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Status and management of coffee plantations in Burundi: Reasons to worry

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Coffee is an important cash crop for smallholder farmers and provides more than 80% of hard currency in Burundi. To highlight coffee growing conditions, agronomic practices and coffee yield, a survey was carried out in Buyenzi, Kirimiro and Mumirwa natural regions of Burundi in 2008. Data on coffee yield, age after planting or after rejuvenation and agricultural practices were collected through interview with coffee growers. Soil and coffee leaves were sampled for laboratory analysis. Results showed high variation of yield between two consecutive years particularly in Kirimiro and Buyenzi. Coffee trees age was high with over 70% of them aged more than 20 years. Mineral fertilizers were regularly applied by less than 7% of coffee growers and mulch was applied by more than 70%. N and Zn deficiency was observed in Kirimiro and Mumirwa while K excess was observed in all natural regions. Coffee was intercropped with various crops in the following descending order: Taro > beans > banana > maize. Agricultural techniques recommended in coffee cultivation were not properly followed, leading to a biennial variation and low yield.

Key words: Coffee-yield, rejuvenation, zinc-deficiency; biennial-variation; crop-intercropping.

INTRODUCTION

Coffee was introduced in Burundi during the 1930's (Gaie and Flémal, 1988) and the cultivated coffee is exclusively *Arabica* coffee (Ngayempore, 2007). It is grown by nearly 750,000 smallholder farmers managing between 100 and 300 coffee trees (Gaie and Flémal, 1988). With a production of 29,950 Mg of green beans in 2006, coffee sale had provided around 20 million dollars in rural areas (Kimonyo and Ntiranyibagira, 2007).

Coffee introduction in Burundi was accompanied by a technical package proposed to coffee growers to ensure good productivity. This package was related to coffee pruning, fertilizer application, mulching, pests and

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diseases control, as well as intercropping of coffee with other crops. Pruning of branches is to be carried out after harvest and consists in removing unproductive and dried branches. This pruning aims to maintain a conical morphology of coffee plant and ensure fair ventilation (Gaie and Flémal, 1988), thereby reducing the incidence of diseases (Lambot and Bouharmont, 2009) such as rust (Avelino et al., 2004) and coffee berry disease (Bedimo et al., 2008). Pruning is also performed for plant rejuvenation (Gokavi et al., 2021) for which it is recommend 7 years of periodicity (Gaie and Flémal, 1988).

Urea is the main fertilizer used for coffee fertilization. Research recommends to apply 132 g of urea per plant per year, split into 3 or 4 applications from October to March (Gaie and Flémal, 1988). Even though coffee has high K requirements (Carvajal, 1984) to achieve good yields and to produce quality cherries (Cong et al., 2001; Mancuso et al., 2014), no fertilization recommendations were issued for K. It was assumed that K, P and micronutrients should be provided through mulching. Furthermore, mulching is recommended because it helps to preserve soil moisture, to reduce weeds pressure, to control erosion and provides nutrients (Beer, 1987; Nzeyimana et al., 2017). It is recommended to apply between 10 and 12 cm of mulch thick before the dry season, between the end of April and the beginning of May (Gaie and Flémal, 1988). This can easily require over 40 Mg ha^{-1} of DM per year (Cochet, 1996). Despite the decreasing availability of mulch as a result of high population pressure and testing of alternative techniques (Snoeck et al., 1993), full mulching remains the recommended technique.

Rust and coffee berry are the main diseases affecting coffee production in Burundi. These diseases are mainly present in marginal production areas with low rainfall, poor soils and high temperatures (Lambot, 1990). Treatment with 5 sprays of insecticides at 1 month of intervals starting 3 weeks after the end of flowering stage is recommended to control those diseases. Among the pests, the coffee bug (*Antestiopsis orbitalis ghesquierei* Carr.) is the most important (Autrique et al., 1989; Gaie and Flémal, 1988). This pest is controlled by insecticide application in November and January (Bouyjou, 1992).

For more land productivity, coffee can be intercropped by annual crops or perennial crops. In Burundi, research recommends to intercrop young coffee trees with annual crops such as beans, soybeans and tomatoes before first coffee production (Gaie and Flémal, 1988). Intercropping with perennial crops was not recommended (Gaie and Flémal, 1988). All the above-mentioned recommended agricultural practices for coffee plantations are labor-demanding, costly (e.g., pesticides) and sometimes difficult to implement (e.g., mulching). Already in 1992, Hubert and Maganda (1992) reported that in the region of Buyenzi, mulching, mineral fertilization and renovation of old coffee plantations were not performed as recommended. In recent years, strong biennial fluctuations of coffee production and low prices granted to coffee growers have resulted less incentive for farmers to invest time and money in their coffee plantations. This may affect in the short or medium term the essential role of coffee in the economy of Burundi. The objectives of this study were therefore (i) to describe current coffee cropping system and (ii) to highlight possible pathways for revitalizing coffee productivity in the main coffee production regions of Burundi.

MATERIALS AND METHODS

Study area and farms selection

A survey was carried out in December 2008 in three natural regions of Burundi namely Mumirwa, Buyenzi and Kirimiro. Those regions were chosen according to the importance of coffee production. Indeed, Buyenzi, Kirimiro and Mumirwa represent more than 59% of national coffee production (Gaie and Flémal, 1988) and 83% of fully washed coffee. Kirimiro Natural Region is between 3.05° and 3.8° south latitude and 29.6° and 30.1° east longitude. The altitude is between 1400 and 1750 m asl. Annual rainfall is between 1200 and 1300 mm; the annual mean temperature is around 18°C. The dominant soils are Ferralsols and Kaolisols (Sottiaux et al., 1988); the landscape consists of a hill with flat tops. Buyenzi natural region is located between 2.7° and 2.9° south latitude and 29.06° and 39.5° east longitude. The altitude is between 1500 and 1900 m. The average annual rainfall is between 1200 and 1300 mm. The annual average temperature average is around 18°C, the landscape consists of hills with flat tops and slight slopes.

The dominant soils are Ferrisols, Feralsols and Regosols (Sottiaux et al., 1988). Mumirwa natural region is located between 2.6° and 3.9° south latitude and 29.6° and 30.1° east longitude. The altitude is between 1170 and 1700 m. The average annual rainfall is between 1400 and 1700 mm and average temperature between 18 to 22°C. The landscape consists of hills with steep slopes. The dominant soils are Ferrisols, Feralsols and Regosols (Sottiaux et al., 1988). Within each natural region, 4 communes were randomly selected (Figure 1). Selected communes were Bukinanyana, Mubimbi, Isare and Buyengero in Mumirwa; Mwumba, Ruhororo, Kayanza and Muhanga in Buyenzi and Rutegama, Nyabihanga, Bugendana and Makebuko in Kirimiro. In each commune, 20 farms were randomly selected. The selection of farms was conducted with the aim to cover the entire commune. Thus, farms selected were located in different villages. Rainfall data (1989-2008) by natural region were provided by the Institut Géographique du Burundi (IGEBU) from existing weather stations in the region, that is, Nyamuswaga for Buyenzi, Gitega for Kirimiro and Butara and Mubimbi for Mumirwa.

