Katholieke Universiteit Leuven

Faculteit Bio-ingenieurswetenschappen

ON-FARM ASSESSMENT OF BANANA PLANT DENSITY IN RWANDA

(Veldonderzoek betreffende de bananen plantdensiteit in Rwanda)

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Abstract

Bananas are an important staple and cash crop in Rwanda. An on-farm research was executed in three contrasting agro-climatic zones in Rwanda. It is concluded that rainfall is a major factor influencing banana plant density. High rainfall (>1400 mm) leading to high plant densities (>1800 mats/ha) and low rainfall (between 1000 and 1200 mm) leading to lower plant densities (between 1000 and 1500 mats/ha). Intercrops and varieties found in banana plantations are also influenced by prevailing conditions. A positive correlation was found between plant density and yield (kg/ha). Surprisingly no correlation was found between bunch weight and plant density. It was observed that smaller fields are planted more densely, and thus higher yielding. Fields are planted with many different banana varieties, on average 5.6 per field, most varieties are East African highland bananas. Results indicate that fields remain productive for a very long time, up to 90 years. And finally bananas are cultivated at very high altitudes, up to 2000 m.a.s.l..

Abstract (Ned)

Bananen zijn een belangrijk inkomengenererend- en stapelgewas in Rwanda. Een veldonderzoek werd ondernomen om de factoren die plantdensiteit beïnvloeden te achterhalen. Onze data suggereren dat hoge regenval (>1400 mm) leidt tot hoge plantdensiteit (>1800 mats/ha) en lage regenval (tussen 1000 en 1200 mm) leidt tot lagere plantdensiteit (tussen 1000 en 1500 mats/ha). Omgevingsfactoren, zoals regenval, zijn bepalend voor de begeleidende gewassen en de bananen variëteiten die in de velden worden aangetroffen. Er werd een positieve correlatie gevonden tussen plantdensiteit en opbrengst (kg/ha). Verrassend genoeg werd geen correlatie vastgesteld tussen de plantdensiteit en het trosgewicht. Verder werd er waargenomen dat kleinere velden dichter beplant worden en dus een hogere opbrengst realiseren. Gemiddeld werden 5.6 variëteiten aangetroffen in elk veld, de meeste van deze variëteiten zijn Oost Afrikaanse hoogland bananen. Velden kunnen tot 90 jaar in productief gebruik blijven. Tot slot, werd ook vastgesteld dat bananen tot op zeer grote hoogte kunnen verbouwd worden, tot 2000 m.

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1. Introduction

Rwanda is a small landlocked country in the hart of tropical Africa. Banana's are grown on 20% of it's cultivated green rolling hills. As 80% of Rwandan households are involved in banana cultivation, it is an important staple and cash crop. Nonetheless, not much is known on optimal plant densities and varieties used in complex intercropping systems. The East African highland bananas, a subgroup within the *Musa* family, are very important in Rwanda.

This thesis is an attempt to clarify factors influencing plant density as applied by local subsistence farmers. Initially production (kg/ha) will rise with increasing plant density, as each extra plant produces one extra bunch. With rising density, competition between individual plants will increase. Consequently, any additional plant will produce a bunch that weighs less than the average bunch weight. An optimum yield (kg/ha) will be reached, whereafter production (kg/ha) will no longer increase with increasing density. Physical factors e.g. rainfall influence plant density as well as farmer perception, management and intercrops. A review of the available literature on banana plant density showed that virtually no density trials have been executed with East African highland bananas. Previous trials were mostly on-station and dealt with monocropping, hence an on-farm survey was executed to map the current situation in subsistence farmer's fields. This is to be considered as a basis to provide improved agronomic guidelines, to produce more food for the growing population.

2. Rwanda

2.1 Geographical data

Rwanda is a small landlocked country in Central Africa, with Kigali as the capital (Fig2.1). The neighboring countries are in the north Uganda, in the east and south, UR Tanzania and Burundi and in the west the DR Congo.

Figure 2.1: Geographical location of Rwanda (Wikipedia online)

Goods transported to Rwanda have to travel long distances, either from the ports of Mombasa (1900 km) in Kenya or from Dar Es Salaam (1700 km) in Tanzania. The landscape is dominated by hills, with forested tops, cultivated hill sides and marshy valleys. The average altitude of the country is 1250 m.a.s.l., the lowest point is the Rusizi valley at 950 m.a.s.l. and the highest point is the summit of the volcano mount Karisimbi at 4507 m.a.s.l.. For African standards, roads are in good shape. The total surface is 26 340 km², a bit smaller than Belgium, with a population range from 8.5 to 10.5 million inhabitants, according to different authors (CIA 2009; AQUASTAT 2005). We will work with the figure of 9 464 000 inhabitants, since it is the average between the two. Population growth rate is estimated at 2.8% (CIA 2009). In comparison to it's neighboring countries and Kenya, Rwanda is very densely populated, with a population density of 359 inh/km². It is even more densely populated than Belgium (Table2.1), (AQUASTAT 2005). The age distribution is

- 0-14 years: 42.1% (male 2,216,352/female 2,196,327)
- 15-64 years: 55.4% (male 2,897,003/female 2,909,994)
- 65 years and over: 2.4% (male 100,920/female 152,686)

Total fertility rate is estimated at 5.25 children/women and HIV/AIDS prevalence is estimated at 2.8% (CIA 2009).

Table 2.1: Surface, population, population density and % of GDP in agriculture of Belgium, Burundi, DR Congo, Kenya, Rwanda, Uganda and UR Tanzania (AQUASTAT 2009)

Country	Surface (1000 ha)	Population (1000 inh)	Population density (inh/km²)	% of GDP in agriculture
Belgium	3 053	10 430	342	1.01
Burundi	2 783	8 173	294	34.80
DR Congo	234 486	60 644	25	42.50
Kenya	58 037	36 553	63	22.70
Rwanda	2 634	9 464	359	35.60
Uganda	24 104	29 899	124	29.00
UR Tanzania	94 730	39 459	42	45.30

As of January 2006, the Rwandan government reorganized the administrative division of the country. Rwanda now consists of five provinces and 30 districts, each district being divided in separate sectors. Many of the old district names have changed as well. For convenience we will use the old names and indicate the new ones between brackets. Prior to 2006, Ruhengeri, Butare and Kibungo all were province as well as city names. The city names have changed (Table2.2). Following the reduction in the amount of provinces, the new names no longer indicate provinces, but districts.

Table 2.2: Change of administrative division

Prior to 2006 Province name		Today District name
Butare	=>	Huye
Kibungo	=>	Ngoma
Ruhengeri	=>	Musanze

2.2 Climate

Since Rwanda is located near the equator and its altitude is relatively high, its climate is best described as sub-equatorial.

2.2.1 Rainfall

Rwanda is a tropical country, located close to the equator. It receives much rainfall, but rains can be erratic, especially in the East (Verdoodt & Van Ranst 2003). Rains are concentrated in two rainy seasons, as a consequence some crops can complete two cycles per year. Four different seasons are present:

- Short rainy season: mid-September to the end of December (30% of annual rainfall)
- Short dry season: January to February (22% of annual rainfall)
- Long rainy season: March to May (48% of annual rainfall)
- Long dry season: June to mid-September

(AQUASTAT 2005)

In figure 2.2 it is seen that rainfall patterns follow a South-North orientation, with highest rainfall in the Western Highlands and lowest rainfall in the Eastern lowlands.

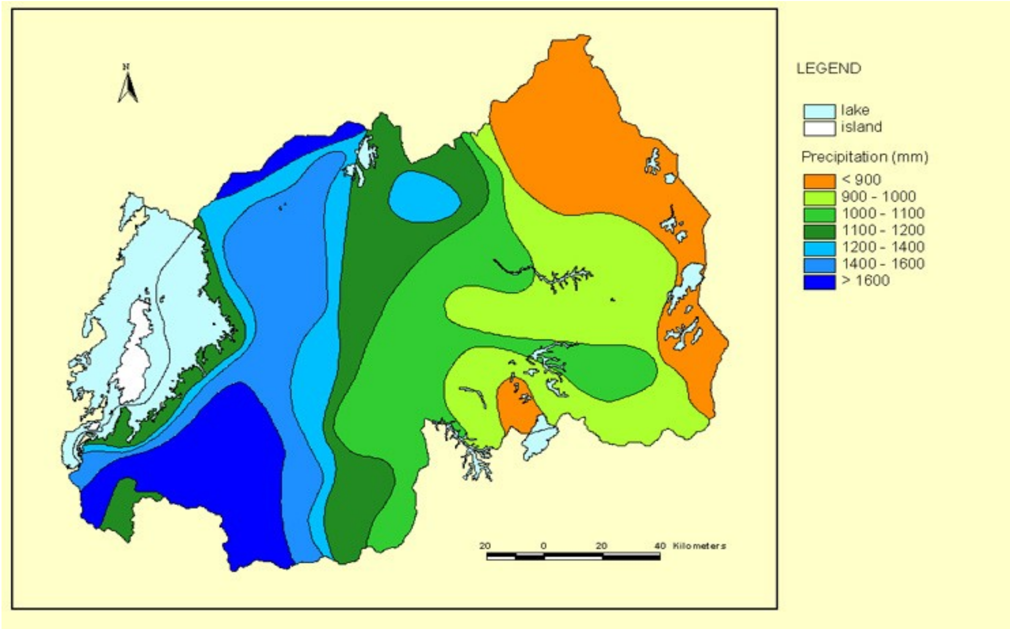


Figure 2.2: Average annual rainfall distribution (Verdoodt & Van Ranst 2003)

2.2.2 Temperature

Temperatures vary little throughout the year, but diurnal fluctuations can exceed 12°C. Average temperatures are strongly linked with altitude. The high altitude regions have the lowest average temperature, ranging between 16-17 °C. The central plateau has average temperatures of 18-21°C and the highest average temperatures of 20-24°C are found in the Eastern Plateau and the Western lowlands. Average temperature distribution is seen in figure2.3.

