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Agronomic and economic benefits of coffee–banana intercropping in Uganda's smallholder farming systems

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ABSTRACT

Coffee and banana are major cash and food crops, respectively, for many smallholders in the East African highlands. Uganda is the largest banana producer and 2nd largest coffee producer in Africa. Both crops are predominantly grown as monocultures. However, coffee–banana intercropping is common in densely populated areas. This study assessed the profitability of intercropped coffee–banana systems compared to mono-cropped systems in regions growing Arabica (Mt. Elgon) and Robusta (south and west) coffee in Uganda. The study was carried out in 152 plots in 2006/2007. Data were collected through structured farmer interviews, field measurements and observations. Coffee yields did not differ significantly ($P \leqslant 0.05$) between mono-crops and intercrops. Arabica coffee yields were 1.23 and 1.18 t ha^{-1} year^{-1} of green beans in mono-cropped and intercropped plots, respectively. Robusta yields averaged 1.25 and 1.09 t ha^{-1} year^{-1} of green beans in mono-crops and intercrops, respectively. Banana yields were significantly higher ($P \leqslant 0.05$) in intercrops (20.19 t ha^{-1} year^{-1}) compared with mono-crops (14.82 t ha^{-1} year^{-1}) in Arabica growing region. In Robusta growing region, banana yields were significantly lower ($P \leqslant 0.05$) in intercrops (8.89 t ha^{-1} year^{-1}) compared with mono-crops (15.04 t ha^{-1} year^{-1}). Marginal rate of returns of adding banana to mono-cropped coffee was 911% and 200% in Arabica and Robusta growing regions, respectively. Fluctuations in coffee prices are not likely to affect the acceptability of intercrops when compared with coffee mono-crops in both regions, but an increase in wage rates by 100% can make intercropping unacceptable in Robusta growing region. This study showed that coffee–banana intercropping is much more beneficial than banana or coffee mono-cropping and that agricultural intensification of food and cash crops in African smallholder systems should not solely depend on the mono-crop pathway.

1. Introduction

Coffee and banana are important crops in Uganda and surrounding East African highland areas in Rwanda, Burundi, northwest Tanzania, west Kenya, and east Democratic Republic of Congo (DRC). Coffee is the main cash crop harvested once or twice a year while banana is a primary food and cash crop produced throughout the year. In 2008, Uganda was the 11th largest coffee producer in the world, and the 2nd largest banana producer (FAO, 2010a). The estimated area under coffee and banana in Uganda was 265,000 and 1,815,000 ha, respectively in 2008 (FAO, 2010a). Arabica (*Coffea arabica*) and Robusta (*Coffea canephora*) are the two types of coffee grown and are estimated to comprise 10% and 90% of the total production in Uganda, respectively (Masiga and Ruhweza, 2007). The East African highland banana (*Musa* spp. AAA-EA) is the major banana genome in Uganda (Gold et al., 2002). Coffee and banana are predominantly grown as monocultures but coffee–banana intercropping is common in densely populated areas (Oduol and Aluma, 1990).

Intercropping coffee with bananas and other shade crops also occurs in other parts of the world. For example, coffee is sometimes intercropped with plantain bananas in Colombia (Grisales and Lescot, 1993) and mature coffee plantations in Latin-America are commonly grown under shade trees (Roskoski, 1982). In Indonesia, coffee is intercropped with fruit trees (e.g. guava and banana) (Godoy and Bennett, 1989). Despite the importance of coffee intercropping in Latin-America and beyond, relatively few quantitative data are available that would allow modeling the underlying processes of coffee agroforestry systems (van Oijen et al., 2010). Beer et al. (1998) concluded from a literature review that the benefits of maintaining shade trees over perennial crops were described as early as the late 19th century in Sri Lanka and Colombia. Trees providing shade to coffee generally reduce stress, but the same authors concluded that the relative importance of the different

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effects of shade trees, and hence the need for shade, is strongly affected by site conditions and management practices, such as the use of external inputs (i.e. fertilizer and pesticides).

Despite strong competition for resources in some intercropped systems (Brown, 1984), the systems are credited with increased total biological productivity per unit area of land (Willey, 1979). Oduol and Aluma (1990) suggested that competition between coffee and banana may be important when intercropped. A literature review by Beer et al. (1998) on shade management suggested that banana offered stronger competition to coffee than some of the shade trees. However, his conclusions were mainly drawn on the basis of only two on-station coffee–banana intercropping trials in Tanzania conducted in the 1950s (Robinson, 1961; Mitchell, 1963). Ouma (2009) suggests that growing coffee and banana in association could be more profitable than growing coffee as a sole crop. In addition, mixed cropping systems were less risky for farmers, since the chance of simultaneous crop failure or low prices for both crops was low (Fernandes et al., 1985; Oduol and Aluma, 1990). This is especially important in coffee and banana production as outbreaks of diseases have been reported in the past. For example coffee fusarium wilt disease (Tracheomycosis) has increasingly become a major constraint to Robusta production in DRC, Tanzania and Uganda (Rutherford, 2006) and banana *Xanthomonas* wilt (BXW) was reported to be spreading in Uganda (Smith et al., 2008). Furthermore, farmers experienced strongly declining coffee prices from the mid 1990s until around 2005 when prices started to significantly recover. Farm-gate coffee prices closely follow international prices (Matthews et al., 2009). Farm-gate banana prices also show strong temporal variations (Birabwa et al., 2010) as a function of gluts and shortages and prices within the year.

