was 9,972 kg/ha for P, 3,983 kg/ha for PR, 7,036 kg/ha for medium-density (PPR), and 11,453 kg/ha for high-density (PPPR). The yield recorded at Jomoro was 9,765 kg/ha for P, 3,287 kg/ha for PR, 7,851 kg/ha for medium-density (PPR), and 11794 kg/ha for high-density (PPPR) (Table 7). The highest yield of 11,453 kg/ha and 11,794 kg/ha were recorded in the high-density treatment at Ellembelle and Jomoro, respectively. Plantain yield from both the sole plantain (P) and high-density rubber-plantain intercropping (PPPR) were not significantly different. The number of hands per bunch was seven each for medium and high-density treatments and there was no significant difference between the two treatments. The sole plantain (P) and the PR treatments each recorded six hands which were similar to the

Table 5: Number of leaves of intercropped plantain at Ellembelle and Jomoro.

Treatments	Ellembelle										
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	11 MAP				
P	12	14	15	15	19	22	25				
PR	10	13	16	16	19	22	22				
PPR	14	15	16	16	19	22	26				
PPPR	12	13	14	16	17	25	30				
SED (5%)	1	1	NS	NS	NS	NS	1				
CV (%)	7.30	4.30	8.00	9.10	5.20	6.2	7.0				
Treatment	Jomoro										
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP	12 MAP	13 MAP	15MAP
P	11	16	20	22	23	26	27	31	36	40	43
PR	13	18	22	24	26	29	30	35	40	44	48
PPR	14	20	27	30	32	35	36	42	47	51	56
PPPR	15	21	30	33	35	39	41	47	53	58	63
SED (5%)	1	1	1	1	1	1	1	1	1	1	1.3
CV (%)	5.80	4.2	2.60	1.80	1.90	2.00	2.30	3.30	2.80	2.80	3.10

MAP = months after planting; P = sole plantain; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; NS = not significant; SED = standard error of the difference; CV = coefficient of variation.

Table 6: Morphological and flowering characteristics of intercropped plantain at Ellembelle and Jomoro.

Treatments	Height (cm)	Leaf area (cm^2)	No. of functional leaves	No. of months to flowering	Stem girth	No. of suckers/plant
			Ellembelle			
P	225.47	4644.40	9	10	56.57	4
PR	234.61	5283.60	10	10	49.38	3
PPR	240.72	5516.80	10	10	51.77	4
PPPR	253.00	6176.80	12	10	55.86	4
SED (5%)	1.90	362.30	1	NS	1.15	NS
CV (%)	1.00	8.20	6.40	4.70	2.60	18.90
Treatments			Jomoro			
P	226.50	5363.60	8	14	56.49	4
PR	230.90	5013.60	8	15	56.97	5
PPR	241.30	5215.60	8	14	62.94	5
PPPR	260.80	6452.00	9	13	65.85	5
SED (5%)	8.01	249.44	NS	NS	0.65	NS
CV (%)	4.10	5.50	6.20	9.30	4.80	20.60

MAP = months after planting; P = sole plantain; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; NS = not significant; SED = standard error of the difference; CV = coefficient of variation.

medium and the high-density treatments. Yield from both study sites increased with increasing population density of the plantain. This finding was consistent with that of Rodrigo et al. [9] who recorded a similar trend under a rubber-banana intercropping system. The average plantain yield in Ghana ranged between 10.55 and 10.79 t/ha for rom 2010 to 2014. Plantain yield increased from about 8 t/ha to 11 t/ha between 2003 and 2009 due to good cultural practices and disease tolerant varieties [33]. The mean plantain yields recorded at both sites from the high-density rubber-plantain intercrop at both sites were higher than that recorded by FAOSTAT [33], whiles that of the sole plantain crop (P), low-density and medium-density were within or below-average yield. Thus, intercropping plantain holds a key in improving plantain yield in Ghana.