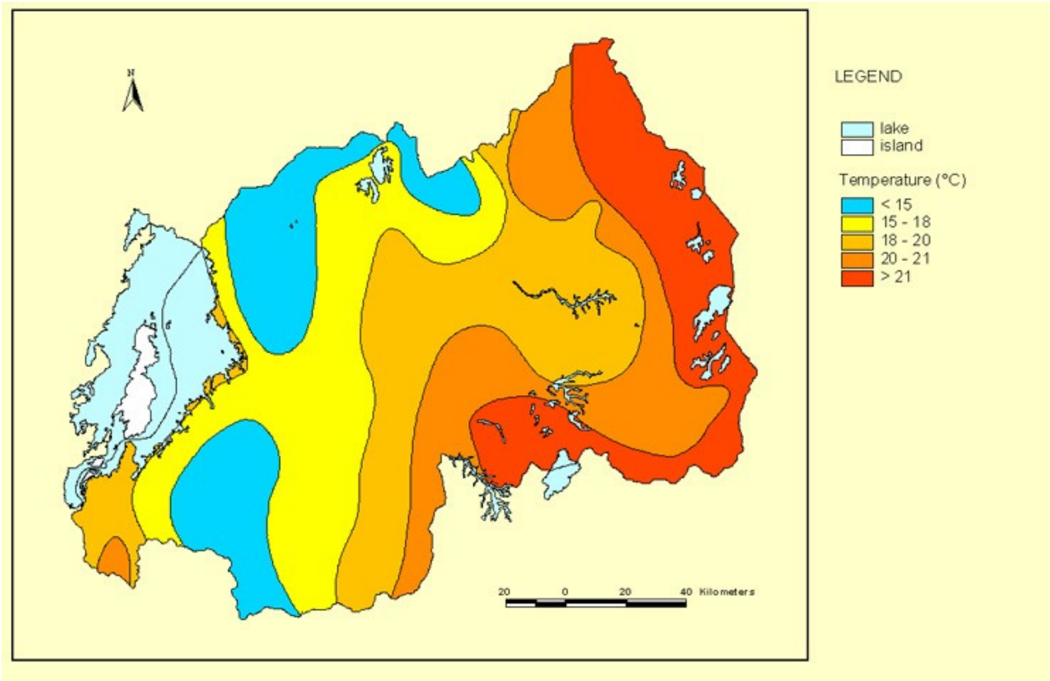


Figure 2.3: Average temperature distribution (Verdoodt & Van Ranst 2003)

2.3 Agro-climatic zones

Taking into account rainfall, average temperature, length of the growing season, soil temperature and moisture regime, 10 agro-climatic zones are delimited in Rwanda. The three sites considered in the present study (Butare, Kibungo and Ruhengeri) are each located in a different ago-ecological zone. It is observed that zones have a North-South orientation (Fig2.4).

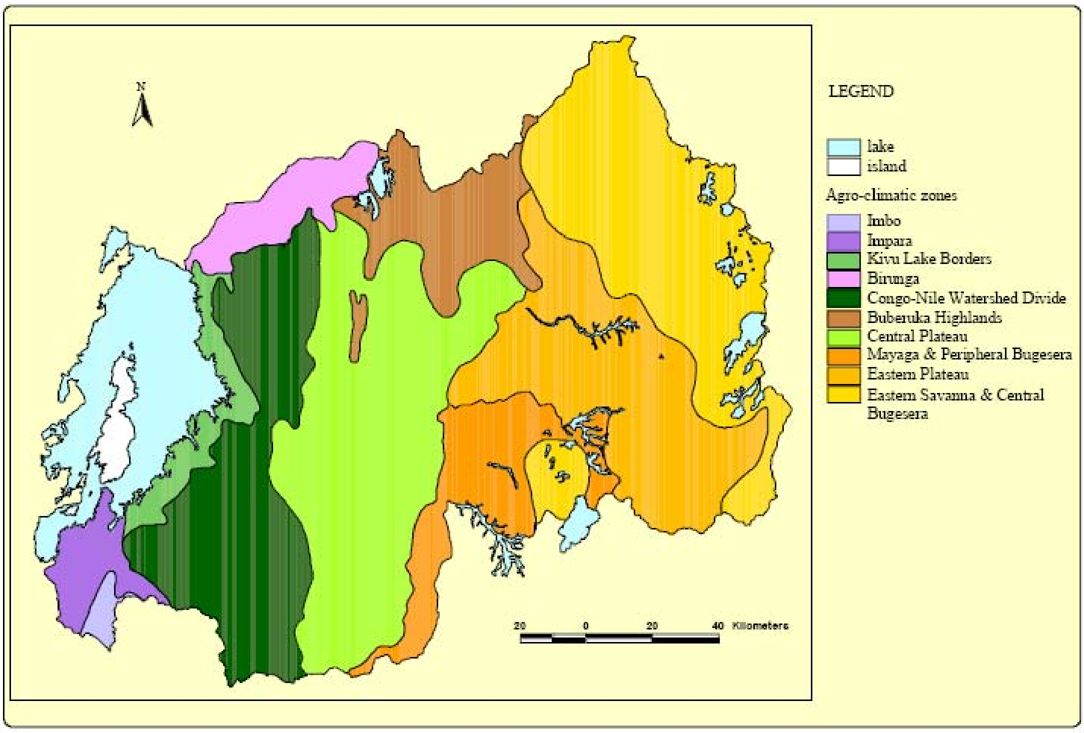


Figure 2.4: The 10 agro-climatic zones of Rwanda (Verdoodt & Van Ranst 2003)

2.4 Soils

The soil types of Rwanda are derived from rock degradation of one of the following basic rock types: schist and quartz, gneiss and granite or they are volcanic soils. Soils are subdivided in 5 types:

- Derived from schist, sandstone and quartz
- Derived from granite and gneiss
- Derived from basic intrusive rocks
- Alluvium and colluvium
- Derived from recent volcanic material
- Derived from old volcanic material (Ministry of lands resettlement and environment, 2003)

Since fertilizer application rates are very low in Rwanda, the chemical properties of the underlying rock formations are very important for soil fertility.

2.4.1 Soil capability classes

Verdoodt and Van Ranst (2003) divided Rwanda in 8 soil capability classes, taking into account: soil depth and stoniness, parent material, risk for flooding, internal drainage, development stage and base saturation. The rational behind this classification is that soil suitability is the major factor in determining suitability of a given field for cultivation. These classes illustrate the general capability of a land unit for agricultural use. The classification criteria are based on the range of crops that can be cultivated and the importance of conservation practices required. Verdoodt and Van Ranst (2003) made a division between actual capability classes and potential capability classes and dominant and associated soil types. We will only deal with the actual capability classes of the dominant soil types. For a more detailed discussion the reader is referred to Verdoodt and Van Ranst (2003).

It is observed in table2.3 that 45% of Rwandan territory is classified in soil capability class 7, hence not suitable for agriculture unless very carefully managed. Class 1, 2 and 3 cover 25% of Rwandan territory and are generally well suited for most crops. The spatial distribution of the suitability classes is depicted in figure2.5 It is observed that no clear north-south orientation prevails but a certain zonation can be observed. Capability class 7 dominates in the western part of the country, followed by class 4 in the central-south. In the eastern part of Rwanda class 2, 3 and 5 dominate (Verdoodt and Van Ranst 2003).

Table 2.3: Soil capability classes of Rwanda (Verdoodt and Van Ranst 2003)

symbol	*capability classes* *description*	*area (km²)*	*(%)*
1	very suitable for most crops; unsuitable for tea; valleys are potentially suitable for irrigated rice	1	<1
2	very suitable for most crops; marginally suitable for tea; valleys are potentially suitable for irrigated rice	1,078	5
3	suitable for most crops; marginally suitable for tea; valleys are potentially suitable for irrigated rice	4,578	19
4	marginally suitable; deep soils are very suitable for tea; marginally suitable for low demanding crops; actually unsuitable for demanding crops	3,524	15
5	suitable for pasture, valley cropping during the dry season, irrigated rice and eventually tea	1,074	5
6	suitable for pasture; actually unsuitable for crops; potentially suitable for low demanding crops after exceptional management	2,358	10
7	suitable for forests; actually unsuitable for crops; potentially suitable for low demanding crops after exceptional management	10,469	45
8	land with serious limitations	404	2
total		*23,487*	*100*

