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Intercropping Arabica Coffee (*Coffea arabica*) with Banana (*Musa Spp*) at Teppi, Southwest Ethiopia

Behailu Mekonnen[1, *], Shiferaw Temteme[1], Essubalew Getachew[2]

[1]Ethiopia Institute of Agricultural Research, Teppi Agricultural Research Center, Teppi, Ethiopia

[2]College of Agriculture and Veterinary Medicine, Jimma University, Jimma, Ethiopia

Email address:

behailumekonnenba@gmail.com (Behailu Mekonnen)

[*]Corresponding author

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Abstract: A field experiment aimed to determine the optimum ratio of intercropping Arabica coffee with banana was conducted at Teppi, Southwest Ethiopia, from 2012 to 2016. The experiment consisted of four cropping arrangements (1:1, 1:2, 1:3 ratios of coffee with banana, and staggered planting) with sole stands of each crop, arranged in a Randomized Complete Block Design with three replicates. The yield and yield-related attributes of the component crops were collected, and the efficiency of the cropping arrangement was estimated using a land equivalent ratio. The analysis of variance showed that the clean coffee yield was significantly ($p < 0.05$) affected by intercropping with bananas. Intercropping of the component crops also significantly ($p < 0.05$) influenced the fruit yield of bananas. Thus, the highest clean coffee yield was obtained from the sole coffee plot (2007.4 kg ha^{-1}) followed by the plot in which coffee and banana were arranged staggeringly (1782.6 kg ha^{-1}). Similarly, the highest values of land equivalent ratio (1.25) and yield advantage of coffee (0.88) were recorded from staggeringly arranged coffee with banana compared with other intercrops. The result also indicates the enhanced productivity and compatibility of the component crops when they are inter-planted staggeringly. Accordingly, the aforementioned planting arrangement can be recommended for farmers and growers in the study area for increased yield productivity of the component crops. Further study needs to be repeated one more season in different agro-ecologies with different varieties of component crops.

Keywords: Yield, Coffee, Intercropping, Banana, Land Productivity, Yield Advantage

1. Introduction

Coffee is one of the most important cultivated crops in the world. It is grown in about 80 countries on 10.2 million hectares of land in the tropical and subtropical regions [1, 2]. Economically, the crop is the second most exported commodity in the world after crude oil, and it provides a livelihood for more than 25 million people living in developing countries [3-5]. In Ethiopia, coffee is the major cash crop that plays a crucial role in the household as well as the national economy. It also has socio-economic importance in the well-being of rural communities, including cash generation and job creation. Currently, coffee is cultivated in many parts of Ethiopia. The main coffee-growing areas are found in Oromia and SNNP regional states, with modest production in Gambella, Benishangul Gumuz, and Amhara regional states. According to [6], the Southwest part of the country (including Jimma, Kaffa, Bench Maji, Teppi, etc.) is the largest coffee-producing area. In these potential areas, a coffee-based intercropping system is widely practiced and provides improved farm earnings for smallholder farmers without an adverse impact on the yield and quality of coffee. The system also offers more agronomic benefits to smallholder farmers than coffee mono-cropping, with an increase in organic matter, nutrient recycling, soil conservation, providing shade to coffee, increasing the productive life cycle of coffee trees, and bio-diversification [7-9]. Additionally, it plays a vital role in food security, reducing farmers' risks associated with crop failure and fluctuations in coffee prices [10].

Several perennial crops were identified for the coffee-based intercropping system, among which banana is one [11-17]. Unlike coffee, bananas can be planted and established quickly, particularly in lowland areas [18, 19]. It can provide shade for the growing coffee seedlings to enhance the yield and quality of clean coffee [14]. It also provides natural mulch, which helps to recycle organic matter and nutrients and suppress weeds. The crop ensures a continuous flow of income throughout the year, thereby balancing the cash flow constraints during the year when the coffee is not yet productive. So, intercropping coffee with bananas can be used as a source of income and food security for smallholder farmers. However, the growth yield and quality of coffee can be significantly affected by the inter-specific competition with bananas unless the competition is minimized. A reasonable yield of Arabica coffee with a higher yield equivalent ratio per unit area can be obtained by minimizing the competition with bananas for growth resources, viz., moisture, nutrients, space, light, etc. Thus, inter-specific competition can be minimized by adjusting the planting density or planting geometry of the component crops, thereby increasing their biological efficiency and economic feasibility. Previous research information related to optimum ratios of intercropping for Arabica coffee with banana is lacking. Accordingly, this study was proposed to determine biologically optimum intercropping ratios between Arabica coffee and banana that can enhance the land-use efficiency and yield productivity of the component crops at Teppi, Southwestern Ethiopia.