At both Ellembelle and Jomoro, increasing plantain population in the inter-row did not affect soil moisture content at 0–15 cm soil depth (Table 8). However, increasing plantain population significantly increased soil moisture content at 15–30 cm soil depth at both Ellembelle and Jomoro study sites. The high soil moisture content under the high-density plantain intercropping system (PPPR) could be a major contributing factor to the improved growth of rubber under the high-density plantain intercropping system relative to the sole rubber (Tables 2 and 3).

Rubber is a deep-rooted plant, with rooting depth (taproot) of 3–4 m, and higher soil moisture at 15–30 cm depth could benefit the tree crop [34]. The improved rubber growth at a higher plantain population (medium-density and high-density plantain) compared with sole rubber (R) could be attributed to the availability of soil moisture at lower soil depth. In intercropping systems, radiation-use efficiency (RUE) becomes less important in terms of intercrop advantage under condition of limited soil moisture supplies [35]. Soil moisture, therefore, plays a significant role in the improved growth of the rubber in the high-density plantain intercrop relative to the sole rubber crop.

Even though other workers like Rodrigo et al. [4] attributed the improved growth of intercrop relative to the sole

Table 7: Yield and yield components of plantain at harvest under various intercropping treatments at Ellembelle and Jomoro.

Treatments	NFL	MHAF	NH/bunch	NF/hand	NFSH/bunch	NS/plant	WSHB (kg)	HTS (cm)	BW (kg/ha)
					Ellembelle				
P	2	3	6	5	6	4	1.12	89.10	9972
PR	1	3	6	5	7	3	1.26	90.800	3983
PPR	2	3	7	5	7	4	1.36	104.30	7036
PPPR	2	3	7	5	7	4	1.36	114.5	11453
SED (5%)	NS	NS	1	NS	NS	NS	NS	3.03	1717.60
CV (%)	41.20	8.90	5.30	7.50	12.00	18.90	8.30	3.70	10.60
					Jomoro				
P	2	3	5	5	5	5	1.61	154.40	9765
PR	2	3	5	4	4	5	1.77	140.10	3287
PPR	2	3	6	5	5	5	1.69	177.00	7851
PPPR	3	3	6	5	4	6	2.18	183.90	11794
SED (5%)	NS	—	NS	NS	NS	NS	NS	7.08	426.40
CV (%)	21.00	—	10.20	18.90	3.30	11.20	14.90	5.30	6.40

NFL = number of functional leaves; MHAF = months to harvest after flowering; NH/bunch = number of hands per bunch; NF/hand = number of fingers per hand; NFSH/bunch = number of fingers of second hand per bunch; NS/plant = number of suckers per plant; WSHB (kg) = weight of second hand of bunch; HTS (cm) = height of the tallest sucker; BW (kg/ha) = bunch weight; P = sole plantain; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; NS = not significant; SED = standard error of the difference; CV = coefficient of variation.

Table 8: Effect of plantain population density on soil moisture content in plantain-rubber intercropping system at Ellembelle and Jomoro.

Treatments	Depth (cm)	Ellembelle Moisture (%)	Jomoro Moisture (%)
P	0–15	8.02	19.60
R	0–15	5.59	20.30
PR	0–15	5.59	18.20
PPR	0–15	7.64	19.00
PPPR	0–15	7.87	21.00
SED (5%)	—	NS	NS
CV (%)	—	28.50	25.70
P	15–30	6.00	13.85
R	15–30	5.72	13.84
PR	15–30	6.21	13.74
PPR	15–30	7.39	22.66
PPPR	15–30	10.94	23.85
SED (5%)	—	0.95	1.31
CV (%)	—	16.00	9.20
P	30–60	4.03	Hardpan
R	30–60	3.97	Hardpan
PR	30–60	4.03	Hardpan
PPR	30–60	4.19	Hardpan
PPPR	30–60	4.04	Hardpan
SED (5%)	—	NS	—
CV (%)	—	3.00	—

P = sole plantain; R = sole rubber; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; NS = not significant; SED = standard error of the difference; CV = coefficient of variation.

rubber to radiation-use efficiency, Willey and Reddy [35] found out that radiation-use efficiency (RUE) alone becomes less important in terms of intercrop advantages under conditions of limited soil moisture supplies.