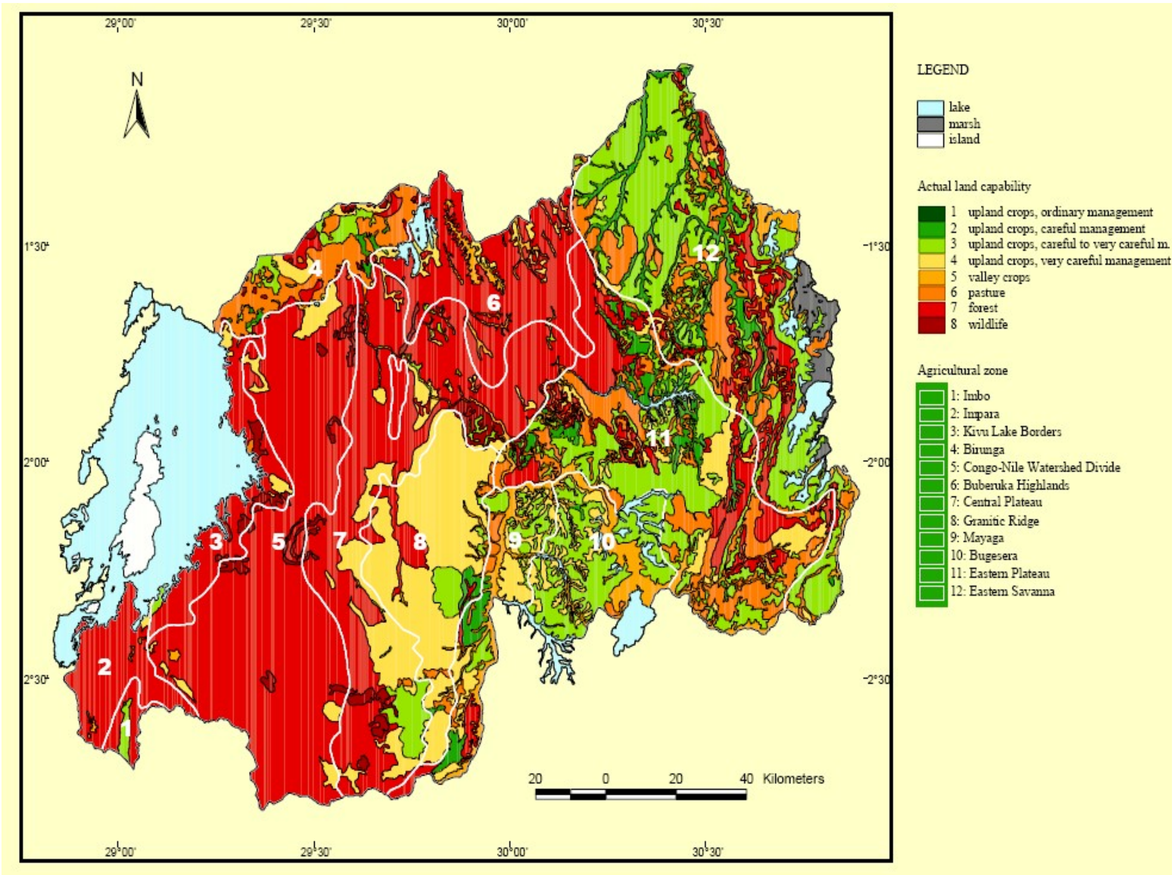


Figure 2.5: Actual capability classes of dominant soil types in Rwanda (Verdoodt and Van Ranst 2003)

3. Agriculture in Rwanda

3.1 Land use

The total surface of Rwanda is 2 634 000 ha, of which 1 475 000 ha are in agricultural use (AQUASTAT 2005). These figures are a bit higher than the ones found in the report of MINAGRI (2003). Which states that of all the land used in agriculture 74% is cultivated, 14% is in use as pasture and fallow, 7% are woodlots and 5% is in other use (Fig3.1).

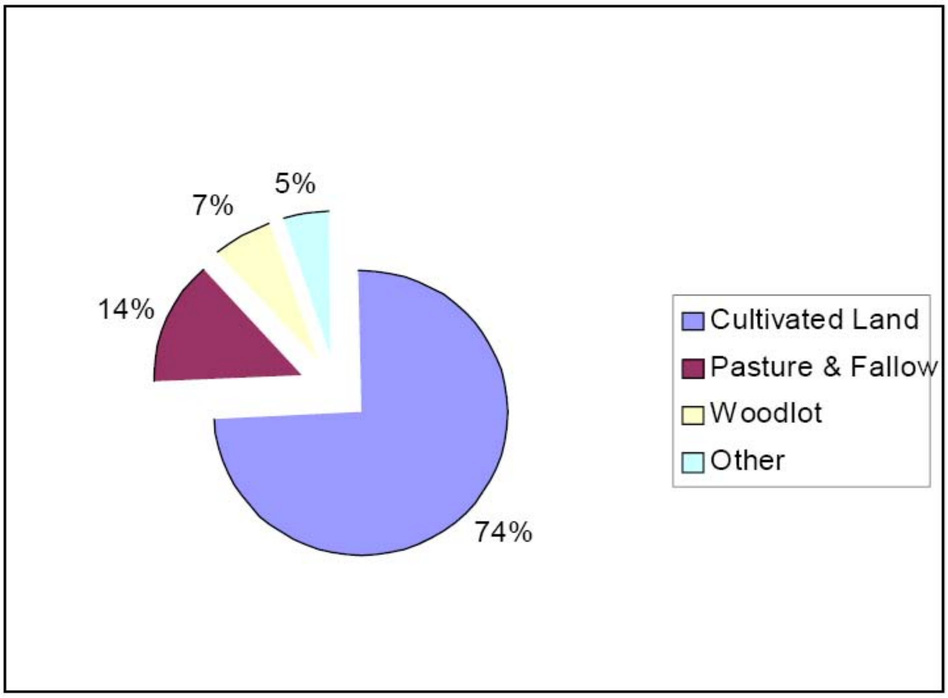


Figure 3.1: Land allocation in agricultural use in Rwanda (MINAGRI 2003)

The main crops grown are:

- banana, beans, sorghum, cassava and sweet potato in the low and medium lands
- beans, maize, sweet potato and Irish potato in the highlands (AQUASTAT 2005)

All crops are usually grown in complex intercropping systems and rotations. The cultivated area per crop is represented in figure3.2. It is observed that bananas take up 20% of the total cultivated area.

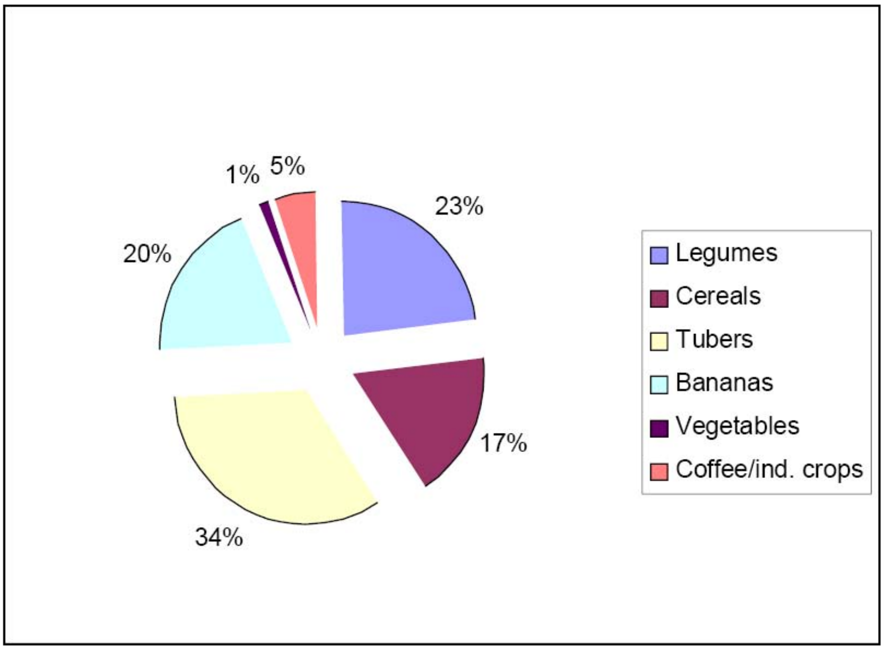


Figure 3.2: Crop distribution by area (MINAGRI 2003)

However banana is not the most cultivated crop in terms of surface allocation, as legumes and tubers cover a greater surface, 23% and 34% respectively (Fig3.2). Cereals make up 17% of the total surface, the remaining 6% is planted with industrial crops and vegetables. However, on a fresh weight basis, bananas contribute more than 50% to total Rwandan production (CIALCA 2008a). Banana are important as they produce year round thus improving food security. Bananas also have important soil conserving properties, which is extremely important in an undulating country as Rwanda. It is mentioned by Lufafa *et* al. (2003) that erosion is 30% lower in fields cropped with bananas compared to annual cropped fields. However they also state that soil coverage is more important than canopy coverage. Thus mulching in banana plantations is an important aspect of their soil conservation properties. Bananas also play a very positive role in the formation of organic matter.

3.2 Economical importance of agriculture

An important characteristic of subsistence farming is the lack of regional and individual specialization, a weak integration between agriculture and the economic markets and an important dependence on climatic conditions (Verdoodt & Ranst 2003). All countries in the region, including Rwanda rely heavily on agriculture, with up to 45% of GDP depending on it. In contrast in Belgium, an industrial country, agriculture is negligible in terms of GDP (Table 2.1). Rwandan export profits are mainly made from agricultural commodities (71%), with tea and coffee contributing 38% and 26% respectively (MINAGRI 2004).

Agriculture employs 90% of the total active population in Rwanda, 66% of their production is for auto-consumption and is realized on farms with an average surface of 0.76 ha (MINAGRI 2004). It is further noted that in 2002, 60% of Rwandan population lived under the poverty line, most of these households are found in rural areas. Most agricultural production is for auto-consumption and is not sufficient to feed the total population. Hence direct food aid and imports are necessary (AQUASTAT 2005). This is also reflected in Fig3.3, Fig3.4 and Fig3.5 which shows the percentage of kilocalorie, proteins and lipids requirements covered by home production in the different regions of Rwanda. It is observed that only the Eastern part of the country is producing enough kilocalories and proteins for self consumption, and that lipid production is too low in the entire country. The north of the country is not producing enough of any of the three variables. The western part is also not producing enough for self reliance but is producing more than the north (MINAGRI 2002).

In 1996, 34% of households were female headed, of which 21% were widows. On top of that 11.5% of households are landless.