2. Materials and Methods

2.1. Site Description, Soil Properties, and Meteorological Data

The experiment was conducted at Teppi Agricultural Research Center (TARC) from the years 2012 to 2016. The center is located at 70 10 'N latitude and 350 25' E longitude and is situated at an altitude of 1200 meters above sea level, representing a lowland altitude according to Ethiopian traditional agro-ecological division. The elevation is the basis for this classification [20]. It is characterized by a hot, humid climate with an average annual rainfall of 1559 mm and a mean maximum and minimum temperature of 30.23 oC and 16.09 oC, respectively [21]. The soil type of the experimental site is classified as Nitisols, which is dominated by a loam texture with a pH range of 5.60 to 6.0 [22]. The soil depth is very deep (>150 cm) and has a color of dark brown (7.5 YR3/2) when moist. The organic matter content is medium to very high (2.47 to 7.02%) according to [23] classification. The total nitrogen content is low to very high (0.09 to 0.73%) according to [24]'s classification, while the available phosphorus is low to medium (0.97 to 7.36 ppm) based on the rating of [25]. The meteorological data for the years 2012 to 2016 were obtained from the Teppi Agricultural Research Center and are presented in Table 1 and Figure 1.

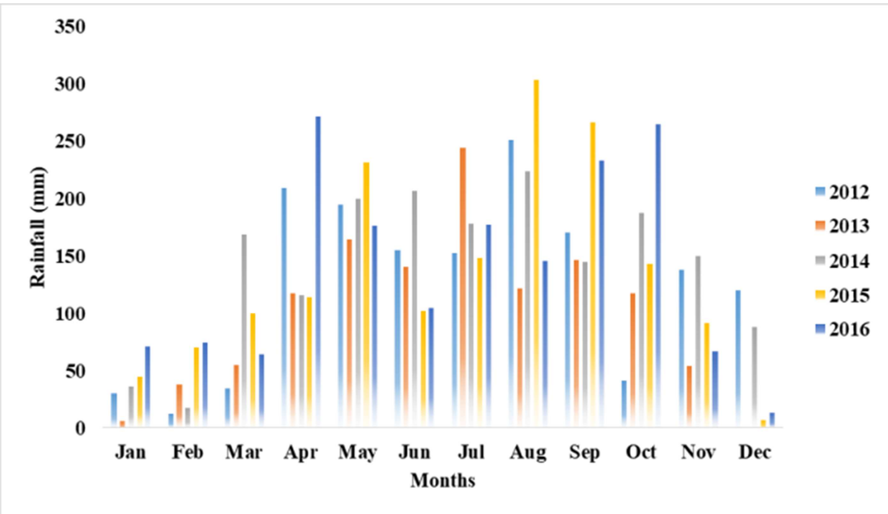

Figure 1. *Monthly rainfall (mm) of the study area (2012-2016).*

Table 1. *Monthly minimum and maximum temperature (°C) of the study area (2012-2016).*

Months	2012		2013		2014		2015		2016	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Jan	13.9	31.3	11.7	31.8	12.3	33.6	13.5	29.3	12.6	31.4
Feb	12.8	32.2	13.7	34.7	13.7	34.2	12.9	30.6	13	32.2
March	15.3	33.2	15	33.4	14.8	32.6	14.6	32.7	13.6	32.1
April	15.8	30.3	15.7	31.7	15.3	30.6	16.5	30.7	15	29.6
May	15.5	29.6	15.3	29	14.8	29	16.2	29.1	14.5	29.3
Jun	15.2	28.2	15.4	28.4	14.4	28.6	15.6	27.5	14	28.3
Jul	14.4	27.5	15	27.2	14.9	27.4	15.6	27.1	13.7	26.1
Aug	14.5	27.9	14.8	28.2	14.4	27.4	15.3	26.9	13.9	27
Sep	14.6	28.2	15	28.3	14.4	27.2	15.1	27.8	13.7	28
Oct	13.3	30.1	13.9	29.2	14.4	29.3	14.25	28.85	14.1	28.4
Nov	13.5	29.4	12.3	30.4	14.4	28.4	13.1	30.1	-	-
Dec	13.4	29.7	9.4	33.1	14.4	28.6	11.3	31.2	-	-