Although the benefits of coffee–banana systems in East Africa have not been quantified, the importance of banana to coffee productivity has been suggested. Lufafa et al. (2003) observed that the canopy and root systems of perennial systems like bananas reduce erosion in the East African highlands to only a third of that seen in annually-cropped fields, but the banana mono-crop system was predicted to have lesser soil loss, compared with coffee–banana intercrop. Since publications on coffee intercropped with agroforestry or fruit trees have documented the possible benefits of shade on coffee yields (e.g. Gaie and Flémal, 1988; Beer et al., 1998; Staver et al., 2001) and quality of coffee beans (Muschler, 2001; Vaast et al., 2005), it is possible that use of banana as a shade crop in coffee can contribute to improved coffee yields.

Although intercropping of coffee and banana is a common practice in East Africa, there exist no official recommendations on how (or if) to intercrop the two. On the contrary, several countries in the region currently recommend (e.g. Rwanda and Burundi), or in the past even imposed, that farmers grow coffee as a mono-crop. These recommendations are possibly a remnant of the colonial past, where the ruling power was more interested in coffee produce for export than in banana produce for local consumption. The emphasis on mono-cropping coffee was probably the result of the fear that farmers would not be able to control shading levels, thereby negatively affecting coffee production. However, there seems to be a renewed drive to encourage African smallholders to adopt mono-cropping practices as part of agricultural modernization in the pursuit of an African green revolution. For example, a land law was passed in 2005 in Rwanda, which encourages consolidation of fragments of land parcels with the aim to replace traditional subsistence farming with commercial 'modern' mono-cropping (Pottier, 2006).

Developing recommendations on intercropping coffee with banana would encourage production of both crops, which would contribute towards improved food security and increased family income. Bananas occupy a substantial portion of the agricultural land in the region compared with coffee (FAO, 2010a). If coffee–banana intercropping would be beneficial, then this may help the region to increase its coffee production area and output. Furthermore, agricultural diversification has been encouraged in coffee-producing countries by the International Coffee Organization (ICO) as a way of coping with declines in coffee prices (Watson and Achinelli, 2008).

This paper reports on the results of a diagnostic survey on coffee and banana mono-cropping systems, and coffee–banana intercropping systems in Arabica and Robusta growing regions of Uganda. The objectives of this study were (i) to quantify the agronomic productivity of banana and coffee mono-cropping and intercropping systems, with the aim to (ii) assess the profitability of the intercropping systems for smallholder farmers.

2. Materials and methods

2.1. Study area

The study was conducted in the Arabica growing region around Mt. Elgon in the east of the country (Mbale, Manafwa, Sironko and Budada districts) and Robusta growing region in south (Masaka and Rakai districts) and west (Bushenyi district) in 2006/2007. The study area for Arabica lies approximately between latitudes 1°17′N and 0°51′N and longitude 34°13′and 34°25′E at an altitude of 1288–2135 m above sea level. For Robusta, the study area lies approximately between latitudes 0°01′N and 0°39′S and longitude 30°16′ and 31°1′E at an altitude of 1174–1681 m above sea level. In the Arabica growing region, the soils are predominantly sandy clay loams and the parent rocks underlying these soils have been described by Schlüter (2008) as predominantly Cenozoic volcanic outcrops. In the Robusta growing region, the soils are predominantly loams, sandy clay loams and sandy loams and the parent rocks underlying these soils have been described as Archaean Gneissic-Granulitic-Complex, Proterozoic metamorphic rocks and Proterozoic sedimentary rocks by Schlüter (2008).

2.2. Plot selection

Within each district, neighboring plots were selected that had coffee and AAA-EA cooking banana varieties as either intercrops or adjacent mono-crops. A field was selected if (i) the minimum number of coffee trees and banana mats mono-cropped or intercropped was 50, and (ii) the crops were actively managed and did not show signs of severe neglect; i.e., plots with poorly managed coffee, which had not been pruned for more than a year, were not selected. In total 22 banana mono-crop, 31 coffee mono-crop and 30 coffee–banana intercrop plots were selected in Arabica growing region. In the Robusta growing region, 28 banana mono-crop, 21 coffee mono-crop and 20 coffee–banana intercrop plots were selected.

2.3. Data collection

Data on yield related parameters for bananas, management practices (i.e. mulch thickness; intensity of pruning of coffee, de-suckering of coffee and banana, de-trashing of banana, weeding; population), and pests and disease pressure were recorded during single or two farm visits. Data on costs of external inputs (manure, mulch), labor costs for application of external inputs, prices at which farmers sold their coffee and amount of coffee harvested per plot were obtained through structured farmer interviews during farm visits.