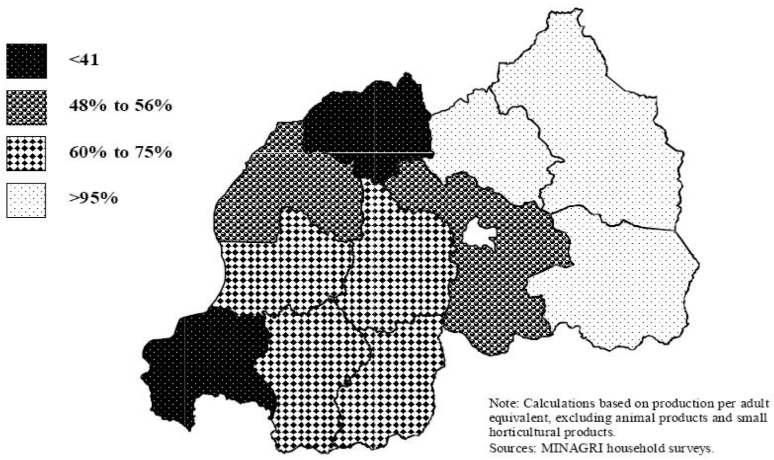


Figure 3.3: Percentage of Kilocalorie requirements met through own production per province (MINAGRI 2002)

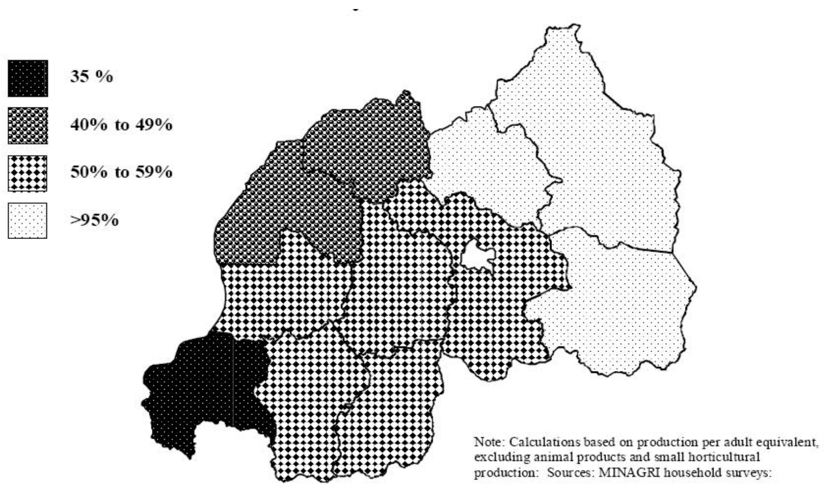


Figure 3.4: Percentage of proteins requirements met through home production per province (MINAGRI 2002)

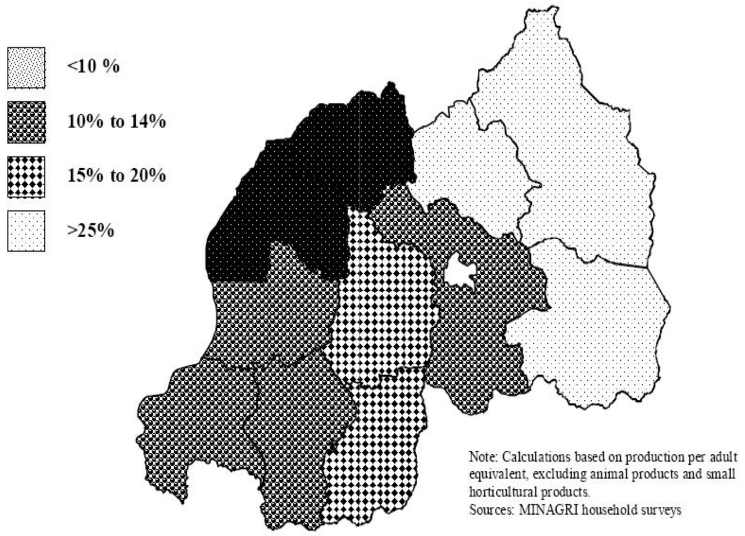
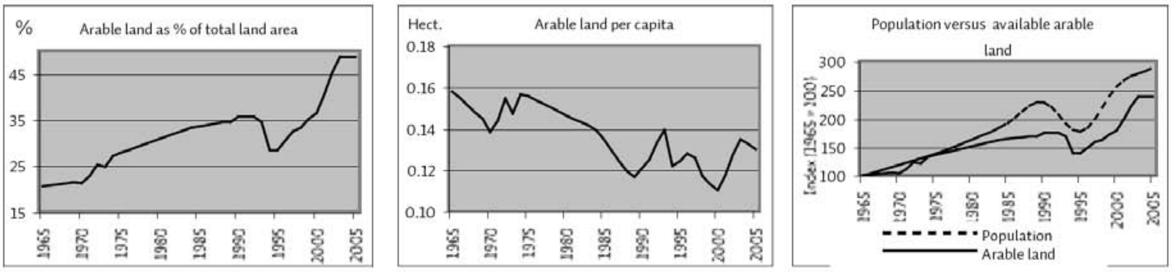


Figure 3.5: Percentage of lipid requirements met through home production per province (MINAGRI 2002)

3.3 Field surface versus yield

Land used in agriculture in Rwanda has continually increased over the past 40 years (Fig.3.6a), with a temporal decrease due to the nationwide outbreak of violence about 15 years ago. The increase in arable land is due to the rising population (Fig.3.6c), which forced people to expand the area under agriculture. Until now land expansion remained possible, but an ecological boundary is now being encountered (Fig.3.6a), as since 2004 the total cultivated land has not increased. Although arable land increased, a declining trend can be observed in the arable land per capita (Fig.3.6b), indicating that farm size is decreasing and people now dependent on less land. As land became scarcer, land expansion went hand in hand with intensification of cropping strategies (Fig.3.7a), which resulted in higher land productivity. This evolution was offset by the country wide outbreak of violence in 1994. The absence of an economical sector that can absorb extra labor implies that farmers can not employ labor outside their farm. Extra labor due to higher land productivity is spent on the farm. As a consequence labor productivity did not rise over the years (Fig.3.7b). The fact that people became dependent on less and less land, implied that food production per capita has actually decreased (Fig.3.7c). These figures suggest that a sound agricultural policy is needed to improve land and labour productivity and food production per capita (Ansoms *et al.* 2009).



a b c

Figure 3.6: Arable land as % of total land, arable land per capita and population versus arable land (Ansoms *et al.* 2009)

a b c

Figure 3.7: Land productivity, labour productivity and food production per head (Ansoms *et al.* 2009)

Land ownership in Rwanda is very unequal; in 2000 the per capita land ownership had a Gini coefficient of 0.52. Fig.3.8 illustrates the Rwandan land productivity in the local currency (Rwandan francs, Frw) and Kilocalorie (Kcal) per hectare. It is seen that smaller farms are more productive, and that productivity starts rising again once farms are larger than 2.1 ha; however, they are not as productive as smaller farms.

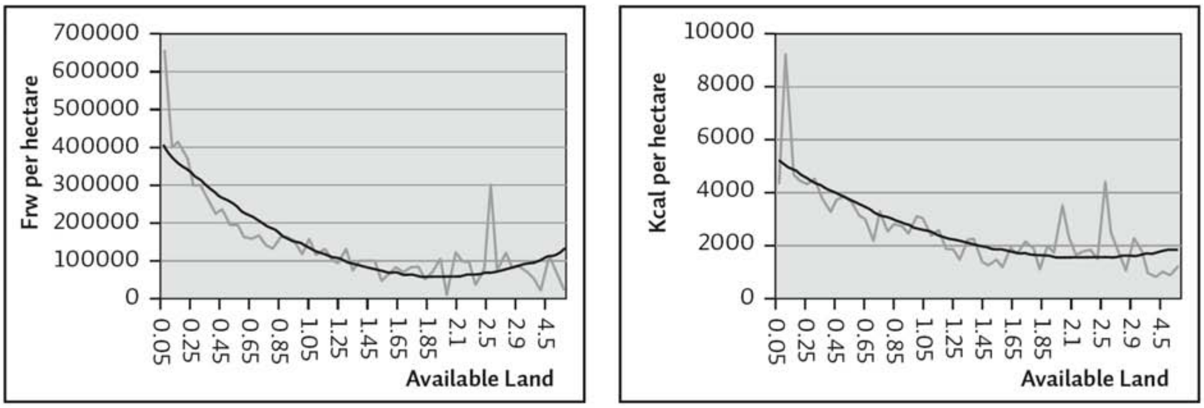


Figure 3.8: Rwandan land productivity in Rwandan francs (Frw) and Kilocalorie (Kcal) per ha (Ansoms *et al.* 2009)

The relationship between farm size and productivity depicted above is not universal. Indeed, larger farm size can also be linked with a raise in productivity; this is due to improved management of land quality, reduced secondary cultivation costs (e.g. fencing, transportation) and changes in crop choice due to improved conditions of cultivation (e.g. irrigation). It is also suggested that the inverse relationship between farm size and productivity will not hold in a modernized agriculture, were mechanization and irrigation are applied.

But smaller farms can be more productive due to the fact that large farms owners have enough alternatives to earn their living. As land is relatively abundant to them, they have no incentives to exploit it to the maximum. Smallholders on the other hand might overexploit their land to meet their needs.

The current Rwandan agricultural policy is based on land consolidation. It attempts to prevent division of fields smaller than 1 ha. It attempts to create favorable conditions for private investment and to entrepreneurship and employment development in agri-business, hence it supports commercialization of agriculture (MINAGRI 2004). Farm concentration, regional specialization in certain crop types, and the abandonment of multicropping, in favor of monocropping are supported policies. At this point however, it is doubtful if large scale farmers are indeed more productive than smallholders (Ansoms *et al.* 2009). As the Habyarimana regime before them, the current regime attempts to improve food security by discouraging the production of beer bananas (Verwimp 2002). Okech *et al*. (2005) suggest that marketing aspects of the cultivation of beer bananas are not dearly considered. Indeed factors that have influenced the spread and increasing importance of brewing bananas appear not to have been given due consideration and attractive alternatives to brewing bananas have not been offered to farmers. Annual crops have failed to replace brewing banana because they provide seasonal rather than year-round income, are less profitable than brewing banana and have limited markets in some areas (Okech *et al.* 2005).

3.4 Farming systems

Most agricultural production in sub Saharan Africa is carried out by subsistence farmers under shifting cultivation, fallow systems and permanent upland cultivation. The former two systems are characterized by a low population density and enough land reserves that allow a fertility restoring fallow period. In Rwanda on the other hand, with a population density of 359 inh/km² land is a limiting factor in production, and production increases by fertility restoring measures during fallowing is becoming impossible. As a consequence, fallow periods shorten or completely disappear, and combined with the lack of inorganic fertilizers results in declining soil fertility and yields.