2.2. Experimental Materials, Design, and Procedures

The treatments included sole stands of coffee and banana; four intercropping ratios of coffee and banana, *viz.*, coffee and banana in alternate rows (1:1); 2 rows of coffee to a row of banana (2:1); 3 rows of coffee to a row of banana (3:1); and a staggered planting of coffee with banana (i.e., four coffee trees were planted alternatively around the banana tree); and a detailed description of the treatment was depicted in Table 2. The experiment was laid out in a randomized complete block design with three replications. Six-month-old suckers of banana were planted on the field at the end of March 2012, when the rainfall started at a spacing of 3m x 2m and 2m x 2m in the sole and intercropped plots, respectively. Whereas the coffee seedlings were transplanted when they attained about eight pairs of true leaves [26] in June 2012 at a spacing of 2m x 2m both in the sole and intercropped plots. It was also planted in a staggered fashion between rows of the banana plants with the aforementioned spacing. Among the lowland coffee and banana varieties, Geisha and Poyo varieties were used as component crops, which are widely adopted and cultivated in the study area.

The sole coffee plot was established under a uniformly planted temporary shade tree type, namely *Sesbania sesban* [17, 27, 28], at a 4m x 4m distance. Coffee trees were trained in a single stem pruning system, and undesirable laterally grown branches and suckers were removed throughout the study. During harvesting, red cherries were collected manually from sample trees in each experimental plot. On the other hand, the banana plants were allowed to grow three suckers per mat or stool to manage the overcrowding, and finally, these appeared as mother, daughter, and granddaughter banana plants. The banana bunch was harvested when the fruit fingers became round and the bunch started to turn its color from dark green to light green [19, 29, 30]. After harvesting, the unwanted pseudo-stem was cut down at the base of the soil, chopped into pieces, and spread over the soil surface to provide mulch. Other field and crop management practices were applied for both crops as per the recommendation [12, 31, 32].

Table 2. *Detail information about experimental treatments.*

Treatments	Plot Area (m^2)	Coffee		Banana	
		Trees $Plot^{-1}$	Trees Ha^{-1}	Trees $Plot^{-1}$	Trees Ha^{-1}
Sole Coffee	180 m^2	60	3333	-	-
Sole Banana	112 m^2	-	-	28	2500
Coffee to Banana (1:1)	175 m^2	24	1371	16	914
Coffee to Banana (2:1)	185 m^2	36	1946	12	649
Coffee to Banana (3:1)	180 m^2	36	2000	12	667
Staggered	180 m^2	60	3333	15	833

3. Data Collection

Data on growth, yield, and yield-related traits of coffee were recorded from a randomly selected sample tree as per the scheduled periods using a procedure adopted by [33] and [34]. The yield and yield-related parameters of bananas were measured following the procedures adopted by [35-38].

3.1. Land Equivalent Ratio (LER)

The productivity of the intercropping system in terms of the land equivalent ratio (LER) was used to measure the yield advantage of coffee-banana-based cropping over the sole crops [39]. Thus, LER for clean coffee and banana fruit yield was calculated by using the following formula [40];

$$\text{Land Equivalent Ratio (LER)} = \left(\frac{YCB}{YSC}\right) + \left(\frac{YBC}{YSB}\right)$$

Where Y is the yields of component crops per unit area, YSC and YSB mean yields of sole coffee and banana, and YCB and YBC mean yields of intercropped coffee and banana, respectively. When the value of LER is greater than 1, the intercropping system favors the growth and yield of the component crops. In contrast, if the value of LER demonstrates <1, the intercropping system negatively affects the growth and yield of the component crops grown in mixtures [41, 42]. Besides, interspecific competition becomes stronger compared with interspecific interaction within the intercropping system when the value of LER is less than 1 [43].

3.2. Data Analysis

The collected data were subjected to statistical analysis. Analyses of variance were carried out using SAS version 9.2 English [44]. Significant differences between and or among treatments were delineated by Least Significant Differences (LSD) at 5% probability [45].