Average spacing between coffee plants was determined by measuring the distances from a randomly selected plant to the nearest four coffee plants. Banana mats were defined as a single family of banana plants with interconnected living corms; i.e. single mother plants and their connected suckers. Banana mat spacing was determined by measuring the distances from 5 randomly selected mother plants to the nearest four mother plants that did not belong to the same mat, resulting in 20 spacing measurements per plot. The same procedure was used to determine coffee plant spacing. Average population (number of coffee plants or banana mats ha^{-1}) densities were then estimated from average plant spacing. Since coffee is harvested twice a year, data on amount of coffee harvested for the two seasons was collected at the end of the second season for Arabica coffee, and at the end of each season for Robusta coffee. Farmers estimated amount of parchment and "kiboko" coffee (dried coffee cherries) harvested per plot for Arabica and Robusta, respectively. As recommended for parchment coffee and dried coffee cherry in the International Coffee Agreement of 2007 (ICO, 2007), conversion factors of 0.8 and 0.5, were used for Arabica and Robusta, respectively, to convert farmer estimates of parchment and kiboko coffee production to kg of green coffee per plot per year. Coffee yield (t ha^{-1} $year^{-1}$ of green beans) was estimated based on the amount of coffee harvested, the total number of coffee trees, and average plant spacing. Data on girth of the pseudostem at base and at 1 m, number of hands, and number of fingers in the bottom row of the second lowest hand were collected from at least 10 fruiting banana plants. These data were used to estimate bunch weights using the general allometric regression derived by Wairegi et al. (2009). Banana yield (t ha^{-1} $year^{-1}$) was estimated based on bunch weights, mat spacing, and average crop cycle duration (i.e. time between two subsequent harvests from the same mat) as used by Wairegi et al. (2010) in the same regions. Data on application of manure were based on information gathered during farmer interviews. Data on mulch thickness were collected using a 20 m long cord that was randomly placed in the plot three times. Mulch thickness measurements were then taken at 1 m intervals along the cord, resulting in a total of 60 readings. Weeding, pruning of coffee, de-suckering and de-trashing of banana were qualitatively assessed and rated as light, moderate or intensive. In bananas, root necrosis caused by root lesion nematodes (*Radolpholus similis*, *Helicotylenchus multicintus*) was assessed according to Speijer and Gold (1996). Banana weevil (*Cosmopolites sordidus*) damage in the corm was estimated at harvest using the methods described by Gold et al. (1994). In coffee, the level of damage caused by coffee berry borer (*Hypothenemus hampei*), scales (*Coccus* spp.), stem borer (*Bixadus siericolla*) and mealybugs on berries and leaves (undefined species) was assessed and rated as light, moderate or high. In banana, black sigatoka (*Mycosphaerella fijiensis*) was assessed on flowering plants using the methods described by Orjeda (1998) and the presence of banana *Xanthomonas* wilt (BXW) was recorded. In coffee, the presence and intensity (ranked as light, moderate or high) of coffee fusarium wilt disease, coffee berry disease (*Colletotrichum kahawae*) and coffee leaf rust (*Hemileia vastatrix*) was recorded.

2.4. Data analysis

2.4.1. Agronomic analysis

Yield, management practices, pest and disease pressure for different cropping systems were compared using the *t*-test for independent samples, Chi-square test and correlation analysis. Yields in intercrops and mono-crops were also compared using the land equivalent ratio (LER) (Willey, 1985).

$$\mathrm{LER} = \frac{Y_{cint}}{Y_{cmono}} + \frac{Y_{bint}}{Y_{bmono}}$$

where Y_{cint}, Y_{cmono} are coffee yields in intercrops and mono-crops, respectively, and Y_{bint} and Y_{bmono} are banana yields in intercrops and mono-crops, respectively. LER > 1 signifies higher total yields from intercropping while LER < 1 signifies higher yields from mono-cropping.

Statistical analysis of data was performed using SPSS for Windows, release 11.0, standard version (SPSS Inc., 1989–2001).

2.4.2. Economic analysis

The profitability of intercropping banana in coffee plots was evaluated using partial budget analysis as described by CIMMYT (1988). Monetary values were converted from the local currency (USH) at a rate of 1750 USH/USD, which was the average exchange rate during the survey period. Value of yield of coffee was obtained using price data provided by farmers. Value of yield of banana was obtained using average farm gate prices for 2006/2007 (i.e. USD 0.10 and 0.07 kg^{-1} in Arabica and Robusta growing regions, respectively) recorded in a monitoring study carried out during the same period by Wairegi and van Asten (2010). Costs of establishing banana mats were not taken into consideration because bananas are perennials and plantations can last for more then 50 years after establishment. The labor associated with harvesting of banana was not taken into consideration because banana for sale was often harvested by traders while banana for other purposes was harvested piece meal during daily movements in the farm. The labor costs associated with de-trashing, de-suckering and corm removal, in bananas, were considered as variable costs. These activities were estimated to take 337 and 283 man days ha^{-1} $year^{-1}$ in Arabica and Robusta growing region based on data by Bagamba (2007), information from farmers, and our field experience. We assumed that labor for these activities was hired. Costs of other management practices (manure, mulch, weeding and pruning) were included in the analysis whenever these practices varied significantly ($P \leqslant 0.05$) between mono-crops and intercrops. The change in benefits of the intercropped coffee and banana compared to mono-cropped coffee was calculated as the change in the value of the yield less the change in the total variable costs (TVC). This change in benefits over change in TVC gave the marginal rate of return (MRR).