The soils under the sole rubber and low-density plantain intercrop treatments tend to be exposed to high temperatures due to the bigger gaps between the canopies of the plants and this can eventually lead to higher water loss through evaporation. However, due to the closeness of the canopy of leaves from the high-density plantain intercropping system (PPPR) coupled with their large leaf area, moisture retention was high under the high-density treatment and this could have benefitted the associated rubber, resulting in its enhanced growth relative to the sole rubber.

The difference in the rooting depth of both crops might also have contributed to a reduction in competition for soil nutrients and moisture, with the rubber absorbing from a deeper depth compared to the plantain. Soil moisture content could therefore be a major factor for enhanced growth of associated rubber and yield of plantain in high-density rubber-plantain intercropping system.

Since plantain does not have a taproot system like rubber coupled with the fact that plantain is a water-loving plant, it might have taken most of its water around the 0–15 cm layer. Soil moisture at the 15–30 cm depth could therefore be available to the associated rubber. The improvement in growth (rubber and plantain) and yield of plantain could be attributed to reduced competition for soil resources as a result of rubber picking from deeper layers of the soil compared with the plantain in the shallow layers [35].

The improved growth of plantain and rubber under the intercrop (low, medium, and high density) relative to the sole rubber crop (R) could also be attributed to the symbiotic relationship of Arbuscular Mycorrhizal Fungi (AMF) with the plantain. There is a symbiotic relationship between plantain plants and indigenous mycorrhizal fungi in Ghanaian soils [36]. In their study, False Horn plantain was found to have a higher frequency and intensity of mycorrhizal colonization than French plantain in all root samples. In a related study, it was also found that AMF could increase nutrient content and growth parameters of banana plants [37] and improve soil structure by releasing glomalin when hyphae die and decay, hence improving soil stability and increasing water retention [38]. These advantages of the

AMF in association with the plantain could have resulted in the significantly higher moisture content recorded under the high-density treatment which benefitted the associated rubber.

3.5. Effect of Population Density on Plantain Sucker Development. Increasing plantain population in the plantain-rubber intercrop did not significantly influence the number of suckers in the first seven months after planting and at harvest of the plantain (Table 9). However, on the 8th, 9th, and 10th months after planting at Jomoro, the number of suckers obtained from the medium- and high-density treatments were significantly higher than that from the sole plantain (P) and the PR treatments (Table 9). Plantain suckers obtained by a farmer is important for securing planting materials for next season's planting and income generation from surplus.

At both study sites, there was no significant difference in the number of plantain suckers/plant after harvesting of plantain. After the harvest of the plantain, the height of suckers differed significantly among the different plantain densities. The height of the plantain sucker under the medium- and high-density plantain intercrops was significantly higher than the sole plantain and low-density plantain intercrop at both sites. The medium- and high-density plantain intercrops were likely to obtain an early yield from their ratoon crops relative to the sole plantain and low-density plantain intercrop due to the early height attainment which can give them a competitive advantage.

3.6. Population Density Effect on Days to Flowering and Leaf Area Index (LAI). The number of days to flowering of plantain was not influenced by plantain population density in both sites. At the Ellembelle site, it took 10 months for plantain to flower in all the plantain densities and 3 months between flowerings to harvesting. At Jomoro, it took an average of 15 months for flowering to occur after planting but the number of months from flowering to harvest remained 3 months (Table 6). The longer duration of flowering recorded at Jomoro might be due to the phosphorus (P) deficiency in the soil. Soils that are inherently low in phosphorus can delay the gestation period of some plants [39].