Agricultural practices in Rwanda can best be described as permanent upland cultivation, combined with wet-valley-bottom cultivation, both of which are at the subsistence level and without modern management practices. In modern western agriculture, irrigation, pesticide and fertilizer use allow for a better control of the plant environment and hence reduce risk and increase yield. Western farmers alter the natural environment to improve plant performance. In most of Rwanda such inputs are absent and hence farmers adapt their cropping practices to the prevailing biotic and abiotic conditions. Three main sources of variation in the spatial organization of cropping are observed: distance to the homestead, position along the catena and differing micro-climates:

- distance to the homestead: is reflected in a fertility gradient, since household refuse and manure are more applied to plants close to the homestead. Hence fertility and yield decreases with distance from the house.
- position along the catena: soils vary along the catena and hence suitability for cropping varies, hence types of crops and mixture of crops vary within the catena.
- micro-climate: the amount of rain, sunlight, land gradient and danger of wind damage or flooding cause as well diversification of cropping.

A further feature of permanent cultivation systems is the variety of forms in mixed cropping, relay planting, and rotations (Ruthenberg 1980):

- Mixed cropping and relay-planting (phased planting): implies planting of several crops in the same field. This enhances soil coverage, maximizes light interception and diversifies production.
- Crop rotations: breaks disease and pest cycles and allows the planting of crops under the most favorable conditions. Crop rotations with legumes also improve the nitrogen content of the soil. In the case of intercropping with bananas, beans will be harvested and bananas will be left standing, so the banana cycle will continue undisturbed.
- Adapting cropping to drought risk: implies adapting the planting date of a given crop to the beginning or ending of the rains. In general, farmers will plant too late in order to be sure to have sufficient water for germination. Too late planting incurs more soil erosion and loss of mineralized nutrients. This does not really apply to bananas, since they are perennial crops.
- Combining upland annuals with perennials and wet-valley-bottom cropping. In the case of Rwanda this implies the cultivation of rice in the valleys and more drought resistant crops on the hill slopes.

Subsistence farming also needs to fill in other needs of the family than just maximal banana production. Since a diversified diet is preferred, intercropping will prevail. This implies that bananas will be interplanted with different crops, which will in turn influence the optimal planting density and leaf area index (LAI).

3.5 Banana production & consumption in Rwanda

Total banana production in Rwanda is estimated at 2.65 MT/year, that of Uganda is 9.68 MT/year and that of Burundi 1.54 MT/year (CIALCA 2008a). Consumption is one of the highest in the great lakes region and is estimated at an annual per capita consumption of 258 kg. About 80% of Rwandan households produce bananas. The average agricultural enterprise consists of 50% tubers, 30% bananas and 20% legumes, cereals and vegetables. Although Rwanda ranks among the top 20 banana producers in the world, a lot of bananas are imported as well, mainly from Uganda, Tanzania and the DR Congo. This is partly due to falling productivity as a result of banana diseases and demographic pressure which has led to land fragmentation and deterioration of the natural resource base (CIALCA 2008a). In general, beer bananas cover 64% of the banana surface, cooking and dessert bananas occupy 30% and 6% respectively (Okech *et al*., 2005). This distribution varies according to region .

4. Banana

4.1 Morphology

An adult plant consists of a corm with suckers, a pseudostem with leaves and carries a bunch. The other morphological parts are shown in figure4.1.

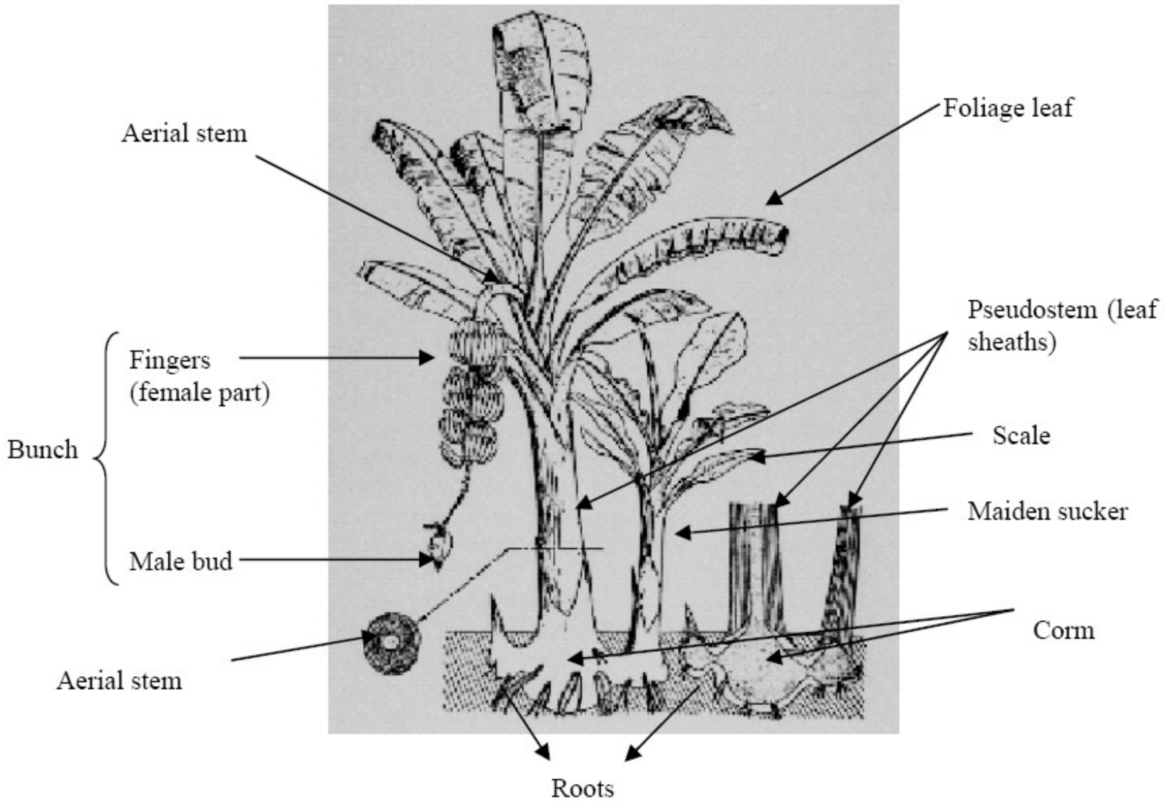


Figure 4.1: Banana morphology (Champion 1963)

After harvesting the bunch, the adult plant dies, and new suckers emerging from the corm will mature and produce new bunches. Cultivated bananas are parthenocarpic, and can only be reproduced vegetatively.

4.1.1 Roots

Main functions of banana roots are nutrient uptake, anchorage and water uptake. As such root architecture greatly influences plant vigor and yield. There exists a strong correlation between shoot and root growth traits. Hence management practices such as mulching, which enhances soil organic matter and root ramification also improve yields (Blomme et al. 2006a).

Roots emerge in groups of 2 to 4 from primordia in the inner edge of the corm. Roots are divided in primary, secondary and tertiary roots. The primary or cord roots are longer, thicker and longer living, than the secondary roots emerging on them, the secondary roots in turn give rise to tertiary roots. This implies that cord roots play a very important role in determining distribution of lateral roots in the soil. This greatly influences the sorption area, as it is believed that lateral roots are responsible for most of the root uptake.

In one of the few articles dealing with East African highland bananas, Sebuwufu *et al.* (2004) reported, that genotype and soil depth are significant factors in explaining root concentration. It was also reported that there are no differences in root density at 30, 60 or 90 cm away from the mother corm. Within the EAHB group, significant cultivar differences in root dry weight are present.

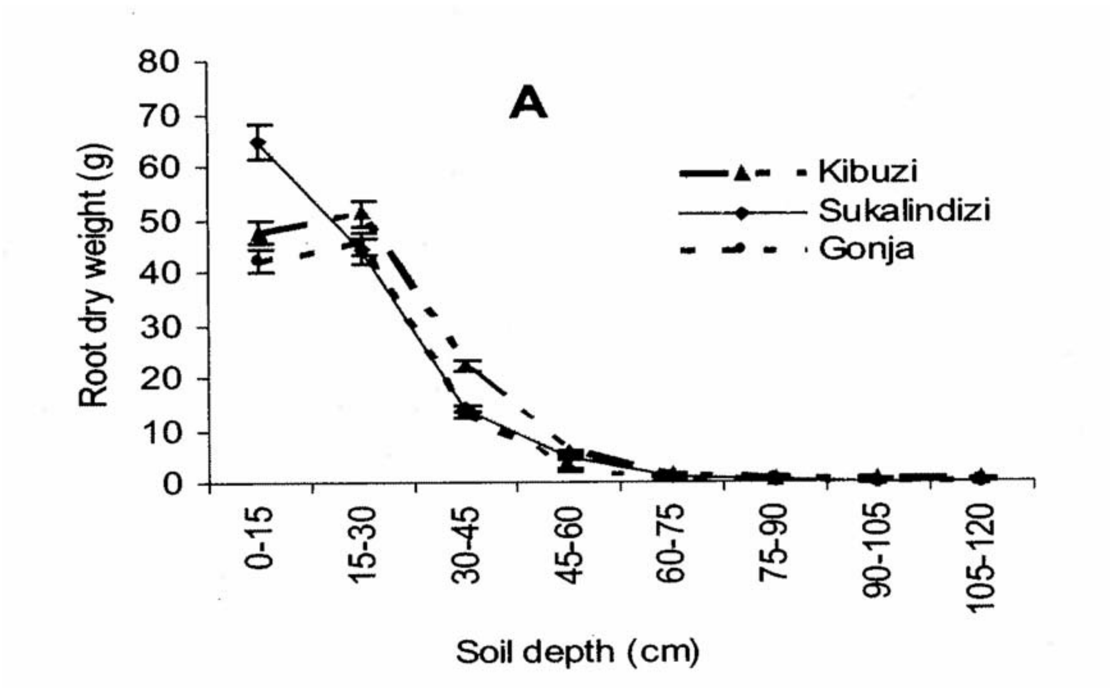


Figure 4.2: Root dry weight at different soil depths for 3 East African highland bananas (Sebuwufu *et al.* 2004)