Sensitivity analysis was performed to evaluate how change in coffee prices and wage rates affected profitability using the approach described by Alimi and Manyong (2000). Marginal Rates of Return were calculated based on 50%, 100% and 200% of the coffee prices, and 100%, 150% and 200% of the wage rates, of 2006/2007. Other costs and benefits related to intercropping banana in coffee plots remained unchanged from those reported in 2006/2007.

3. Results

3.1. Yield

For both Arabica and Robusta coffee, yields in mono-cropped and intercropped systems did not differ significantly ($P \leqslant 0.05$) (Table 1). In Arabica growing region, banana yields were significantly ($P \leqslant 0.05$) higher in intercropped systems compared with mono-cropped systems (Table 1). For Robusta growing region, banana yields in the mono-cropped systems were significantly higher ($P \leqslant 0.05$) when compared to yields in the intercropped systems. The LER for intercropping coffee and banana was 2.3 and 1.5 in Arabica and Robusta growing regions, respectively.

3.2. Soil management parameters

3.2.1. Manure

Manure was applied in 71% and 77% of mono-cropped and intercropped Arabica, respectively, 62% and 60% of mono-cropped and intercropped Robusta, respectively, and in 68% and 75% of

Table 1
Averages (±standard deviations) of yields of mono-cropped and intercropped coffee (t of green bean ha^{-1} $year^{-1}$) and banana (t of fresh fruit ha^{-1} $year^{-1}$) in Arabica and Robusta growing regions in Uganda.

Cropping system	Arabica growing region		Robusta growing region	
	Coffee	Banana	Coffee	Banana
Coffee mono-crops	1.23 ± 0.88[a]	–	1.25 ± 0.65[a]	–
Coffee–banana intercrops	1.18 ± 0.99[a]	20.19 ± 10.25[a]	1.09 ± 0.62[a]	8.89 ± 3.22[b]
Banana mono-crops	–	14.82 ± 8.10[b]	–	15.04 ± 6.15[a]

Different letters within a column, for a crop, signify significant differences ($P \leqslant 0.05$) in yield.

mono-cropped banana in Arabica and Robusta growing region, respectively (Table 2). In both regions, the percentage of plots that received manure did not differ significantly ($P \leqslant 0.05$) between mono-crops and intercrops for both crops. In Arabica growing region, both coffee and banana yields in intercrops were significantly ($P \leqslant 0.05$) higher in plots that received manure compared with plots that did not receive manure. In both regions, both coffee and banana yields in mono-crops did not differ significantly ($P \leqslant 0.05$) between plots with and without manure.

3.2.2. Mulching

For coffee, mulch thickness did not differ between mono-cropped and intercropped coffee and banana in the Arabica growing region (averaged 1 cm in all cropping systems) (Table 2). In the Robusta growing region, mulch thickness was significantly higher in mono-cropped banana (3 cm) compared with intercropped and mono-cropped coffee (2 cm). For both coffee and banana, yields were not significantly ($P \leqslant 0.05$) correlated to mulch thickness.

3.3. Crop management parameters

3.3.1. Population

The number of coffee trees in mono-cropped and intercropped systems averaged 2209 and 2253 ha^{-1}, respectively, in Arabica growing region and 1014 and 880 ha^{-1}, respectively, in the Robusta growing region (Table 2). The population of coffee trees did not differ significantly ($P \leqslant 0.05$) between cropping systems in both regions. For banana, the number of mats in mono-crops and intercrops averaged 885 and 1055, respectively in the Arabica growing region, and 1089 and 830, respectively in the Robusta growing region. Banana population in the two cropping systems differed significantly ($P \leqslant 0.05$) in Robusta growing region but not in Arabica growing region. Yields of the two coffee types were positively correlated ($P \leqslant 0.05$) with coffee population in mono-crops but not in intercrops (Fig. 1). Banana yields in both Arabica and Robusta growing regions were positively correlated ($P \leqslant 0.05$) with banana population in both mono-crops and intercrops. Coffee yields were positively correlated ($P \leqslant 0.05$) with banana population in Robusta growing region but not in Arabica growing region. Banana yields were not significantly correlated ($P \leqslant 0.05$) with coffee population in both regions.

3.3.2. Management practices

Level of de-suckering in coffee and banana, pruning in coffee, and weeding was moderate in at least 60% of mono-crops and intercrops in both regions and did not differ significantly ($P \leqslant 0.05$) between cropping systems in both regions (Table 2). The relationships between these management practices and yields of coffee were not significant ($P \leqslant 0.05$) in both regions. For both regions, the level of de-suckering and pruning were not significantly ($P \leqslant 0.05$) related to coffee and banana yields. The level of weeding was positively and significantly ($P \leqslant 0.05$) related to yields of intercropped banana in the Robusta growing region but not in the Arabica growing region.

3.3.3. Pest and disease incidence

In Arabica coffee, levels of damage caused by mealybugs and scales were low (Table 2). In Robusta coffee, levels of damage caused by mealybugs and scales did not differ significantly

Table 2
Management, pest and disease parameters in mono-cropped (mono) and intercropped (inter) coffee and banana in Arabica and Robusta growing regions in Uganda.