4. Results and Discussions

4.1. Yield of Clean Coffee

The analysis of variance revealed that almost all growth and yield parameters of Arabica coffee were not significantly influenced by different ratios of coffee-banana intercropping during the 2014/15 cropping season. However, the clean coffee yield was significantly ($p<0.05$) influenced during the 2015/16 cropping season (Table 3). During the first harvest, the highest yield of clean coffee was found from a staggered planted coffee followed by a solely planted coffee, but it was not statistically influenced by the intercropping with a banana. During the 2015/16 cropping season, the clean coffee yield of solely planted coffee was statistically different from other intercrops, except for a staggeringly planted coffee. Thus, the highest clean coffee yield per unit area was found from a sole stand of coffee, followed by a staggered planting of coffee. On the contrary, the lowest clean coffee yield per unit area was recorded at an equal (1:1) ratio of intercropping coffee and banana (Table 3). This finding agrees with the study results of [11, 13, 15, 16, 46], who reported that the highest yield of clean coffee was found in the sole stand rather than intercrops with enset, avocado, and korarima.

Table 3. *The clean coffee yield (kg ha^{-1}) influenced by intercropping with bananas during 2014/15 and 2015/16 cropping seasons at Teppi.*

Treat.	2014/15	2015/16	Mean
Sole Coffee	1216.60	2798.20^{a}	2007.40^{a}
Sole Banana	-		-
Coffee to Banana (1:1)	360.90	1332.20^{b}	846.60^{b}
Coffee to Banana (2:1)	791.20	1388.10^{b}	1089.60^{b}
Coffee to Banana (3:1)	423.20	1274.20^{b}	848.70^{b}
Staggered	1416.50	2148.70^{ab}	1782.60^{a}
CV (%)	66.82	30.91	20.67
$LSD_{(0.05)}$	Ns	*	*

Ns=Not significant (P>0.05), * = P<0.05, Means with the same letter are not significantly different according to LSD test at P=0.05, Staggered=Four coffee trees were planted alternatively around the banana tree.

The highest yield of solely and staggeringly planted coffee may be associated to having more coffee trees per unit area, and is therefore attributed to effective use of the growing resources, *viz.*, light, moisture, nutrients, and spaces. [34, 47]. On the contrary, the high competition of bananas with coffee trees for available soil nutrients and other environmental resources might have contributed to the low clean coffee yield of Arabica coffee planted in a 1:1 ratio of intercropping with bananas. Besides, the sparse planting density of Arabica coffee could also be attributed to the lowest yield of clean coffee compared with other intercrops. According to [48], the lower population density of coffee trees is a major factor causing a low yield per unit area. Several authors reported the strong correlation of coffee yield with the population density of coffee trees per unit area [12, 34, 47, 49-52].

4.2. Fruit Yield of Banana

Regarding bananas, most of the growth parameters of bananas were not significantly influenced by intercropping with Arabica coffee in the study period. However, the fruit yield of bananas was significantly (p<0.05) affected by different ratios of intercropping with Arabica coffee (Table 4). During the study period, the fruit yield of the sole banana stand was significant over other intercrops. Accordingly, the highest banana fruit yield (53.4 and 62.8 t ha^{-1}) was obtained from the sole stand plot in the 2014/15 and 2015/16 cropping seasons, respectively. Among the intercrops, the staggeringly planted banana gave the highest fruit yield (19.38 and 23.26 t ha^{-1}) followed by the banana at an equal (1:1) ratio of coffee and banana intercropping (18.9 and 22.02 t ha^{-1}) during the same cropping seasons (Table 4). Likewise, the pooled mean analysis result also pointed out the influence of different intercropping ratios on the fruit yield of bananas. The highest fruit yield (58.12 t ha^{-1}) was obtained from a solely planted banana tree, followed by banana trees planted staggeringly (21.32 t ha^{-1}) and equally (1:1) ratio of intercropping with Arabica coffee (20.46 t ha^{-1}). Whereas, the lowest fruit yield was found from the plot in which the banana was intercropped with Arabica coffee in a 1:3 ratio of planting arrangement (Table 4).