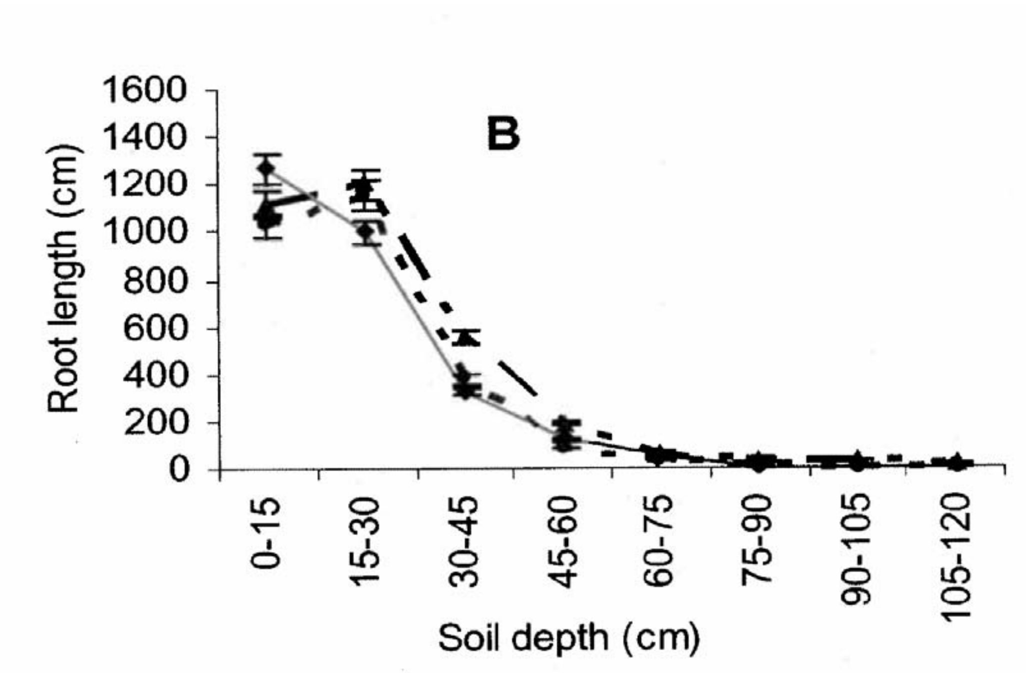


Figure 4.3: Root length distribution according to soil depth (Sebuwufu *et al.* 2004).

Fig.4.2 shows that roots are concentrated in the upper 30 cm of the soil. The depth up to which roots occur is strongly dependent on soil type and drainage. It is observed in Fig.4.3 that cord root length of East African highland banana in the upper soil layer varies between 1 and 1.4 m. Blomme *et al.* (2000) report that a healthy corm can bear 200 to 400 cord roots, with a total length of 230 m. In another study Turner *et al.* (2007) state that cord root length extends 2 to 3 m, but may reach up to 5 m away from the mother corm. It is suggested by Blomme *et al.* (2006) that a good distribution of roots near the corm supports vigorous growth of the plant, given that nutrients are not limiting. This has great implications for optimal planting density. If plants are planted too close, root zones overlap and plants compete for nutrients.

4.1.2 Leaves and leaf area index

The leaf is the source of primary production in a banana plant. Light is captured and carbohydrates are formed and transported to the rest of the plant. Environmental, edaphic and ontogenic factors influence leaf size. Banana leaves are very hydrated tissues, regardless of soil moisture content. They counter dessication by closing their stomata. The stomata are the primary sites for gass exchange in banana plants, and hence the greatest water evaporation from the plants to the atmosphere occurs via the leaves (Turner 1998).

The rate of appearance of new leaves is a measure of development in bananas and plantains and is governed by temperature and plant ontogeny. The leaf lamina size will change through the four main stages of banana development: peeper, sword sucker, maiden sucker and adult plant. A peeper will have no leaves, a sword sucker will have scale leaves, followed by laceolate leaves. New emerging leaves will gradually become broader (Fig.4.4). In the end fully laminated leaves form the canopy (Blomme *et al.* 2008). Maximum leaf area of the plant is obtained during the emergence of the inflorescence. Bunch formation is preceded by the formation of 30 to 50 leaves but a plant can only have between 10 to 14 living leaves at a time. After the emergence of the inflorescence, no new leaves are formed (Turner *et al.* 2007). Stover and Simmonds (1987) (cited by Turner 2003) state that leaf area increases exponentially up to leaf 30, after which it stays practically constant up to leaf 42. The last leaves emerging before bunch formation are smaller than their predecessors.

Kumar *et al.* (2002) and Turner (2003) have formulated different methods to estimate the total leaf surface of banana plants. Both methods encountered difficulties because of the change from exponential to constant leaf area increase. In the current study it is assumed that the middle leaf is representative for all leaves. When the LAI (leaf area index) was calculated, a distinction was made between plants taller than 2 m, plants between 1 and 2 m, and plants smaller than 1m. It is assumed that leaves of plants taller than 2 m will have a constant area. The discrepancy in leaf area in plants between 1 and 2 m is not accounted for. However they make up a smaller part of total LAI. It is assumed that plants shorter than 1m have no leaves.

Figure 4.4: Change in leaf lamina shape (Blomme *et al.* 2008)

The leaf area index of a plantation is a measure of the amount of light captured and the amount of carbon fixed by the canopy. The LAI of a single banana plant may vary from 2 to 5. The LAI of a plantation is made up of leaves of plants in different developmental stages.

It was further observed by Turner *et al.* (2007) that in plantations with a LAI of 4.5, 90% of the ground surface is shaded on a sunny day. Thus 90% of radiation will be intercepted from which they conclude that raising LAI above 4.5 will have little effect on production. This contradicts the findings of Robinson & Nel (1989) who state that productivity rose linearly up to a LAI of 5 and peaked at a LAI of 6. In another publication by Robinson & Nel (1989b) it is stated that optimal LAI depends strongly on plantation vigor. They observed an optimum LAI of 3.5 in a low vigour plantation and an optimal LAI of 6.3 in a more vigorous plantation in a different location. Optimal LAI can be obtained through managerial practices such as application of the right density and pruning.

4.2 Bunch weight estimation

It is very hard to measure yields (kg/ha) of perennial crops such as bananas. As they are harvested all year round, bunch weights are seasonally dependent and length of the growing cycle is highly variable. One should in principle be continually present in the field to weigh all bunches at harvest. Alternatively farmers could also weigh their bunches but many are illiterate. Also literate farmers will usually produce higher yields as they are more open for innovation. Farmers might also overestimate their production when they are refunded for it. In order to avoid these biases, Wairegi *et al.* (2009) worked out a non-destructive way to estimate bunch weights. This allows for a rapid appraisal of bunch weights in the field. The details of the formula are found in the material and methods section.

From a plant physiological point of view it is important to include source sink relationships in bunch weight estimation formulas. The sources (typically mature leaves) are the sites where carbohydrates are produced, and the sinks are the sites in the plants were these are used in the metabolism. Sites where sugars are stored can act as a source or as a sink, depending on the growth stage of the plant. Carbohydrates will move through the plant from the sources to the sinks. Bunches are always sinks (Dens *et al.* 2008). Swennen and De Langhe (1985) estimated source size by the length of the pseudostem. Their study was executed in a humid tropical station in Nigeria, on plantains (AAB). The formula proposed by Wairgie *et al.* (2009) uses the volume of the pseudostem from ground level to 1m of height as an estimation of source size. Swennen and De Langhe (1985) also found that date of flowering and the number of fingers were significant factors in determining bunch weights.

4.3 Classification

Bananas are monocotyledons and seeds are only found in wild varieties. They belong to the family of *Musaceae*, genus *Musa* and *Ensete.* Modern varieties are derived from hybrids of the wild subspecies *Musa acuminata* (A genome) and *M. balbisiana* (B genome). The wild bananas occur within the tropics from India to Oceania but there is an overlap in the distribution of *M. acuminata* and *M. balbisiana* (Turner *et al.*, 2008). In general *M. balbisiana* is considered more drought and disease resistant, than *M. acuminata*. This may have a major influence on the genotypes grown in a particular region. If sufficient varieties are present, the AAB and ABB varieties tend to be grown in more arid regions (Gowen 1995).

The original wild banana varieties were diploid and produced seed. Early man selected plants with much pulp and little seeds. Thus accumulating genes for pulp production, these fruits were preferred, so they were reproduced vegetatively. The end results were edible, fairly sterile and parthenocarpic (development of fruit without pollination) varieties. Further crossing between wild varieties and these domesticated varieties resulted in triploid varieties, which are more vigorous and produce even bigger fruits with even less seeds (Fig.4.5).