	Arabica region			Robusta region		
	Mono coffee	Inter	Mono banana	Mono coffee	Inter	Mono banana
Manure[a]	71	77	68	62	60	75
Mulch thickness (cm)	1	1	1	2	2	3
Population[b]	2209	2253	885	1014	880	1089
De-suckering[d]	90	71	60	94	81	100
Pruning of coffee[d]	94	87	–	89	88	–
Weeding[c]	100	97	95	100	100	100
Coffee wilt[c]	0	0	–	70	63	–
Coffee berry disease[c]	10	17	–	0	0	–
Coffee leaf rust[c]	69	43	–	79	65	–
Black sigatoka in banana[d]	–	10	9	–	40	54
Banana *Xanthomonas* wilt[e]		70	56		0	0
Coffee damage by mealybugs[d]	0	0		35	32	
Coffee damage by scales[c]	0	0		30	31	
Banana corm damage (%)	–	2	2	–	5	7
Banana root necrosis (%)	–	3	3	–	5	8

[a] The proportion of plots (%) that were applied manure.
[b] Number of coffee trees ha^{-1} in mono-cropped and intercropped coffee, and number of banana mats ha^{-1} in mono-cropped banana. The population of banana in intercrops averaged 1055 and 830 in Arabica and Robusta growing regions, respectively.
[c] Proportion of plots with moderate to high intensities, expressed as%, presented.
[d] Proportion of plots with moderate intensities, expressed as%, presented as there was no high intensities.
[e] Proportion of plots in which banana *Xanthomonas* wilt was present.

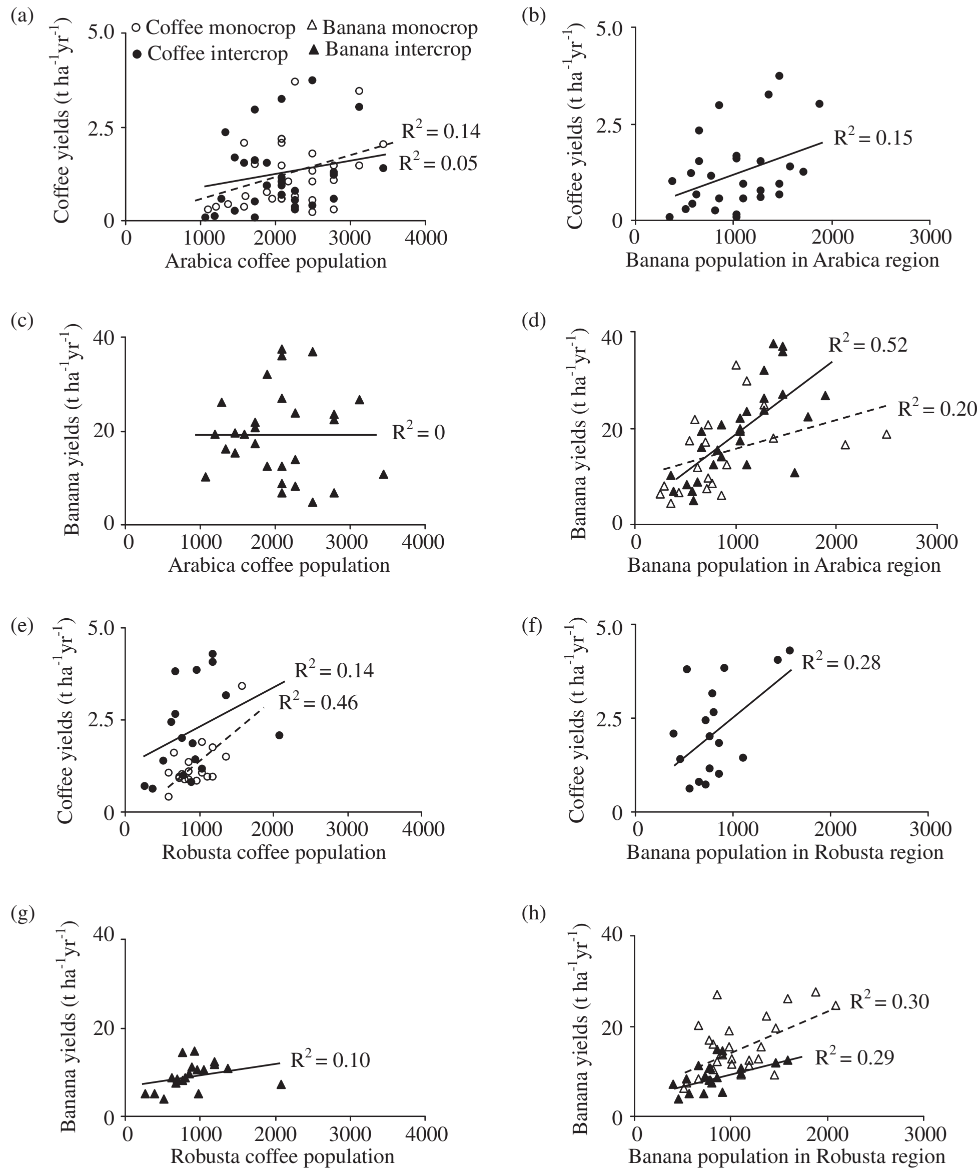

Fig. 1. Relationships between population density (coffee trees ha^{-1} and banana mats ha^{-1}) and yields of coffee and banana, grown in mono-crops and intercrops, in Arabica and Robusta growing regions. The dotted and continuous lines depict relationships between population and yield in mono-crops and intercrops, respectively.

between mono-crops and intercrops did not have any significant ($P \leqslant 0.05$) impact on coffee yields. In bananas, both corm damage and root necrosis did not differ significantly ($P \leqslant 0.05$) between cropping systems in both regions and did not relate significantly ($P \leqslant 0.05$) to banana yields.