Most plants need about 0.2–0.5% P (on a dry matter basis) for normal growth [40]. Roper et al. [41] reported that plants do not need to take up new P for every cell function because phosphorus existing in plant cells is recycled over and over again. However, early plant growth is dependent on P because of the need for rapid cell division and expansion. The primordial for future roots, stems, leaves, flowers, and seeds are produced very early during plant growth and therefore P deficiency during the early growth of plants and germinating seedlings can greatly affect the yield potentials of crops and pastures [39].

The observed values for leaf area (LA) and leaf area index (LAI) differed significantly among treatments. High-density treatment obtained a significantly higher value at both sites (Tables 10 & 11). The results show that the leaf area of rubber increased with increasing population density of plantain under the different intercropping systems. Generally, the leaf area of rubber in the intercrop was significantly higher than that of the sole rubber (R). With plantain, a significant difference in the leaf area was observed under the treatments. The leaf area values increased with increasing population density with the PPPR treatments recording higher values in both sites (Tables 10 & 11).

The high-density plantain in the rubber-plantain intercropping system (PPPR) recorded a significantly higher leaf area relative to the other treatments. The greater leaf area index in the high plantain density rubber-plantain intercropping could lead to an increase in fractional light interception and ground cover [4]. The growth of weeds could also be reduced under the high-density treatment due to the higher LAI [42]. There was a positive correlation between the plantain population density and the leaf area and leaf area index of the plantain in the rubber-plantain intercropping systems (Figures 7 and 8). The leaf area (LA) and leaf area index (LAI) increased with the increasing population density of the plantain in the rubber-plantain intercropping systems at both Ellembelle and Jomoro sites (Figures 7 and 8).

The increased ground cover could also lead to reduced soil erosion [43], resulting in higher soil moisture being recorded under the high-density plantain intercrop relative to the sole rubber or plantain (Table 8). This could result in protecting the long-term sustainability of the farmland [43]. Due to the expected immediate yield from plantain, the farmers' attention and care would be better under the intercrops than the sole rubber crops due to the absence of immediate yield from the sole rubber crop [44].

3.7. Partial Land Equivalent Ratio (PLER). The total land area required under sole cropping to give the same yield obtained in the intercropping is called Land Equivalent Ratio (LER). In this study, only the yield of the plantain described as Partial Land Equivalent Ratio (PLER) was used. This is because the rubber yield was not ready during the study period. The PLER values for plantain at Ellembelle showed no intercrop advantage in the low and the medium density treatments, but the high-density treatment was advantageous (Table 12). In the PR system, intercrop yield was only 40% of the sole plantain crop and 60% of the land was needed to get the same yield as in the sole plantain. In the medium-density treatment, the intercrop yield was 71% of the sole plantain and 29% of the land was needed to produce the same yield as the sole plantain. The high-density treatment system was however advantageous, recording a PLER of 1.15. The yield from the high-density treatment was 15% more than that that of the sole plantain. It can be concluded that, with the high-density system, 15% more land would be needed for the sole plantain (P) to get the same yield.

Generally, the PLER at Jomoro Ellembelle followed a similar trend as observed at Ellembelle Jomoro. The PLER values for low-, medium-density, and high-density treatments were 0.34, 0.80, and 1.21, respectively. Intercrop yield was 34% of the sole crop yield in the low-

Table 9: Number of suckers of plantain under the different plantain densities at Ellembelle and Jomoro.

Treatments	Ellembelle							
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
P	0	0	0	0	1	3	3	4
PR	0	0	0	0	1	2	2	3
PPR	0	0	0	0	1	2	3	4
PPPR	0	0	0	0	2	3	3	4
SED (5%)	0	0	0	0	1	1	NS	NS
CV (%)	0	0	0	0	26.70	12.40	17.60	18.90
Treatments	Jomoro							
	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	10 MAP	11 MAP
P	1	1	1	1	2	2	3	3
PR	1	1	1	1	1	2	2	5
PPR	1	2	2	1	3	3	4	4
PPPR	2	2	2	2	3	4	4	5
SED (5%)	NS	NS	NS	NS	0.45	1	1	1
CV (%)	44.20	43.30	48.40	48.10	24.60	29.10	25.20	9.80

MAP = months after planting; P = sole plantain; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; NS = not significant; SED = standard error of the difference; CV = coefficient of variation.