Age, agricultural practices and coffee yield

The age of coffee plantations was provided by the coffee growers. To guide them, a time scale on which were mentioned the major events that took place in Burundi over the last 7 decades was given. Starting from a well-known event, the coffee grower could determine how many years before or after he had planted his coffee. The time since the last rejuvenation was obtained by asking the coffee grower the year in which he made the last rejuvenation.

Data on crop management practices were provided by the coffee

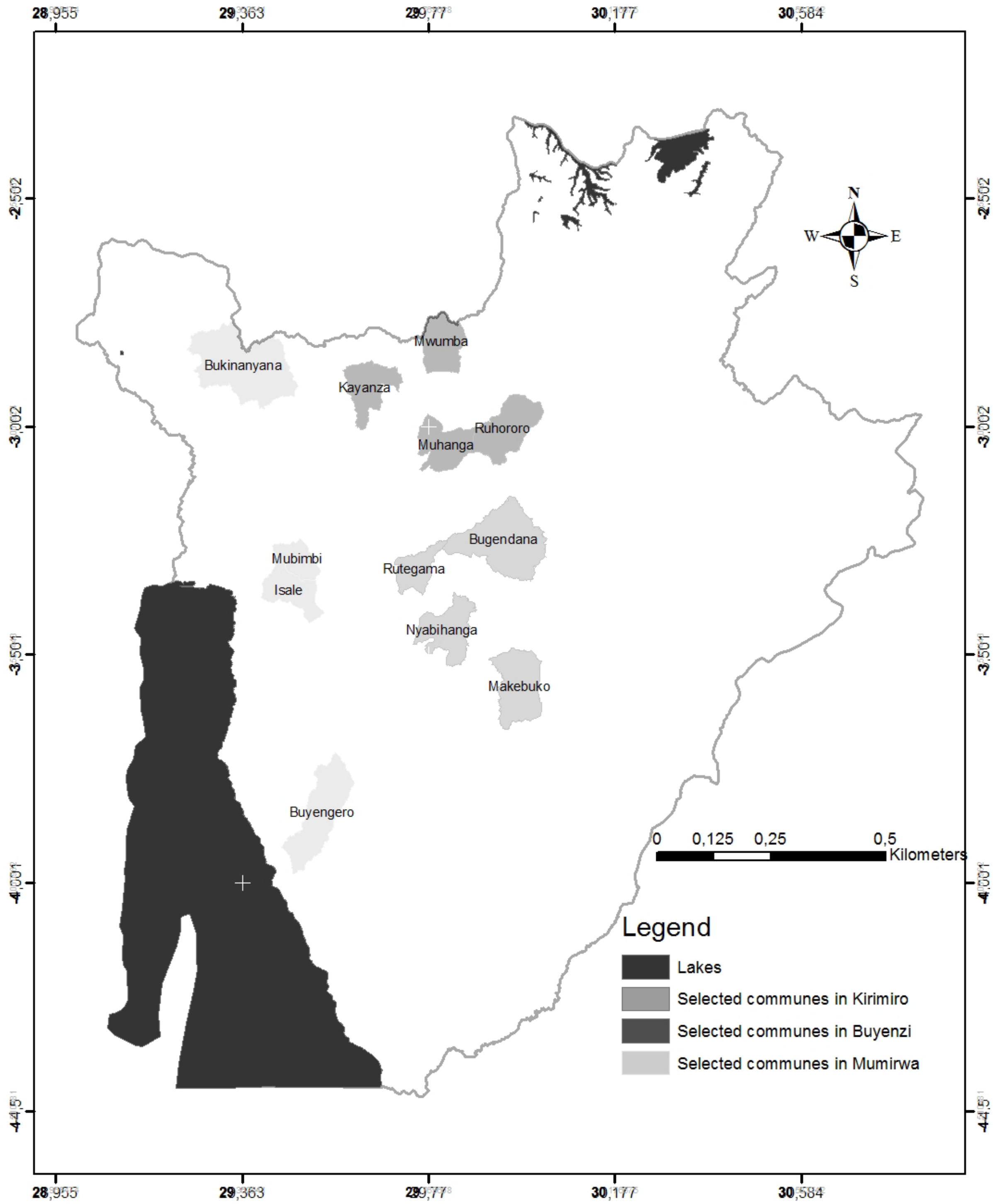


Figure 1. Selected communes locations.

growers. Data on coffee intercropping with other crops were collected by the interviewer. All crops intercropped with coffee were recorded. For each crop, the intensity of intercropping was scored with score 1 when the crop covered only a part of the coffee plot at a low density, score 2 when the crop occupied the whole plot at lower density than in monocropping, and score 3 when the intercropped crop occupied the whole plot at density which is closer to the density observed in monocropping.

Coffee production was provided by coffee growers. The first production to be estimated was for 2008 because this was easy to remember. It was estimated from the weight of cherries sold to washing stations and / or the weight of dry coffee sold to the local market.

To convert dry coffee in cherry weight, dry coffee weight was multiplied by 4.75 (Gay and Flémal, 1988). After estimating the 2008 production, coffee growers were asked to estimate the production of 2007, 2006 and 2005 in term of 2008 production percentage.

The aim was to evaluate the amplitude of biannual variations of coffee production. With the total number of plants and the plot area measured by the interviewer, yield per hectare was estimated for the four years from 2005 to 2008.

Soil and leaf analysis

Composite samples of soil and coffee leaves were taken in November 2008 in four farms per commune. Soil samples were collected at a depth of 0-30 cm. Leaf sampling was made on the third or fourth pair counted from the last pair recently expanded selected on the whole coffee tree (Wrigley, 1988). In each plot, 10 plants were randomly selected and on each plant 5 pairs of leaves were harvested. Leaf samples were then oven-dried for 96 hours at 65° C. Soil and leaves analyses were performed at the Agricultural Chemistry Laboratory of ISABU (Institut des Sciences Agronomiques du Burundi). Soil pH was measured using a pH meter in a 1:5 soil water suspension. Organic carbon was determined using Walkley-Black method (Walkley and Black, 1934). Total nitrogen was determined using the Kjeldahl digestion method and measured colorimetrically. Exchangeable cations were extracted using Metson method and measured with an atomic absorption spectrometer. Available phosphorus was determined with Olsen-Dabin method. For leaves, P, K, Ca, Mg and Z contents were obtained by digestion with nitric acid after calcination at 450°C. P was measured calorimetrically and cations by atomic absorption spectrometry. Total nitrogen content was determined using Kjeldahl method.

To ensure quality of analysis, ISABU laboratory is involved in inter-comparison tests in Kenya for East Africa and at BIPEA (Interprofessional Bureau of Analytical Studies) in France at world level. In each batch of 50 samples, 3 samples of known results through inter-comparison tests were integrated to verify the reliability of results. If the different values were found, the analysis was repeated for all samples.

Compositional Nutrient Diagnosis indices (CND) for N, P, K, Ca and Mg were determined using standard norms proposed by Wairegi and van Asten (2012). Each element is deficient when its index is < 0, is excess when > 0 and balanced when it is = 0. Relative value of Zn was used and corresponds to the difference between the leaf Zn content and the norm proposed by Snoeck and Lambot (2009). These authors propose a normal content of Zn between 10 and 15 mg kg^{-1}. In this study, the value of 10 mg kg^{-1} was used.