Coffee wilt disease was observed in Robusta but not in Arabica. Coffee berry disease was observed in Arabica coffee but not in Robusta. Coffee rust was observed in both regions. Intensities of the coffee diseases were not related significantly ($P \leqslant 0.05$) to coffee yields. In bananas, black sigatoka severity was light to moderate in both regions and did not differ significantly ($P \leqslant 0.05$) between mono-cropped and intercropped banana. The bacterial disease banana *Xanthomonas* wilt (BXW) was present in 56% of the mono-cropped and 70% of the intercropped plots in Arabica growing region but not in Robusta growing region. Differences between the cropping system were not significant ($P \leqslant 0.05$) and the number of plants affected per field was generally very small (<5%).

3.4. Economic benefits of intercropping

Coffee prices averaged USD 1.93 and 1.03 kg^{-1} of green beans for Arabica and Robusta, respectively. Labor costs (in USD man day^{-1}) averaged USD 0.86 throughout the Arabica growing region and but varied between USD 0.57 and 1.71 in the Robusta growing region, depending on location. Costs associated with manure use, mulching and weeding were not taken into consideration because there were no significant differences ($P \leqslant 0.05$) between mono-cropped and intercropped coffee in proportion of plots applied manure, mulch thickness and intensity of weeding. The average marginal rate of return of intercropping banana in coffee plots was 911% and 200% in Arabica and Robusta growing regions, respectively (Table 3). MRR calculated using 50% and 200% of coffee prices of 2006/2007 were 934% and 863%, respectively, in Arabica growing region, and 250% and 98%, respectively in Robusta growing region. MRR calculated using 150% and 200% of wage rates of 2006/2007 were 574% and 405%, respectively in

Table 3
Partial budget comparing mono-cropped coffee with coffee and banana intercrops in the Arabica and Robusta coffee growing regions in Uganda (USD ha^{-1} $year^{-1}$).

Gross revenues	Arabica					Robusta				
		Coffee price[a]		Wage rate[a]			Coffee price[a]		Wage rate[a]	
	100%	50%	200%	150%	200%	100%	50%	200%	150%	200%
Price of coffee (USD kg^{-1})	1.93	0.96	3.86	1.93	1.93	1.03	0.51	2.06	1.03	1.03
Price of banana (USD kg^{-1})	0.10	0.10	0.10	0.10	0.10	0.07	0.07	0.07	0.07	0.07
Value of coffee in mono-crops[b]	2361	1180	4721	2361	2361	1286	643	2571	1286	1286
Value of coffee in intercrops[b]	2268	1134	4536	2268	2268	1121	561	2242	1121	1121
Value of banana in intercrops[b]	2039	2039	2039	2039	2039	649	649	649	649	649
Total value of intercrops	4307	3173	6575	4307	4307	1770	1210	2891	1770	1770
Variable costs associated with bananas[c]										
Wage rate (US$ man day^{-1})	0.57	0.57	0.57	0.86	1.14	0.57	0.57	0.57	0.86	1.14
Labor required (man days ha^{-1})[d]	337	337	337	337	337	283	283	283	283	283
Total variable costs	193	193	193	289	385	162	162	162	243	323
Economic returns										
Increased value of yield on intercropping[e]	1947	1993	1854	1947	1947	484	567	320	484	484
Net benefits[f]	1754	1800	1661	1658	1561	323	405	158	243	161
Marginal rates of return[g]	911	934	863	574	405	200	250	98	100	50

[a] Calculations for 100% based on coffee prices and wage rates for 2006/2007, coffee prices were decreased by 50% and increased by 100% in 'Coffee price' and wage rates were increased by 50% and 100% in 'Wage rate'.
[b] Based on coffee and banana yields presented in Table 1.
[c] Combined costs of labor for de-trashing, de-suckering and corm removal.
[d] Based on data by Bagamba (2007), information from farmers and our experience.
[e] Total value of yield for coffee and banana in intercrops less value of coffee in mono-crops.
[f] Increased value of yield on intercropping less variable costs.
[g] Marginal rates of return of investment of intercrops compared with mono-cropped coffee.

Arabica growing region and 100% and 50%, respectively in Robusta growing region.