Table 10: Effect of different plantain populations on leaf area and leaf area index of rubber at Ellembelle and Jomoro.

Treatment	Leaf area (cm^2)	Leaf area index
	Ellembelle	
R	240.4	0.0013
PR	281.5	0.0015
PPR	394.3	0.0022
PPPR	434.0	0.0024
SED (5%)	23.38	0.00013
CV (%)	8.50	8.50
	Jomoro	
R	193	0.0011
PR	310	0.0017
PPR	412	0.0023
PPPR	480	0.0027
SED (5%)	36.30	0.00020
CV (%)	12.70	12.70

R = sole rubber; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; SED = standard error of the difference; CV = coefficient of variation.

Table 11: Effect of different plantain population on leaf area and leaf area index of plantain at Ellembelle and Jomoro.

Treatment	Leaf area (cm^2)	Leaf area index
	Ellembelle	
P	11611	0.077
PR	13209	0.029
PPR	13792	0.061
PPPR	15442	0.103
SED	905.7	0.0073
CV (%)	8.20	13.10
	Jomoro	
P	13409	0.0894
PR	12534	0.0279
PPR	13039	0.058
PPPR	16132	0.1075
SED	623.6	0.0046
CV (%)	5.50	7.90

P = sole plantain; PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain; SED = standard error of the difference; CV = coefficient of variation.

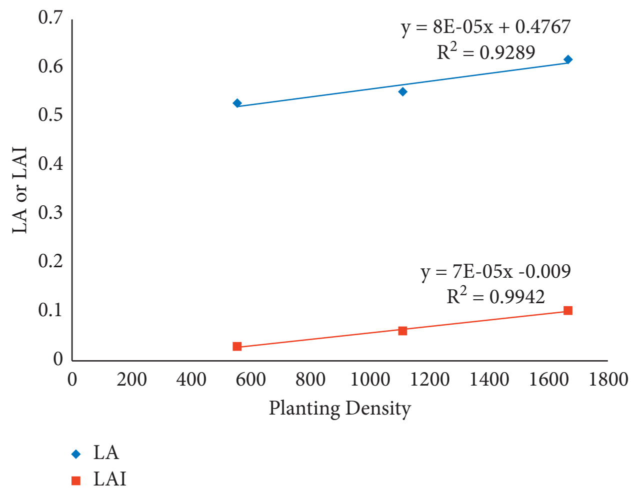

Figure 7: Correlation of plantain population density and leaf area (LA) (m^2), and leaf area index (LAI) at Ellembelle.

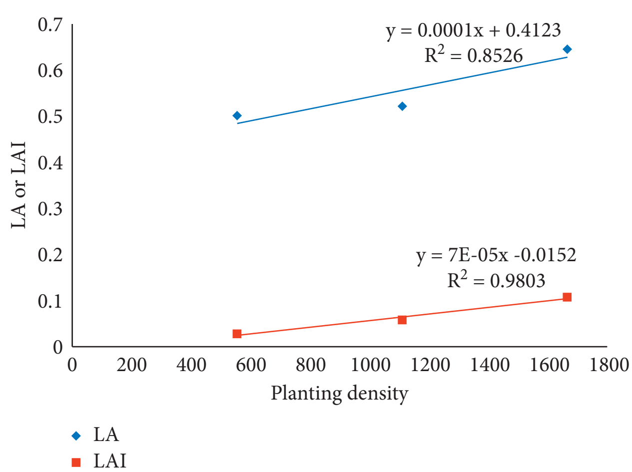

Figure 8: Correlation of plantain population density and leaf area (LA) (m^2), and leaf area index (LAI) at Jomoro.