Statistical analyses

Data normality for age after planting and age after rejuvenation was not confirmed and Kruskal-Wallis's no parametric test has been used to compare regions. Soils results and CND indexes were analyzed using ANOVA I, where the only factor was the natural region. ANOVA I was used because the normality of data was verified with Shapiro-Wilk's test. Statistical analysis was performed using R 2.13.1 software. Classification of means between regions was made using Tukey's test at the level of significance of 5%.

RESULTS

Coffee yield, coffee age and agricultural practices

There was biannual variation of coffee cherry yield in all three natural regions. Strong biannual fluctuations were especially observed in Buyenzi and Kirimiro regions (Figure 2). In these regions, coffee yields were higher in 2006 and 2008. Maximum yield was 3.1 and 2.6 Mg ha^{-1} and minimum yield were 1.2 and 0.8 Mg ha^{-1} respectively for Buyenzi and Kirimiro. The average density of coffee was 2468 plants ha^{-1} in Buyenzi, 2636 plants ha^{-1} in Kirimiro and 2317 plants ha^{-1} in Mumirwa. These densities were not significantly different at $p \leq 0.05$. The weight of cherries harvested per plant was ranged between 1.3 and 0.5 kg in Buyenzi, between 1.0 and 0.3 kg in Kirimiro and between 1.4 and 0.9 kg in Mumirwa.

In all regions, more than 42% of coffee trees were aged between 21 and 30 years (Figure 3a). This proportion was particularly higher at Kirimiro with a percentage of 62%. Plots with new trees (under 10 years) represented less than 10% in all regions. The higher percentage of old coffee trees was observed at Mumirwa with 27% of coffee trees aged more than 40 years and 43% of coffee trees older than 30 years. The median age of coffee trees was 27 years in Buyenzi, 25 years in Kirimiro and 29 years in Mumirwa.

The percentage of coffee trees with less than 7 years since the last rejuvenation pruning was higher at Kirimiro (59%) compared to Buyenzi (26%) and Mumirwa (45%) (Figure 3b). The median age after the last rejuvenation was 10 years in Buyenzi, 7 years in Kirimiro and 8 in Mumirwa. The median age of coffee and the median age after rejuvenation were statistically different between regions with $p = 0.033$ and $p = 0.028$ respectively for age after planting and age after rejuvenation. The percentage of coffee growers who regularly applied mineral fertilizers (4 years out of 4) was 6% in Mumirwa, 5% in Kirimiro and 0% in Buyenzi (Table 1). The average amount of fertilizer applied was 52, 37 and 24 g per tree respectively for Buyenzi, Mumirwa and Kirimiro. Only urea was used as fertilizer. No manure, compost or lime were applied in coffee plots.

The percentage of growers who applied insecticides regularly (4 years out of 4) or often (3 years out of 4) was 54% in Mumirwa, 74% in Buyenzi and 53% in Kirimiro (Table 1). The applied insecticide was KARATE with lambdacyalothrin as active ingredient at a dose of 20 ml in 15 L of water to treat 60 coffee plants.

Mulching was regularly applied by 60% of coffee growers (Table 1). For each year, more than 70% of coffee growers applied mulch. Whole plot mulching was most common, with 94% of growers in Mumirwa, 100% in Kirimiro and 93% in Buyenzi. The percentages of plots well mulched or medium mulched were higher than 53% in all natural regions. The percentage of non-mulched

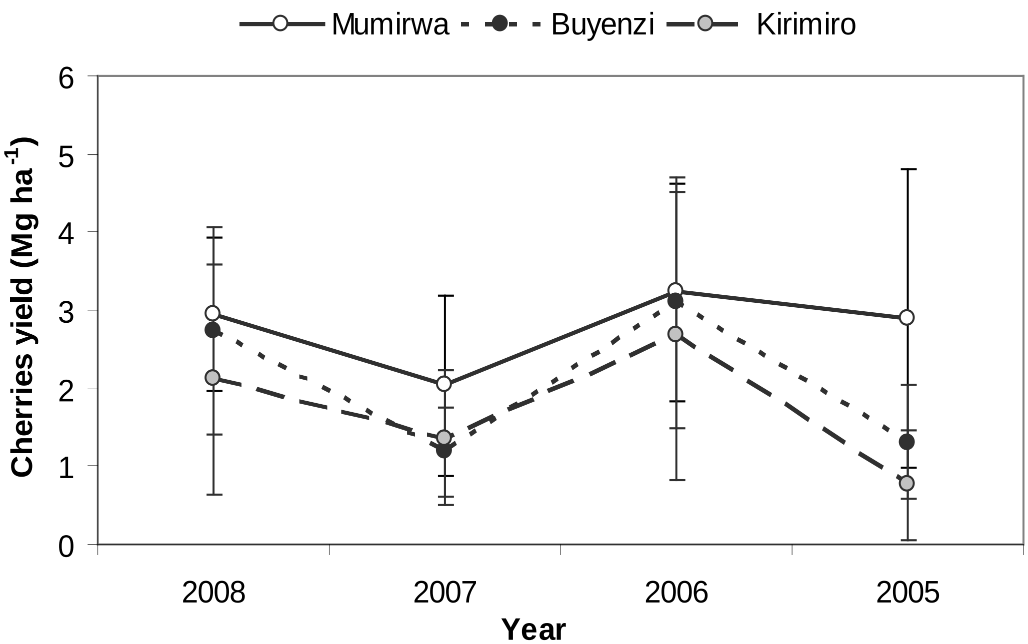


Figure 2. Coffee cherry yield in Buyenzi, Kirimiro and Mumirwa natural regions from 2005 to 2008. The error bars represent standard deviation (n=40). The averages with the same letter are not significantly different at p ≤ 0.05; there is no letter for when no significant different values between regions.