4. Discussion

4.1. Effect of intercropping on production

Although intercropping seemed to increase and decrease banana yields in Arabica and Robusta growing regions, respectively (Table 1), upper boundary lines for bananas in Robusta growing region (data not shown) suggest that the highest banana yields were observed in mono-cropped banana fields compared to intercropped fields. Still, intercropping was beneficial as the effect on coffee yield was minimal (Table 1) and the LER was greater than one in both regions; i.e. LER = 2.3 and 1.5 in Arabica and Robusta growing regions, respectively. Intercropping seemed to have little effect on coffee, yield possibly because competition between coffee and banana for light, soil nutrients and water between coffee and banana in the current intercrop practices may have been low. In addition, coffee may have benefited from the shade provided by banana in the intercrop. The reduction in banana yields on intercropping with coffee in the Robusta growing region could be partially attributed to the lower population (−24%) of banana mats in intercrops compared with mono-crops and due to competition for water and nutrients between bananas and Robusta coffee (Okech et al., 2004). Literature reviewed by DaMatta and Ramalho (2006) suggested that Robusta has a more developed root system than Arabica. Robusta is more vigorous in growth compared with Arabica (DaMatta et al., 2007) and hence competition between coffee and banana may have been higher in Robusta growing region compared with Arabica. It is unlikely that pest and disease pressure created significant yield differences between mono-crops and intercrops, for both coffee and banana, as they did not differ significantly between cropping systems and in general appeared to have a minimal effect on yield.

Although literature on the effect of banana on coffee yields is lacking, the benefits in production of intercropping (LER > 1) and the lack of significant reduction in yields observed in our study agree with findings of studies on shade trees intercropped with coffee. Shade trees were associated with increased yields in coffee yields in Ghana (Amoah et al., 1997) but had no effect on coffee yields in Burundi (Akyeampong et al., 1999). Based on a review by Beer (1987), increased yields in perennial crops grown in association with shade trees can be partially attributed to suppression of weeds, reduction of evapotranspiration of the shaded crop, and reduction of soil erosion on slopes. Our findings appear to be in line with these suggestions.

The lower density of banana in mono-crops compared with intercrops in Arabica growing region suggests that farmers regularly intercrop banana with annual crops, particularly beans. Bean intercropping was not recorded during the survey, but visual observations suggested that bean intercropping is common, particularly in the Arabica growing region. This could be due to the higher population density in the Arabica growing region (266–534 persons per square kilometer) compared with Robusta growing region (191–245 persons per square kilometer) reported by the Uganda Bureau of Statistics (UBOS, 2002). Intercropping banana with annual crops is common in Uganda (e.g. Bekunda and Woomer, 1996; Wortmann and Kaizzi, 1998). Both banana and coffee have very shallow root systems (Blomme, 2000) that are easily damaged by tillage. Farmers often manually till the soil at the start of the wet season to remove weeds. Zero-tillage practices are possible, particularly when combined with mulching to suppress weeds, improve soil fertility, and conserve soil moisture (CIALCA, 2008). Poor banana yields in mono-cropped vs intercropped banana fields in the Arabica growing region could therefore possibly be explained by the less intensive tillage and bean intercropping practices in the latter.

4.2. Economic benefits

The high marginal rates of return of intercropping bananas in coffee plots (MRR = 911% for Arabica, and MRR = 200% for Robusta) suggest that intercropping is more profitable than mono-cropping. Sensitivity analysis performed to evaluate changes in coffee prices and wage rates affected benefits of adding banana to mono-cropped coffee (Table 3) suggested that fluctuations in coffee prices had little effect on benefits of intercropping in both regions but that increase in wage rates by 100% can make intercropping unacceptable (i.e. MRR < 1) in Robusta growing region due to the higher labor demand of intercropped coffee compared to mono-cropped coffee.

Although literature on the profitability of intercropping is scarce, the greater net benefits in coffee intercropped with banana compared with mono-cropped coffee reported by Chipungahelo et al. (2004) in Tanzania are in agreement with our findings. In addition, Ouma (2009) and Oduol and Aluma (1990) suggested that intercropping banana with other crops could be beneficial in terms of increased returns.

It is likely that increased shading of coffee when grown with bananas, could have improved the quality of the coffee bean. Shade improved quality by increasing size and weight of coffee beans, and reducing proportion of imperfect beans but did not influence organoleptic properties (Lara-Estrada and Vaast, 2007). The influence of shade on coffee quality seems to depend on altitude. For example, at low altitude, shade improved physical quality of coffee but had no effect on sensory attributes while at high altitude, shade had no effect on physical quality but improved the sensory attributes (Bosselmann et al., 2009). Quality deserves attention because it could explain the reason behind higher prices in the world market for Kenyan coffee (USD 2.8) compared to Rwandan coffee (2.1) reported by FAO in 2007 (FAO, 2010b), yet both countries grow Arabica coffee only. There is therefore need to explore the effect of intercropping on quality of coffee.

Although data based on farmer recall can be prone to inaccuracies as according to a review of literature by Bernard et al. (1984) memory decays with time, we believe that the yield data provided by our farmers can be considered as reliable because farmers had been trained on record keeping. In addition, agricultural field staff confirmed that the indicated production corresponded to their observations. Still, since coffee tends to alternate biennially between years of good and poor yields while (DaMatta, 2004) and farmers considered yields in the study year as good, recommendations based on these yields should be taken with caution. Furthermore, our findings are based on 1-year's data. On the other hand, since yields of shaded coffee tend to be consistently high (DaMatta, 2004), it is possible that coffee yields in intercropped fields will not be lower than in mono-cropped fields in consecutive poor-production years. Overall, our study shows that intercropping coffee and banana may be beneficial but there is need to conduct on-farm and controlled experiments to confirm our findings.