Table 12: Partial land equivalent ratios of plantain in rubber-plantain intercropping systems at Ellembelle and Jomoro.

Treatment	Intercrop plantain yield (kg/ha)	Sole plantain yield (kg/ha)	Partial land equivalent ration (PLER)
		Ellembelle	
PR	3983	9972	0.40
PPR	7036	9972	0.71
PPPR	11453	9972	1.15
		Jomoro	
PR	3287	9765	0.34
PPR	7851	9765	0.80
PPPR	11794	9765	1.21

PR = low-density plantain; PPR = medium-density plantain; PPPR = high-density plantain.

density treatment, while the yield in the medium-density system was 80% of the sole plantain yield. Sixty-six percent of the land was needed under the low-density treatment to produce the same yield as in the sole plantain. In the same scenario, 20% of the land was needed under the medium-density intercrop treatment to produce the same yield (9,765 kg/ha) as the sole plantain. Both the low- and the medium-density systems had no intercropping advantage in terms of the yield from the various systems. However, the high-density treatment recorded a PLER of 1.21 which showed an intercropping advantage over the sole plantain with 21% more land required under the sole plantain to produce the same yield (11,794 kg/ha) as from the high-density treatment.

4. Conclusion

Rubber trees performed better when intercropped with plantain than under sole crop conditions. The population density of plantain had a significant effect on the growth of the associated rubber with the high-density system having a positive influence on the growth rate of the associated rubber. High-density treatment significantly increased plantain productivity compared to sole plantain. The stem girth and height of the rubber tree were significantly improved in the intercrops relative to the sole rubber. The results suggested the optimum population density of plantain when grown as an intercrop with immature rubber in rubber-plantain intercropping at a rubber spacing of 6 m × 3 m to be three rows of plantain between two rubber rows.

There was a positive correlation between population density of plantain and stem girth of rubber. Stem girth of rubber increased with increasing density of plantain in the rubber-plantain intercropping system with three different planting densities of the plantain between two rubber rows. Partial Land Equivalent Ratio (PLER) showed an intercropping advantage over sole plantain in the high-density rubber-plantain intercropping. The low and medium-density intercropping were not advantageous in terms of yield from the plantain. The results from Ellembelle and Jomoro sites showed intercropping advantage under the high-density treatment with the PLER values of 1.15 ha and 1.20 ha, respectively.

High soil moisture content was found to be one of the major reasons for enhanced growth of associated rubber in high-density rubber-plantain intercropping and this occurred within a depth of 15–30 cm at both sites. The advantages of the AMF in association with plantain could have contributed to the significantly higher moisture content recorded under the high-density treatment which benefitted the associated rubber.

Shading in the intercrops, especially high-density treatment, moderated the microclimate and alleviated plant stress, thereby playing a major beneficial role for associated crop growth. Rubber-plantain intercropping, improved growth, and development of both plantain and rubber and could be demonstrated for adoption by farmers for improved productivity and livelihoods.

Data Availability

All the data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Erasmus Narteh Tetteh contributed to conceptualization, methodology, formal analysis, investigation, writing the original draft, and editing the manuscript. Eric Owusu Danquah contributed to conceptualization, methodology, investigation, and reviewing and editing the manuscript. Akwesi Adutum Abunyewa performed supervision and reviewed and edited the manuscript. Caleb Melenya Ocansey assisted in investigation, analysis, and reviewing and editing the manuscript. Emmanuel Amoah Boakye reviewed and edited the manuscript. Vincent Logah and Stephen Yeboah assisted in analysis and reviewed and edited the manuscript. Henry Oppong Tuffour and Twum-Ampofo performed supervision and reviewed and edited the manuscript. Beloved Mensah Dzomeku and Victor Rex Barnes reviewed and edited the manuscript.

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