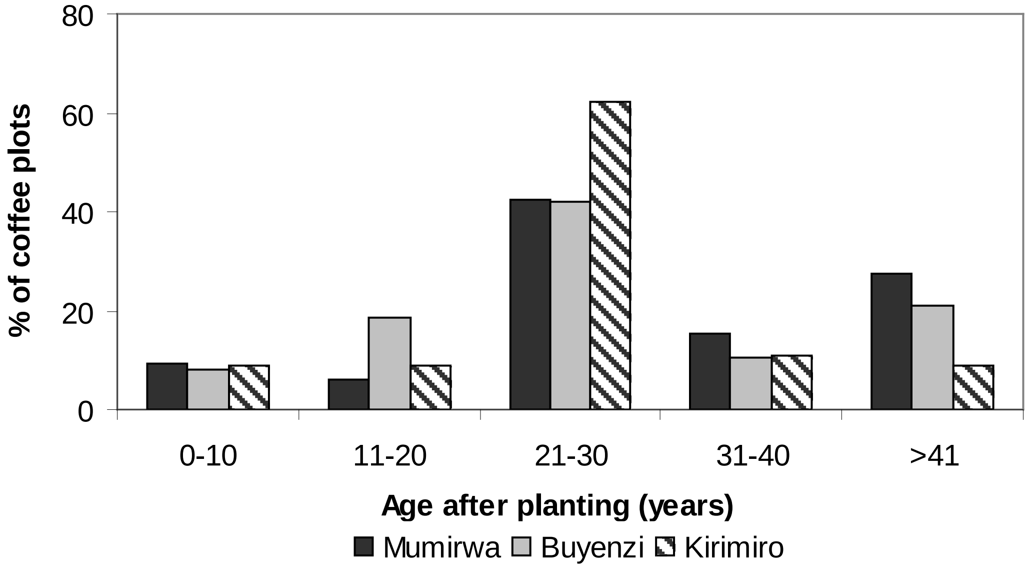
plots was highest in Mumirwa with a value of 13%. Intensive mulching was performed mainly during the dry season in June, July and August (Figure 4a, b and c). The percentages of plots mulched during this period were 70% in Mumirwa, 69% in Buyenzi and 73% in Kirimiro. In Mumirwa and Buyenzi most mulch was applied in August with respective values of 27 and 31%. In Kirimiro, most mulch was applied in June with 27% of coffee plots. The percentages of plots mulched before the dry season (April-May) were close to 15% in all three sites. In Buyenzi and Kirimiro, the mulching materials were dominated by banana residues in 69 and 76% of plots respectively. In Mumirwa, wild grasses were the dominant mulching material in 85% of coffee plots.

Coffee and food crop intercropping was observed in 53, 45and 52% of coffee plots respectively in Mumirwa, Buyenzi and Kirimiro (Figure 5). Taro was the most intercropped crop in coffee plantations. The second crop intercropped with coffee was bean in Buyenzi and Kirimiro, and banana in Mumirwa. Intercropping with beans and tomato was observed in old coffee, with an average age after rejuvenation of 8 years for beans and 10 years for tomato. Coffee was also intercropped with other crops such as maize, sweet potato, pineapple, and sunflower. The intensity of intercropping was high for beans, medium for taro and low for banana. The dominant coffee systems were i) coffee and taro in 30% of coffee plots, ii) coffee and beans in 15%, iii) coffee and banana in 10% of coffee plots and iv) coffee, taro and banana in 6% of coffee plots.

Soil and leaf characteristics

Significant lower soil values were recorded in Mumirwa for pH, N_{tot}, Ca, Mg and K compared to the other two regions (Table 2). In Buyenzi statistically higher values were recorded for N_{tot}. In Kirimiro, pH, K and Mg were statistically higher compared to the values registered in the two other regions. The values of C, P and Zn did not significantly differ between regions (p>0.05). The N content in coffee leaves was significantly higher in Mumirwa with a value of 2.6% (Table 3). K values observed in Mumirwa and in Kirimiro were statistically higher compared to values observed in Buyenzi. Values for Buyenzi, Mumirwa and Kirimiro were respectively 2.8% value, 3.2 and 3.6%. The value of Ca observed in Buyenzi was significantly higher compared to values observed in Kirimiro and in Mumirwa while the value of Zn observed in Kirimiro was significantly lower compared to the values observed in Buyenzi and Mumirwa. There was no significant difference between regions for P and Mg values.

Based on the CND index analyses and literature norms, coffee trees were deficient in N and Zn in the three sites (Figure 6). There was no significant difference between regions for N. For Zn, significantly lower values were recorded in Kirimiro. In Mumirwa, 73% of coffee plots had



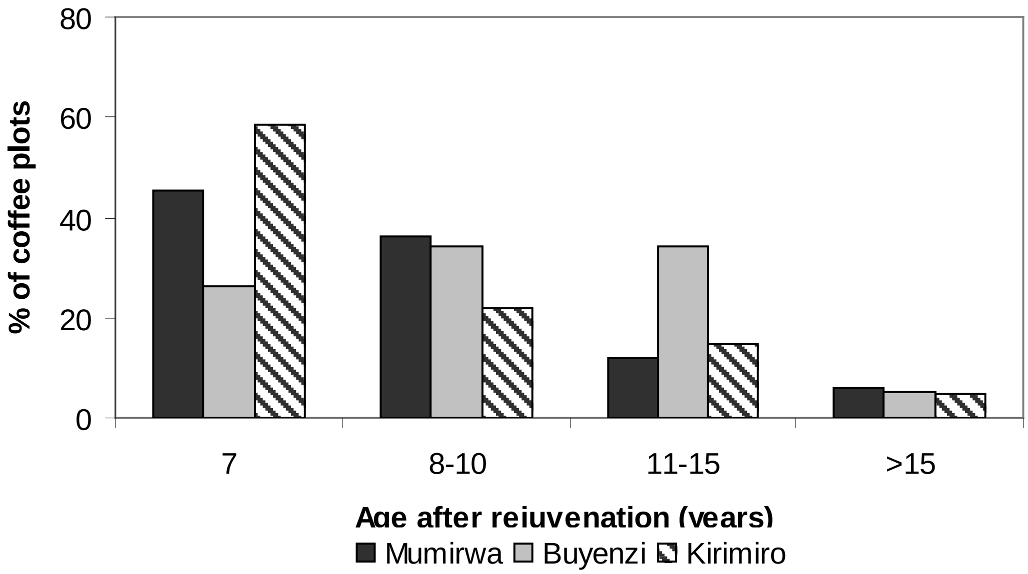


Figure 3. Age of coffee after planting (a) and after rejuvenation (b) in natural regions of Mumirwa, Buyenzi and Kirimiro.

a deficiency of N when this percentage was 94 and 100% in Buyenzi and Kirimiro, respectively. Zn deficiencies were observed in 82% of coffee plots in Mumirwa and 100% of coffee plots in Buyenzi and Kirimiro even if significant lower values of Zn leaf contents were observed in Kirimiro. However, there was an excess of K in the three regions, with significantly higher values in Mumirwa and Buyenzi compared to Kirimiro. The Ca and Mg CND indexes were significantly higher and positive in Buyenzi as compared to Mumirwa and Kirimiro where they were lower and deficient. P indexes were close to 0 with no significant differences between sites.

DISCUSSION

Coffee age and agricultural practices

The age of coffee trees affects coffee yield because 20 to 43% had already exceeded productive age (Figure 3a,

Table 1. Agricultural practices by natural region in Burundi (Mumirwa, Buyenzi and Kirimiro). Values are percentages of coffee plots.

	2008	2007	2006	2005	4 years out of 4[1]	3 years out of 4[2]	Dose(g plant^{-1})
				Fertilizer application			
Mumirwa	9.1	24.2	18.2	21.2	6.1	13.2	37.4
Buyenzi	0.0	2.6	7.9	7.9	0.0	2.6	52.1
Kirimiro	9.8	19.5	12.2	19.5	4.9	10.6	23.9
				Insecticide application			
Mumirwa	42.4	74.3	65.7	66.7	25.7	53.8	-
Buyenzi	31.4	97.4	88.6	80.0	28.6	74.3	-
Kirimiro	41.5	70.7	73.2	75.6	37.1	52.5	-
				Mulching			
Mumirwa	87.5	90.6	84.4	87.5	74.2	80.7	-
Buyenzi	82.9	85.7	82.9	74.3	57.1	82.9	-
Kirimiro	70.0	75.0	71.8	82.1	66.7	87.5	-

[1]Percentage of growers who applied the technique on all 4 years of the study. [2]Percentage of growers who applied the technique during 3 years of 4 years of the study.