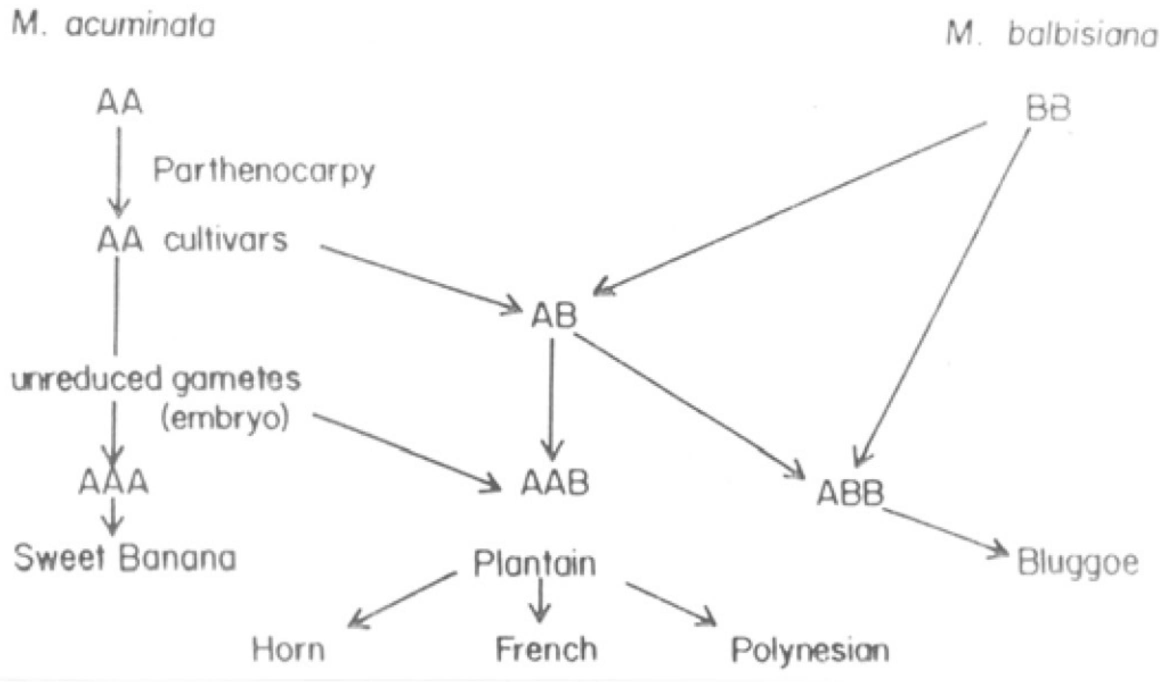


Figure 4.5: Origin of modern banana varieties (Swennen 2008)

In the East African region and especially in the highlands, cultivation is based on AA and AAA varieties, many of them being unique to that region and called East African Highland Bananas (EAHB) (Gowen 1995). As such the region is considered a secondary center of banana diversity. Although many cultivars are grown, little is known about their diversity and distribution in Rwanda (Nsabimana *et al.*, 2008). In Africa AAA cooking bananas and AAB plantains both have a relatively narrow genetic base, which limits possibilities for breeding for disease resistance. Thus the introduction of alien resistant varieties is necessary as well (Gowen 1995).

4.3.1 East African Highland bananas

East African highland bananas are a distinct subgroup in the group of *Musa* spp.. Four divisions are made in East African highland bananas: group, subgroup, clone set and clone (or variety). Five clone sets are distinguished: Beer, Musakala, Nakabululu, Nakitembe and Nfuuka. The distinction between clone sets is mainly based on morphological characters e.g. bunch shape, pulp taste, flower properties etc.... table4.1 depicts the key to identify different clone sets. Nakabululu and Nfuuka are the least distinct clone sets, Nfuuka and Nakitembe are next least distinct to one another. Musakala and beer are most distinct from each other and the other clone sets. A further distinction of the clone sets by agronomic characteristics such as vigour, pest and disease resistance and drought resistance is not yet available. For a more detailed discussion on the classification of East African highland bananas the reader is referred to Karamura (1998)

Table 4.1: Key to identification of different clone sets in East African highland bananas (Karamura 1998)

1	Pulp bitter and astringent, pulp colour before maturity white with brown sticky excretions, pulp colour after maturity cream with brown sticky excretions	**Beer**
	Pulp insipid, pulp colour before maturity white without brown sticky excretions, pulp colour after maturity cream or brownish orange without brown sticky excretions	**2**
2	Mainflorescence rachis with persistent neuter flowers, imbricated male bud, persistent dry or fresh style and at times with persistent dry stamens on fruit apices	**Nakitembe**
	Male inflorescence rachis nude or with semi-persistent neuter flowers, male bud not imbricated, commonly no persistent style or stamens on fruit apices	**3**
3	Bunch orientation subhorizontal, fruits short with length/width ratio less than 3.5 and fruits less than 15 cm long, male buds ovate	**Nakabululu**
	Bunch orientation oblique to pendulous, fruits medium to long with length/width ratio above 3.5 and fruits more than 15 cm long), male bud lanceolate, elliptical, cordate or obovate	4
4	Bunches mainly truncated or cylindrical, very lax with slender bottle- necked fruits	**Musakala**
	Bunches mainly rectangular, compact with inflated or rounded or rectangular fruits with intermediate shaped apices	**Nfuuka**

4.4 Banana uses

Banana plants have many uses, but here we will focus on the use as edible fruit or derived products. Main differences are between cooking types, brewing types and dessert bananas. It is reported by Okech et al. (2005) that there are at least nine ways in which cooking type bananas can be prepared as food. Brewing types are processed into juice or wine and dessert varieties are mainly eaten fresh. It is noted that dessert bananas might be processed into wine as well and in times of hunger, beer bananas might also be eaten. For a more detailed description of the beer production process the reader is referred to Davies (1993).

4.5 Distribution of bananas in Rwanda

In October and December 2000 a survey was executed in four Rwandan banana growing areas (Cyangugu, Kibungo, rural Kigali and Kibungo). Special attention was given to the distribution of beer, brewing and dessert bananas. The findings of the study are presented here.

Although farm gate prices of cooking type bananas are more favorable than for brewing and dessert bananas, brewing type bananas are often preferred. Farm gate prices vary according to distance to markets, prices being lower at longer distances from markets. Banana beer is easily marketed in local markets and bars, hence 80% of beer processing is done at the farm. Bunches easily get spoiled during transport, thus distance to main markets is an important factor in deciding which banana type to grow. This is reflected in the fact that in the Kigali rural region and Kibungo cooking types dominate. Whereas in lake Kivu and the Cyangugu region beer bananas dominate. It is seen in Fig.4.6 that regions where cooking bananas dominate (Kigali rural and Kibungo) are better connected to the main market Kigali. It is mentioned by farmers that beer bananas:

- cope better with harsh conditions,
- withstand poor management practices with reduced input, making it cheaper to produce them,
- have an unrestricted and readily available market,

- have less stringent bunch size requirements than cooking and dessert bananas,
- when processed into beer its value increases, thus profit margins are higher,
- it's products can be stored for a longer time, are more easily transported and are transported at a lower cost (Okech *et al.* 2005).

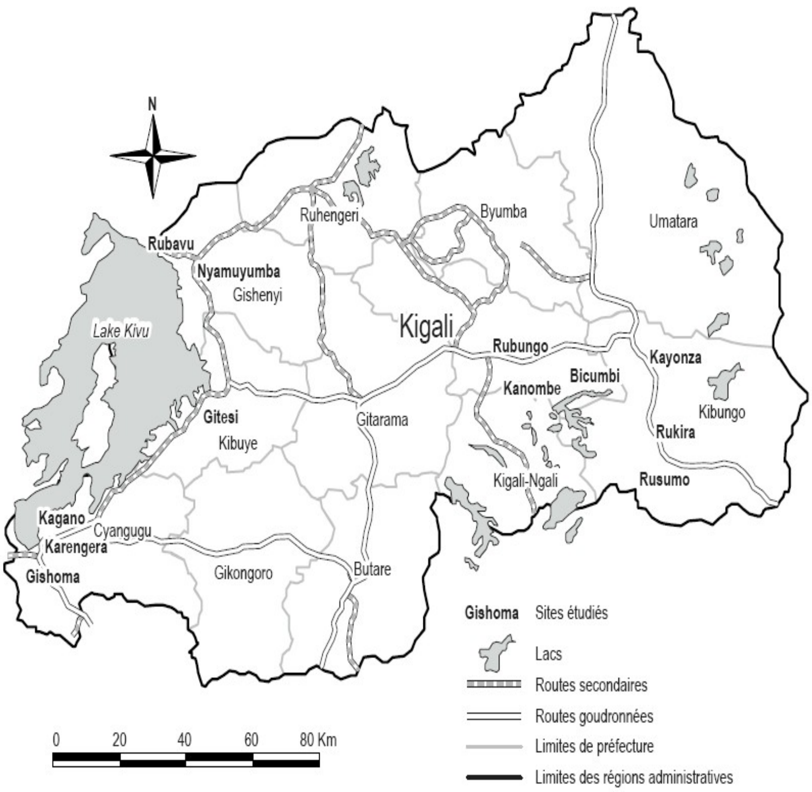


Figure 4.6: Road map of Rwanda (Okech *et al.* 2005)

5 Objectives

5.1 On-farm vs on-station research

The present study was conducted on-farm. Three sites were chosen, each with two replicates, i.e. two villages. Selection of farms was based on a transect through banana growing area's and on the willingness to cooperate of the encountered farmers (see section 8.2.1 site selection). On-farm research is intended to better involve farmers in the design and execution of trials and thus avoiding non-adoption of advanced techniques or varieties, by potential beneficiaries of that research. The objective of applied agricultural research is to identify new farming practices and materials which improve a farmers' production system and increase their productivity and well-being in a sustainable way.

Traditional agricultural research has relied on the transfer-of-technology (TOT) model. Research conducted in this paradigm is concerned with developing technologies and materials which scientists perceive as being important for farmers. Experiments are executed on-station and when the results are positive, these innovations are extended to farmers by extension workers or NGO's. Consequently there is no direct contact between farmers and scientists. This model has proven very effective in raising yields in Western Europe, North America and few well endowed third world countries such as the Indian Punjab. Highest returns are realized in regions where farmers have a relatively uniform environment, effective access to and control over resources, and a well developed infrastructure.

Main beneficiaries are resource rich farmers (RRF), because application of traditional innovations is easier in their production systems, which are very similar to the ones in research stations. So what works well in research stations will work well with RRF as well. RRF are also better in exercising political pressure and mobilizing funds for research.