Table 4. *Fruit yield of banana (t ha^{-1}) as influenced by intercropping with Arabica coffee during 2014/15 and 2015/16 cropping seasons at Teppi.*

Treat.	2014/15	2015/16	Mean
Sole Coffee	-	-	-
Sole Banana	53.40^{a}	62.84^{a}	58.12^{a}
Coffee to Banana (1:1)	18.90^{b}	22.02^{b}	20.46^{b}
Coffee to Banana (2:1)	13.78^{b}	13.84^{c}	13.81^{c}
Coffee to Banana (3:1)	13.75^{b}	11.78^{c}	12.76^{c}
Staggered	19.38^{b}	23.26^{b}	21.32^{b}
CV (%)	23.81	12.67	12.73
$LSD_{(0.05)}$	*	*	*

Ns=Not significant (P>0.05), * = P<0.05, Means with the same letter are not significantly different according to LSD test at P=0.05, Staggered=Four coffee trees were planted alternatively around the banana tree.

Our result concurs with the finding of [10], who reported that the fruit yield of solely planted bananas was highly significant over the other intercrops with Robusta coffee. The increased fruit yield of solely planted bananas could be partially attributed to a higher population density of banana trees per unit area compared to other intercrops. [10] also indicates the positive correlation of fruit yield of bananas with their trees' population density. Besides, the absence of interspecific competition in the sole banana plot could also be a possible reason for the increased fruit yield of bananas compared to the intercropped plots where the component crops compete for the limited growth resources. Similar results were also reported by [13, 15, 17, 46], who showed that the highest yield of enset came from a sole stand plot compared to other plots in which enset was intercropped with Arabica coffee.

4.3. Land Equivalent Ratio (LER)

4.3.1 Partial Land Equivalent Ratio (PLER)

In this study, the partial land equivalent ratio or productivity of Arabica coffee was significantly (P<0.05) influenced by different ratios of intercropping with banana (Table 5). During the 2014/15 cropping season, the partial LER of Arabica coffee in a staggering plot was statistically significantly different from other intercropped plots, except for the plot in which coffee and banana were arranged in a 2:1 ratio. In the second cropping year, the same treatment showed a significant difference over other treatments, except for the treatment that has three rows of coffee with one row of banana arrangement (Table 5). Accordingly, the highest partial LER values of 1.77 and 0.90 were recorded from the aforementioned treatment during the 2014/15 and 2015/16 harvesting years, respectively. Similarly, the same treatment gave the highest partial LER mean value of 0.88, followed by the treatment in which the component crops were arranged in two rows of coffee with one row of bananas (0.54). The increased partial land equivalent ratio or productivity in the staggered plot might be associated with the higher planting density of Arabica coffee compared to other intercrops. This result is in line with the findings of [10-12, 15-17].

Table 5. *The partial land equivalent ratio (LER) of Arabica coffee and banana during 2014/15 and 2015/16 cropping seasons at Teppi.*

Treat	Partial LER of Arabica Coffee			Partial LER of Banana		
	2014/15	2015/16	Mean	2014/15	2015/16	Mean
Sole Coffee	-	-	-	-	-	-
Sole Banana	-	-	-	-	-	-
Coffee to Banana (1:1)	0.56^{b}	0.48^{b}	0.40^{b}	0.37^{a}	0.35^{a}	0.36^{a}
Coffee to Banana (2:1)	0.88^{ab}	0.54^{b}	0.54^{b}	0.27^{ab}	0.22^{b}	0.24^{b}
Coffee to Banana (3:1)	0.50^{b}	0.56^{ab}	0.43^{b}	0.27^{b}	0.19^{b}	0.22^{b}
Staggered	1.77^{a}	0.90^{a}	0.88^{a}	0.37^{ab}	0.37^{a}	0.37^{a}
CV (%)	39.8	27.08	27.91	16.55	19.07	4.58
$LSD_{(5\%)}$	1.00	0.34	0.31	0.10	0.11	0.03

Ns=Not significant (P>0.05), * = P<0.05, Means with the same letter are not significantly different according to LSD test at P=0.05, Staggered=Four coffee trees were planted alternatively around the banana tree.