Table 2. Soil characteristics (0-30 cm) of coffee plots in Mumirwa, Buyenzi and Kirimiro. The given values are means ± standard deviations (n = 24 per natural region).

Characteristics	Mumirwa	Buyenzi	Kirimiro
pH	4.6±0.5[a]	5.2±0.5[b]	5.7±0.3[c]*
Corg (%)	1.7±0.6[a]	2.0±0.9[a]	1.8±0.4[a]
N (%)	0.2±0.1[a]	0.3±0.1[b]	0.2±0.04[a]
P (mg kg^{-1})	12.3±9.5[a]	17.6±11.5[a]	13.3±8.0[a]
K (cmol$_c$ kg^{-1})	0.5±0.3[a]	0.7±0.5[a]	1.2±0.6[b]
Ca (cmol$_c$ kg^{-1})	1.5±1.7[a]	3.6±1.7[b]	3.9±2.9[b]
Mg (cmol$_c$ kg^{-1})	1.0±0.08[a]	1.2±1.0[b]	1.3±0.7[b]
Zn (mg kg^{-1})	3.2±2.7[a]	2.6±1.8[a]	2.7±1.8[a]

* Values with the same letters in the lines were not significantly different at $p \leq 0.05$.

Table 3. Nutrient leaf contents in Mumirwa, Buyenzi and Kirimiro. The given values are means ± standard deviations (n = 24 per natural region).

Characteristics	Mumirwa	Buyenzi	Kirimiro
N (%)	2.58±0.37[b]	2.00±0.51[a]	2.12±0.68[a]
P (%)	0.18±0.04[a]	0.18±0.02[a]	0.18±0.04[a]
K (%)	3.19±0.25[b]	2.78±0.61[a]	3.55±0.92[b]
Ca (%)	0.67±0.13[a]	0.94±0.15[b]	0.69±0.19[a]
Mg (%)	0.29±0.05[a]	0.38±0.10[a]	0.38±0.14[a]
Zn (mg kg^{-1})	7.88±1.06[b]	7.99±0.79[b]	7.00±0.81[a]

* Values with the same letters in the lines were not significantly different at $p \leq 0.05$.

Tibaijuka, 1984). Renovation of existing plantations is currently insufficient, since less than 10% of coffee plots are aged less than 10 years (Figure 3a). The 7-year periodicity for rejuvenation was not respected by 43 to 74% of coffee growers with higher percentage in Buyenzi (Figure 3b). Or, rejuvenation reduces competition between vegetative and reproductive parts of coffee trees (DaMatta and Rena, 2002, DaMatta et al., 2007) and

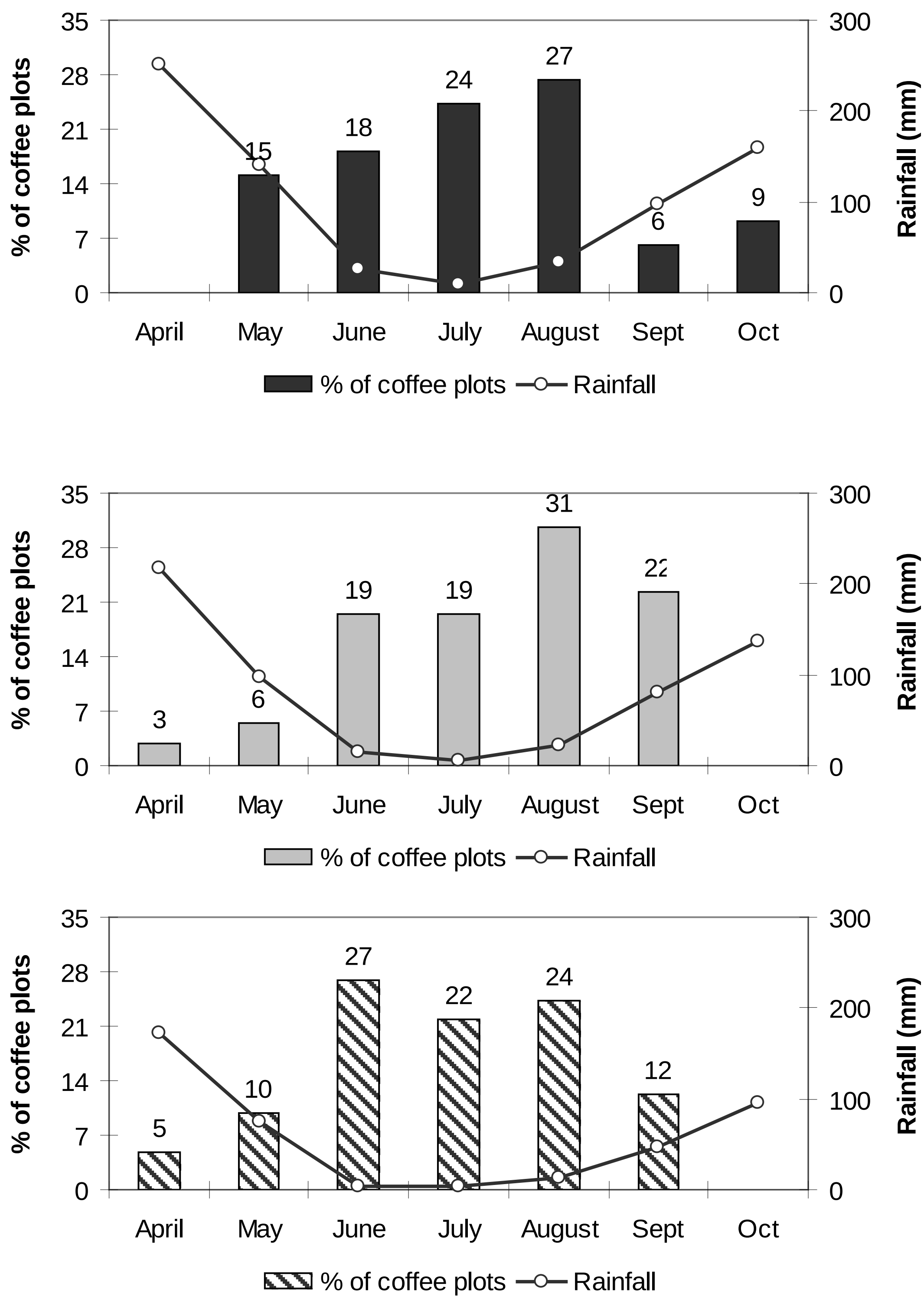


Figure 4. Periods of intensive mulching and the corresponding monthly average of rainfall (1973-2008) in Mumirwa (a), Buyenzi (b) and Kirimiro (C).

revitalizes coffee tree production. It appears therefore that Burundian coffee trees are doubly old, because of their age after plantation and because of the inadequate rejuvenation practice (Figure 3a and b).