The calculated benefits of coffee–banana intercrops compared with coffee grown in mono-crops are obviously overestimated, since we did not take into consideration the initial costs of planting bananas in already established coffee plantations or vice versa. These costs can be substantial in the first years. The costs of digging holes, acquiring quality planting material, planting and manure application can be four times the costs of sanitation (e.g. Inzaule et al., 2005). Some of the other variable costs that were not taken into consideration were costs related to harvesting banana, soil management, and pest control measures.

4.3. Agronomic recommendations

The low reduction in coffee yields on intercropping (Table 1), coupled with the fact that soil management practices did not seem to differ between mono-crops and intercrops suggests that introduction of banana in coffee plantations does not necessarily have to go hand in hand with increased investments in soil fertility management. Still, the positive relationship between yields of coffee and density of banana in Arabica growing region, which was not observed in Robusta growing region, suggests that the environmental conditions (i.e. soils and rainfall) may be more favorable in the Arabica growing region than in the Robusta growing region; i.e. Arabica coffee may have benefited from the shading without being hampered too much by competition for water and nutrients with bananas. This is further supported by greater values of soil organic matter (4.6% vs 3.5%), total soil nitrogen (0.21% vs 0.17%), extractable K (1.49 vs 0.83 $\text{cmol}_c\ \text{kg}^{-1}$) in Arabica growing areas compared with Robusta growing areas. The relatively poorer banana yields in intercrops compared with mono-crops in Robusta growing region (Fig. 1) suggests that coffee can out-compete banana in this region. The competition between coffee and banana could be more intensive for Robusta coffee compared with Arabica coffee. This assumption corresponds to farmer observations in the Robusta region (Okech et al., 2004). Compared with Arabica, Robusta is more vigorous, more competitive (FAO, 2010b), tends to have a shallow root system, and is more resistant to some pests and diseases (ICO, 2010).

Although findings of the study did not suggest increased competition for soil nutrients on intercropping, previous studies suggest that yields may be limited by low soil fertility. For example, banana production was limited by N (Wairegi et al., 2010) and K (Smithson et al., 2004; Okech et al., 2004) in the Robusta growing region and by Mg in the Arabica region (Wairegi and van Asten, 2010). In addition, N and K requirements are high for both coffee (Van der Vossen, 2005) and banana (Bazira et al., 1997). Hence, both crops have similar nutrient requirements and yields in both mono-crops and intercrops can probably be increased by use of external soil inputs. Van Asten et al. (2008) observed that nutrient deficiencies were similar for bananas and coffee in the sites of this study.

The absence of a significant yield reduction of coffee when intercropping banana could possibly be partially due to below-optimal plant densities (Fig. 1). Despite lack of evidence of strong competition for resources between the two crops, long term sustainability of intercropping coffee and banana deserves mention. The intercrop system is likely to remove larger quantities of nutrients compared with the mono-crop system. On the other hand, the intercrop system is likely to increase soil organic carbon through accumulation of organic residues. Omitting the few farms that had unusually high livestock numbers (3% in the Robusta growing region), average Tropical Livestock Units (TLU) per farm computed using the conversion coefficients by Jahnke et al. (1988) was 2.2 and 3.2 in Arabica and Robusta growing region, respectively. The average farm size was 2.8 and 3.4 ha in the Arabica and Robusta growing region, respectively. With an estimated 60% of the land owned being cultivated (Bagamba, 2007), the manure produced can be used to replenish only some, but certainly not all of the nutrients removed by the crops. The use of mulch can contribute towards the sustainability of the system, but availability is often limited in densely populated areas. Mulch controls soil erosion, reduces weed pressure, preserves soil water, contributes organic matter and nutrients to the soil (Mitchell, 1988) and has been reported to increase coffee yields in Kenya (Cannell, 1973).

5. Conclusions

This study shows that intercropping coffee and banana appears to be more profitable than coffee mono-cropping. There is no particular evidence to suggest that coffee–banana intercropping is unprofitable or would lead to significant yield declines of either crop in the short term. Intercropping improves the productivity and returns of the farming system. The benefits of intercropping can probably be further increased by improved soil management practices (e.g. use of mulch, manure and fertilizer), optimal plant densities and planting arrangements, and appropriate agronomic management practices (e.g. pruning, de-trashing). It will be important to conduct more extensive research on water, light, and nutrient competition in coffee–banana intercrop systems, including assessment of the effect of banana intercropping on coffee quality. Such in-depth studies would help understand the system drivers and dynamics and would allow extrapolation of results to the wider region and beyond. Although in the past farmers have been discouraged from intercropping coffee with other crops, our study shows that there is need to encourage farmers to grow coffee and bananas as intercrops instead of mono-crops. This calls for identification of the major production constraints in these systems and subsequently development of site-specific recommendations to address these constraints. Since smallholders in sub-Saharan Africa are often resource-constrained (i.e. land, labor, nutrient inputs) the intercropping systems like coffee–banana may provide an opportunity to optimize resource-use efficiency, allow farmers to spread risks, and strike a balance between food and cash generation. There has been much attention over the past years on agricultural intensification and an African green revolution, but it is likely that this path should not necessarily follow the high-input mono-crop systems approach that western and Asian countries have followed over the past decades.

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