Likewise, the partial land equivalent ratio or productivity of bananas was also significantly (P<0.05) affected by different ratios of intercropping with Arabica coffee (Table 5). However, the partial LER values of the whole intercrops did not achieve the minimum value of partial LER (0.5) as indicated by [53]. The result might be associated with the increased population density of coffee trees at the expense of banana tree density per unit area, resulting in a reduction in yield and partial LER of bananas. However, the partial LER of banana in the plots where banana and coffee were arranged in 1:1 and staggeringly was significantly higher than the other intercrops both during the 2014/15 and 2015/16 cropping seasons. Thus, the highest partial LER of banana (0.37) was recorded similarly at an equally (1:1) and staggeringly intercropped banana during the 2014/15 and 2015/16 cropping seasons, respectively (Table 5). The staggeringly planted banana also gave the highest partial LER mean value of 0.37, followed by an equally (1:1) intercropped banana (0.36). The results revealed that an increase in banana population density per unit area increased the partial LER of bananas in either of the cropping arrangements. The present result is in agreement with the findings of [10, 15, 17, 46] on banana and enset crops.

4.3.2. Total Land Equivalent Ratio (TLER)

The total land equivalent ratio (TLER) was significantly (p<0.05) influenced by different ratios of intercropping between Arabica coffee and banana (Table 6). During the study period, the total LER value of staggeringly intercropped Arabica coffee with banana was significantly different from other intercrops, except for two rows of coffee and one row of banana arrangement during the 2014/15 cropping season. Accordingly, the highest total LER values of 2.14 and 1.27 were recorded from a staggering plot during the 2014/15 and 2015/16 cropping seasons, respectively (Table 6). In the pooled mean value analysis, the same plot gave the highest total LER value (1.25).

Table 6. *The total land equivalent ratio (TLER) of Arabica coffee and banana intercropping during 2014/15 and 2015/16 cropping seasons at Teppi.*

Treat.	Total Land Equivalent Ratio (TLER)		
	2014/15	2015/16	Mean
Sole Coffee	-	-	-
Sole Banana	-	-	-
Coffee to Banana (1:1)	0.93^{b}	0.83^{b}	0.76^{b}
Coffee to Banana (2:1)	1.15^{ab}	0.76^{b}	0.78^{b}
Coffee to Banana (3:1)	0.76^{b}	0.75^{b}	0.65^{b}
Staggered	2.14^{a}	1.27^{a}	1.25^{a}
CV (%)	41.03	20.36	17.56
$LSD_{(5\%)}$	1.02	0.37	0.30

Ns=Not significant (P>0.05), * = P<0.05, Means with the same letter are not significantly different according to LSD test at P=0.05, Staggered=Four coffee trees were planted alternatively around the banana tree.

The pooled mean value of total LER in a staggeringly planted Arabica coffee and banana was greater than one (1.25), which indicates the advantage of a staggering mixture over the sole stand of either of the component crops in terms of exploitation of environmental resources for plant growth [43, 54, 55]. In addition, the total LER value of a staggering plot also showed an additional 25 hectares, or 25% of the area of land, would have been required to obtain an equivalent yield from either coffee or banana pure stand. On the other hand, the total LER values of 1:1, 2:1, and 3:1 ratios of intercropping between Arabica coffee and banana showed less than one (LER<1). This result points out the disadvantages of these cropping arrangements and the occurrence of strong interspecific competition within the cropping arrangements [42, 56, 57]. The result of this study is in line with the findings of [10, 11, 15, 46], who revealed the intercropping advantage of Arabica coffee with banana, enset, and korarima, along with a higher total LER value in the staggered planting arrangement.

5. Conclusion

According to the study results, the clean coffee yield was statistically ($p<0.05$) influenced by different ratios of intercropping with bananas. Among the intercrops, a staggeringly planted Arabica coffee gave the highest mean clean coffee yield, which is statistically similar to the clean coffee yield obtained from the solely planted coffee trees. Similarly, the highest partial and total LER values were recorded from the aforementioned cropping arrangement. The result could be associated with the exploiting capacity of the component crops for the available growth resources when they are arranged in a staggered fashion. The same planting arrangement also showed a significant yield advantage over other arrangements, which indicates the agronomical and biological advantages of this arrangement compared with other arrangements. Accordingly, the study recommended that the staggered planting arrangement of Arabica coffee with banana can be taken as the appropriate cropping ratio for enhancing the yield and land productivity of the component crops in the study area. However, the study needs to be repeated one more season in different agro-ecologies and checked for economic feasibility tests.

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