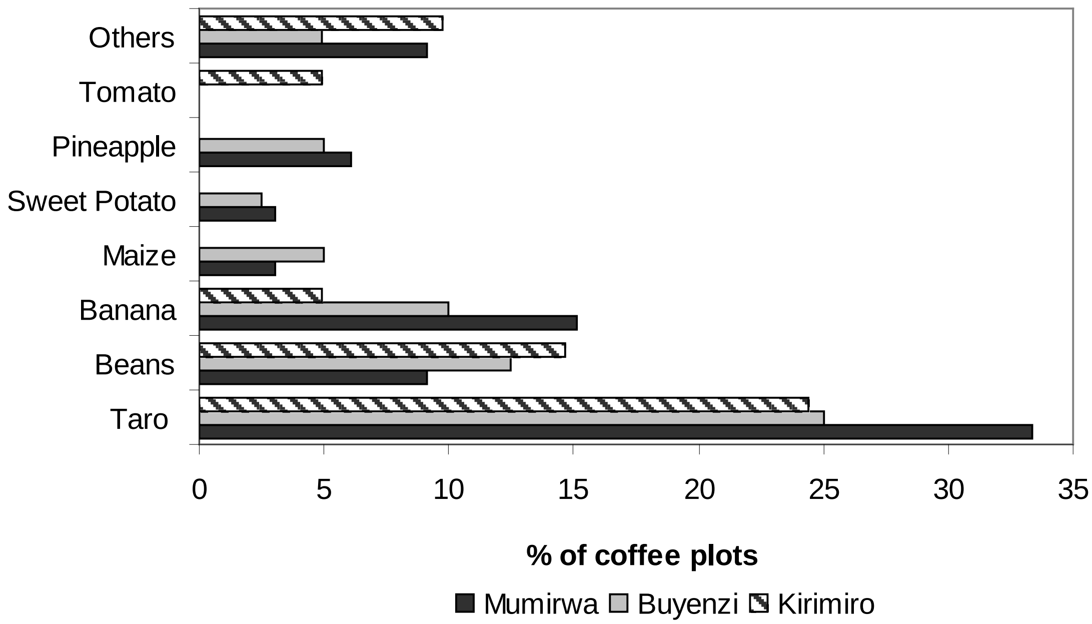


Figure 5. Food crops intercropped with coffee by region. The percentages of all crop for each region were higher than 100 because several crops could be found in a same coffee plot.

Coffee growers generally did not follow the recommended fertilization rate, which is 132 g of urea per plant and per year (Gaie and Flémal, 1988). Coffee growers apply 2.5 to 5 times less than the recommended rate. Biennial coffee yield fluctuations (Figure 2) and the uncertainty of investment return due to the low price of cherries could be the main reasons of less investment in fertilizers. Despite government subsidies, 34% of coffee growers did not apply insecticides each year (Table 1). Heavy logistics and high expenses involved in the transport and distribution of insecticides and sprayers to the farms may in part explain why some farmers do not apply pesticides regularly. No fungicides were applied to control rust and coffee berry disease which are the most important coffee diseases in Burundi.

Mulching was respected by a large majority of coffee growers in the three natural regions (Table 1). In Buyenzi and Kirimiro banana residues were the most common mulching material while wild grasses were mainly used in Mumirwa because banana residues were not exported in coffee plots but retained in banana plots to improve their fertility. The application period was inadequate because the mulch was applied mainly between June and September (Figure 4), which corresponds to the dry season. Mulch applied during dry season cannot therefore fully play its role of soil moisture conservation (Beer, 1987) and water deficit control. Mulch is applied during dry season probably because dead biomass from banana, annual crops residues and wild grass are mainly available during this period.

Intercropping of coffee with other crops was commonly observed (Figure 5). The objective of this intercropping could be to increase income (Chinpungahelo, 2006; Van Asten et al., 2011; Tilman, 2020) or/and to reduce risk and insure food security. Annual crops were the most common intercrops. Intercropping coffee with beans, soybeans, peanuts and tomato has been advocated but only during the first 2 years after coffee planting or after rejuvenation in order to compensate the loss of income during this growth stage (Gaie and Flémal, 1988). But, in this study, it appears that intercropping exists even in old plantations. Furthermore, in 5 to 15% of coffee plots was intercropped with banana, particularly in Mumirwa, although this is not recommended because of his high water and nutrient requirements combined with sunlight competition (Gaie and Flémal, 1988).

Soil and leaf characteristics

Soil characteristics were different in the three natural regions (Table 2). This should be due to differences in soil type and management practices. Soil K contents were higher than the norms in the three regions, which may be related to type of soil (Van Wambeke, 1989), to quantity and the type of mulches used. In particular, banana residues are known to supply large quantities of K (Pozy et al., 1996). This is confirmed by the CND indexes for K which were positive in all three sites (Figure 6). It appears therefore that K fertilization is not required

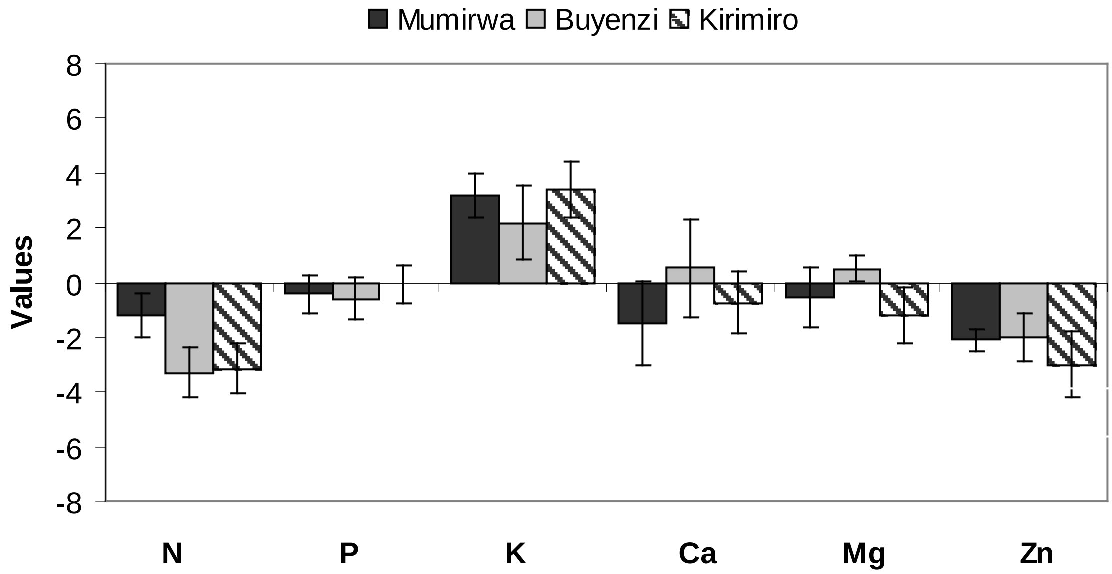


Figure 6. CND index of N, P, K, Ca, Mg and relative Zn content in coffee leaves per natural region (N, P, K, Ca and Mg are in % of DM and Zn in mg kg^{-1}). The bars represent standard deviations. The values with different letters are statistically different at $p \leq 0.05$. There was no letter for no significantly different values.

as long as the current levels of mulching can be sustained. According to standards proposed by Winston et al. (1992), soil pH between 5 and 6 in Kirimiro and Buyenzi is suitable for coffee (Table 2). However, the pH observed in Mumirwa was below standard with pH less than 5 (Table 2). This low pH in Mumirwa which was observed in other studies in Burundi could be due to the type of soil which is geologically recent and in alteration with release of H^+.

The soil organic carbon in coffee plot was in the standard values between 1-3% proposed for coffee by Wintson et al. (2006). Based on the CND indexes and the relative values of Zn, deficiency of N and Zn were observed in all regions. N deficiency has also been observed in coffee in Burundi by Gaie and Flémal (1988). Zn deficiency was significantly higher in Kirimiro (Figure 6). There was also deficiency of Ca and Mg in Kirimiro and Mumirwa. In Mumirwa, this deficiency was due to low levels of Ca and Mg in the soil with lower values than those proposed by Snoeck and Lambot (2009). But, in Kirimiro these deficiencies may rather be due to the imbalance between cations because of high level of K in soil. Mg/K ratio was 1.1 and (Ca + Mg)/K ratio was 4.3 while proposed norms are between 2 and 5 for Mg/K and between 10 and 20 for (Ca + Mg)/K (Snoeck and Lambot, 2009).

In the three natural regions, P levels in the soil were below standard values which are 60-80 mg kg^{-1} proposed by Winston et al. (1992). But, in the leaves, the values obtained were in standards values of 0.15-0.20% proposed by Winston et al. (1992). These low values of P in soil (Table 2) and its presence in a sufficient concentration in the coffee leaves (Table 3 and Figure 6) could be due to good conditions of P uptake such as pH values and C content in soil.

Coffee yield

Large fluctuations of coffee production in two successive years were observed in all regions of the study (Figure 2). The best productions of coffee were obtained in 2008 and 2006 (Figure 2). This corresponds to the best years of coffee production at national level, with a production of 26,000 Mg in 2008 and 29,950 Mg in 2006. The production of 2005 was about 6,200 and 7,950 Mg in 2007 (Office du Café du Burundi: OCIBU, 2009[1]). Coffee yield per hectare, however, was generally higher in Mumirwa and lower in Kirimiro (Figure 2). Higher yields per hectare and lower fluctuations of coffee yield in Mumirwa could be due to a combination of several factors such as more abundant rainfall (Figure 4), more frequent rejuvenation (Figure 3b) and lesser N deficiency in coffee leaves (Figure 6) because of a higher percentage of coffee plots fertilized with urea (Table 1). Deficiency of N observed in all regions although weaker in Mumirwa (Figure 6) should be a source of biennial coffee production variation at farm level. Indeed, combined with water stress during the dry season, N deficiency can lead to considerable leave fall (Clowes

[1] Internal data

and Wilson, 1977; DaMatta and Ramalho, 2006). To allow coffee production, the plant must renew its leaves (Coste, 1989) which takes time and reduces yield the following year. Synchronization of low coffee yield in all plots of Kirimiro and Buyenzi could be due to rainfall deficit. According to climatic data, the years 2005 and 2007 had the lowest rainfall with 1,095 and 1,050 mm respectively against 1315 mm for year 2006 for Buyenzi natural region. For Kirmiro rainfall was 837 mm for year 2005, 1078 mm for year 2007 and 1540 mm for 2006.

RECOMMENDATIONS FOR COFFEE PRODUCTION SUSTAINABILITY IN BURUNDI

The current situation is not encouraging because there are few new plantations (Figure 3), indicating less interest in coffee and this is confirmed by the low investment in fertilizer (Table 1). In this context, coffee production is not sustainable in Burundi and the following recommendations are to be issued to encourage increase in coffee productivity:

(1) Coffee renovation**:** The renovation can be done gradually by removing 20% of old trees and this should be done over 5 years in a same plot to maintain income from coffee. Thus, more than 40% of coffee trees will still be in production during the three first years and up 40% of new coffee trees will be in production at the fifth year.

(2) Increase prize allocated to coffee growers in suitable zones for coffee. This could stimulate investment in inputs and labor used in mulching and rejuvenation. The production of high quality coffee can be used to increase coffee prize at farm level. Incentive price had been achieved during competition on coffee quality organized by coffee sector in Burundi. Coffee growers who sold their cherries at Kinyovu washing station received around 2.8 $ per kg of cherries while the proposed price by coffee authority was 0.30 $ per kg of cherries.

(3) Intercrop coffee with staple crops to increase productivity of plots in sub-optimal zone where production of high quality coffee is difficult to achieve. Thus, the common bean could provide an additional source of income and food to coffee growers while improving the soil by nitrogen symbiotic fixation. Banana could ensure continuous production of mulch and food security and generate additional income.

(4) For late mulching, it is difficult to propose a solution because the mulch is available mainly during the dry season. Furthermore, transport is easy during the dry season because of low water content and relative availability of labor. Mulch production in coffee plots may be an alternative by growing cover crops such as legumes (*Desmodium* spp). This can partly, resolve the issue of late mulching and N deficiency.

(5) N and Zn deficiency correction should be ensured by mineral fertilizers supply. Zn should be applied by foliar. Growers could benefit from the current Government policy of global fertilizer subsidy. The use of manure to improve soil fertility could not be recommended because it is competitive with food crops but can be recommended only in intercropped system.

(6) The cationic imbalance in Kirimiro and low Ca and Mg in Mumirwa could be corrected by an adequate liming which can supply Ca and Mg.

(7) The problem of P is to be studied deeply to see if the low level in the soil will not affect at long-term its presence in leaves.

Conclusion

It is urgent to find out how to stimulate production by revitalizing interest of coffee growers. In fact, i) coffee trees were rarely renewed, ii) rejuvenation was not regularly practiced, iii) mineral fertilization was practiced by very few coffee growers. iv) mulch applied was not often enough and the time of application was not adequate. This has lead to N and Zn deficiencies and a biennial coffee production variation in Buyenzi and Kirimiro even if other factors such as rainfall may have affected negatively coffee production. The production of high quality coffee which can give to farmers an incentive price is limited at few washing stations and the quantity sold in very low. Thus, special efforts are needed to find buyers and to supervise growers who are involved in its production. The increase of incomes from coffee will help to invest in inputs especially fertilizers to reduce generalized N and Zn deficiencies and correct the cation imbalance and acidity observed particularly in Kirimiro and Mumirwa.

In marginal zones, the increase of quality of coffee is difficult to achieve. The intercropping of coffee with food crops in mature coffee which was prohibited could be considered. This can allow the increase of incomes and food security. The lack of mulch will continue to worsen with the increase of population. The production of coffee and mulching material in the same plot could be an alternative solution and this would be achieved by intercropping coffee with food crops or cover crops.

Coffee is a strategic crop because of its role in Burundi macro-economy. To maintain and to increase its production, actors have to be very creative because of many constraints such as low and fluctuating price of coffee, poor management and high density of population which leads to land scarcity, decrease of natural resources like mulch and the increase of food demand.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Autrique A, Perreaux D, Goethals M (1989). Maladies et ravageurs des cultures de la région des Grands Lacs d'Afrique centrale (Vol. 24, pp. 232). Division de la Défense des Cultures, Institut des Recherches Agricoles du Burundi (ISA Bu). Agence Générale de la Coopération au Développement, Bruxelles-Belgique: Publications du Service Agricole.

Avelino J, Willocquet L, Savary S (2004). Effects of crop management patterns on coffee rust epidemics. Plant Pathology 53(5):541-547. http://dx.doi.org/10.1111/j.1365-3059.2004.01067.x

Bedimo JM, Njiayouom I, Bieysse D, Nkeng MN, Cilas C, Notteghem JL (2008). Effect of shade on Arabica coffee berry disease development: toward an agroforestry system to reduce disease impact. Phytopathology 98(12):1320-1325. http://dx.doi.org/10.1094/PHYTO-98-12-1320

Beer J (1987). Advantages, disadvantages and desirable characteristics of shade trees for coffee, cocoa and tea. Agroforestry Systems 5(1): 3-13

Bouyjou B (1992). La lutte chimique contre la punaise du caféier Antestiopsis orbitalis. In: Deuxième symposium sur la recherche caféière au Burundi pp. 71-86.

Carvajal JF (1984). Cafeto. Cultivo y Fertilización. Segunda Edición. Instituto Internacional de la Potasa, Berna.

Clowes MSJ, Wilson JHH (1977). The growth and development of lateral branches of Coffea arabica L. in Rhodesia. Rhodesian Journal of Agricultural Research (Zimbabwe) 15(2):171-185.

Cochet H (1996). Gestion paysanne de la biomasse et développement durable au Burundi. Cahiers des Sciences Humaines 32(1):133-151.

Cong P, Sat C, Härdter R (2001). Response of selected crops to K fertilization on major soil types in South Vietnam. In Plant Nutrition (pp. 820-821). Springer, Dordrecht. http://dx.doi.org/10.1007/0-306-47624-X_399.

Coste R (1989). Caféier et café. Publication technique d'outre meroutre-mer. Paris 288 p.

DaMatta FM, Rena AB (2002). Ecofisiologia de cafezais sombreados e a pleno sol. O estado da arte de tecnologias na produção de café. Viçosa: UFV pp. 93-135.

DaMatta FM, Ramalho JDC (2006). Impacts of drought and temperature stress on coffee physiology and production: a review. Brazilian Journal of Plant Physiology 18(1):55-81. http://dx.doi.org/10.1590/S1677-04202006000100006

DaMatta FM, Ronchi CP, Maestri M, Barros RS (2007). Ecophysiology of coffee growth and production. Brazilian journal of plant physiology, 19(4):485-510. http://dx.doi.org/10.1590/S1677-04202007000400014

Gaie W, Flémal J (1988). La culture du cafeier d'arabie au Burundi. ISABU–Administration Générale de la Coopération au Développement. Publication du Service Agricole (14).

Gokavi N, Mote K, Jayakumar M, Raghuramulu Y, Surendran U (2021). The effect of modified pruning and planting systems on growth, yield, labour use efficiency and economics of Arabica coffee. Scientia Horticulturae, pp. 276- 109764.

Hubert JP, Maganda F (1992). Evolution de l'application des thèmes de conduite de la caféiculture en milieu paysan de 1987 à nos jours. Province de Ngozi. In: Deuxième symposium de la recherche caféière au Burundi pp. 105-117.

Lambot C (1990). The zinc deficiency problem in Arabica coffee in Burundi. In 13. Colloque Scientifique International sur le Cafe, Paipa (Colombie), 21-25 August 1989. ASIC.

Lambot C, Bouharmont P (2009). In Coffee: Growing, Processing, Sustainable Production. Willey-VCH Verlag GmbH & Co. KGaA, WeinHeim pp. 288-311.

Mancuso MAC, Soratto RP, Crusciol CAC, Castro GSA (2014). Effect of potassium sources and rates on arabica coffee yield, nutrition, and macronutrient export. Revista Brasileira de Ciência do Solo 38(5):1448-1456.

Ngayempore E (2007). Contraintes de la caféiculture burundaise. In : Atelier de réflexion sur les contraintes de la caféiculture et les résultats de la recherche café pp. 9-19.

Nzeyimana I, Hartemink AE, Ritsema C, Stroosnijder L, Lwanga EH, Geissen V (2017). Mulching as a strategy to improve soil properties and reduce soil erodibility in coffee farming systems of Rwanda. Catena 149:43-51.

Pozy P, Dehareng D, Deswysen AG (1996). Composition et valeur nutritive des aliments pour animaux au Burundi. Universite Catholique de Louvain.

Snoeck D, Bitoga JP, Barantwaririje C (1993). Avantages et inconvénients de l'utilisation des divers modes de couverture dans les caféières au Burundi. In COLLOQUE Scientifique International sur le Café, 15. Montpellier (Francia), Juin 6-11, 1993. Paris: ASIC pp. 793-795.

Snoeck J, Lambot C (2009). Coffee nutrition in: Coffee growing, processing sustainable production. Seconde edition. Willey-vch, Weinheim pp. 250-273.

Sottiaux G, Oldecam L, Bigura C, Frankart R (1988). Carte des sols du Burundi, Institut des Sciences Agronomiques du Burundi. AGCD, Bruxelles, publication du service agricole,N° 9, 83 p.

Tilman D (2020). Benefits of intensive agricultural intercropping. Nature Plants 6(6):604-605.

Tibaijuka AK (1984). An Economic Analysis of Smallholder Banana-Coffee Farms in the Kagera Region, Tanzania: Causes of the Decline in Productivity and Strategies for Revitalization. Published Ph. D. dissertation, Swedish University of Agricultural Sciences, Department of Economics and Statistics, Uppsala.

van Asten PJ, Wairegi LWI, Mukasa D, Uringi NO (2011). Agronomic and economic benefits of coffee–banana intercropping in Uganda's smallholder farming systems. Agricultural Systems 104(4):326-334.

Van Wambeke A (1989). Tropical soils and soil classification updates. In Advances in Soil Science (pp. 171-193). Springer, New York, NY.

Wairegi, LW I, van Asten PJ (2012). Norms for multivariate diagnosis of nutrient imbalance in arabica and robusta coffee in the East African Highlands. Experimental Agriculture 48(3):448-460. http://dx.doi.org/10.1017/S0014479712000142.

Walkley A, Black IA (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37(1):29-38. http://dx.doi.org/10.1097/00010694-193401000-00003.

Winston EC, LittlemoreJ, Scudamore-Smith P, O'Farrell PJ, Wiffen D, Doogan VJ (1992). Effect of nitrogen and potassium on growth and yield of coffee (*Coffea arabica* L.) in tropical Queensland. Australian Journal of Experimental Agriculture 32(2):217-224.

Wrigley G (1988). Coffee–tropical agriculture series. Harlow, UK: Longman Scientific & Technical.