Resource poor farmers (RPF) on the other hand operate in very different conditions, which hinders adoption of technologies developed far away from their reality and in very different conditions. RPF are unorganized and lack political power to influence the choice of research topics. They have less access to inputs, have less control over the environment, have different objectives than maximal production and apply more complex cropping systems (shifting cultivation, agro-forestry, intercropping etc.).

Methodological characteristics of the TOT approach explain also its lack of success with the RPF. Scientists are mostly not concerned with social consequences of innovations. For example the typical critique on the green revolution is that the yield enhancing effects did not take away inequality problems. As a general rule, scientists are trained in typical linear thinking and textbook approaches of experiments, such as monocropping and block designs, which are incompatible with RPF conditions. In addition this approach thinks that scientific knowledge is superior to traditional knowledge. Personal ambition is to be mentioned as well, as publications and straightforward results will improve a scientist's prestige more than little improvements with many RPF (Chambers & Jiggins 1987).

The lack of success of the TOT model has historically been explained in many ways, however it is only recent that the TOT model itself is criticized. Historical explanations and research responses to the lack of success ranged from:

- blaming ignorant farmers for the non-adoption,
- a change towards the crops and conditions of RPF, for example inclusion of cassava in research,
- modifying the research design to reflect complexity of small farming systems,
- analysis of farm level constraints, to explain the gap between potential and actual yield.

A fifth response developed was farming system research, which differs from TOT. It tries systematically to understand the complexity of total farming systems, and consults all stakeholders. These include the farm household and its needs and objectives, and biological, economic and human dimensions. So a more holistic approach is taken. Typically transdisciplinary teams of scientists join to tackle a given problem.

Main differences between traditional on-station and on-farm research can be summarized as follows. In station trials, the treatment factors are the only variables while anything else is held constant e.g. land preparation, time of planting will be the same throughout the experiment. Therefore, the most important principle of controlled field trials is that 'the non-treatment variables' are applied as uniformly as possible, thereby giving maximum expression to differences due to treatments.

This principle cannot be applied to the same extent in farmer-managed trials. Imposing uniformity would require the choice of uniform fields, planting the crops at a fixed time and at prescribed densities, applying recommended maintenance, etc. In this way, researchers would interfere with the farmers' usual practices to an unacceptable extent. Under these conditions, the technology is certainly not being tested under farmers' conditions and farmer management. Whereas station trials are meant to measure the treatment effect only, on-farm trials should focus on the fact that treatment effect depends on the differences in farmers' management practices. Control over non-treatment variables is then replaced by the observations of farmers' actual practices (Mutsaers *et al.* 1997).

The gains from this non-interference approach are:

- a realistic assessment of technology performance under real farmers' conditions,
- a reduction in the need of supervision.

Main disadvantages are:

- the need for frequent observations of the farmers' management,
- a large number of participating farmers to capture the entire range of variation in management practices,
- the need for more sophisticated statistical analysis.

In the end the ultimate measure of success of an innovation is its adoption by farmers, which in turn depends on their own needs and objectives.

5.2 The CIALCA project

The present study is executed in the framework of CIALCA. The consortium for the improvement of agricultural-based livelihoods in central Africa (CIALCA), is a consortium of three international agricultural research centers (IARC) belonging to the CGIAR: the International Institute of Tropical Agriculture (IITA), Bioversity International and Centro Internacional de Agricultura Tropicál (CIAT-TSBF). It is funded by the Belgian directorate general DGDC. It also incorporates the national agricultural research institutes (NARS) of Rwanda, Burundi and the DR Congo. Several universities among which the Katholieke Universiteit Leuven participate. The mandate areas are DR Congo, Rwanda and Burundi.

The objective of the project is to improve the livelihoods of agricultural-based households, through cooperation between international agricultural research centers (IARC) and national agricultural research institutes (NARS) and to promote exchange of results at the regional level. Agricultural research, concerning the production chain research, density trials, germplasm trials, integrated pest management, soil fertility and erosion, food quality and quantity, post harvest research and fodder production are being executed. The first steps of the project were: mobilizing existing knowledge in the region, followed by a characterization of local farming systems (CIALCA 2007).

5.3 Objectives

Not much research has been executed on planting densities and banana cultivars in Rwandan banana grower fields. In order to be successful, scientific research needs to be combined with an assessment of field realities. Constraints and opportunities as perceived by local banana growers need to be considered. The present study attempts to map banana plant densities in Rwandan banana grower's fields.

It is combined with an on-station density trial, which involves three East African highland bananas in five different densities (1428, 2500, 3333, 4444 and 5000 mats/ha). The on-station trial is executed in the same locations as the present study. More details on methods applied in the current study are found further in the text (see section 8.2 materials and methods). The main objectives of the survey are to assess:

- different planting densities in EAH banana systems,
- how densities vary across ecological gradients and intercrops,

A secondary objective is to assess different varieties present in the surveyed areas.

6. Plant density of bananas in literature

6.1 Introduction

Literature available on the subject of banana plant density will be explored here. A discussion on plant density and competition will be succeeded by an exploration of previous research on planting densities. It is expected that optimal plant density is very dependent on climatic, cultivar, managerial and edaphic conditions.

6.2 Plant density

Plant density is a very important production factor and can hardly be changed during production. Unlike most fruit bearing plants, bananas flower throughout the year and can thus be harvested at any time of the year. Therefore the cycling time between two harvests is an important yield determining factor. To reflect this, yield should be expressed in kg/(ha.year). It is generally accepted that productivity increases with increasing density, but yield gains from increasing density are decreasing (Fig.6.1).

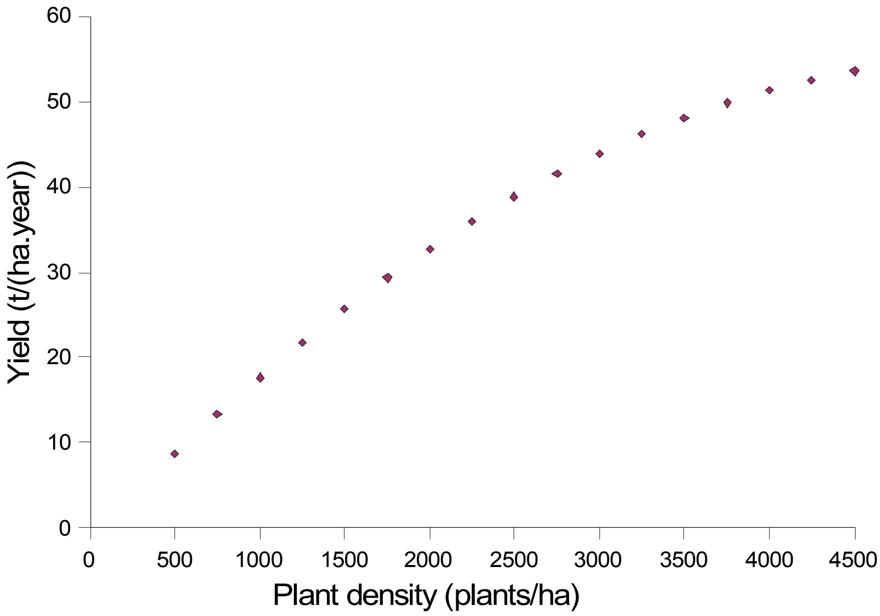


Figure 6.1: A regression curve of Cavendish cv. Williams. Yield (t/(ha.year)) as a function of plant density (plants/ha), Modified from Daniells *et al.* 1985

In the part of the curve up to a plant density of about 2000 plants/ha, resources (e.g. light, nutrients, water, etc.) are not limiting yet. Indeed, every additional plant results in an extra bunch with a weight corresponding to the average bunch weight. At higher plant densities (above 2000 plants/ha) there is increasing interplant competition. From here on additional plants increase cycling time and produce bunches with a weight less than the average bunch weight. Consequently yield (kg/ha.year) increases do not anymore increase linearly with increasing planting densities. Different studies in the past have pointed out that an optimal plant density is heavily dependent on cultivar (Table 6.1, 6.2 and 6.3), climate, soil and desired products.

6.3 Competition

Theoretically an ideal plant density would be one that minimizes interplant competition. This could be achieved by minimizing mutual shading and overlapping of root zones. The increasing interplant competition in higher density plantations is reflected in smaller bunches, smaller fingers, taller plants, longer cycling, smaller girth of the pseudostem and a lower percentage of flowering and harvested plants.

Since it is a lot harder to carry out experiments on underground parts of plants, less literature is available on that subject. Bananas as a monocot have very shallow roots in comparison with other fruit crops. It was reported by Mohan & Rao (1984) who conducted an experiment with Nendran (AAB), Robusta (AAA) & Monthan (ABB) in India that root density increases with planting density. They do not advise on optimal planting density however.

Taking into account that roots can grow several meters away from the mother plant and that leaves can grow up to 3m the ideal spacing to completely avoid interplant competition would be around 6m. Of course the best treatment for individual plants is not necessarily the best treatment for the plantation as a whole. Diminishing marginal returns to individual plants can be combined with increasing marginal returns to the plantation as a whole (Fig.6.1).

6.4 Density trials in literature

A literature review was made and 39 articles identified dealing with planting densities in bananas and plantains. Planting densities varied between 1000 and 7000 plants/ha (Fig.6.2 and Fig.6.3). However it was not always clear whether the authors referred to the number of plants per ha or the number of stools or mats per ha, a stool or mat being a group of plants all on one location and coming from one sucker (Fig.6.4). It can also be seen in Table6.1, 6.2 and 6.3 that a wide variety of spacings and configurations (Triangular, rectangular, in double rows etc...) exists.

In commercial plantations such a distinction in the definition of a mat or stool is usually unnecessary, since every mat is left with one adult plant, one follower and young sucker, jointly considered as one mat or even one plant per ha. Our graphs show that the yields vary from 10 to 110 t/ha for dessert bananas and from 0.5 to 70 t/ha for plantains. This stresses the enormous variation in yield encountered across different banana varieties, and growing conditions but also the potential to obtain very high yields under optimal managerial practices and favorable climatic conditions.

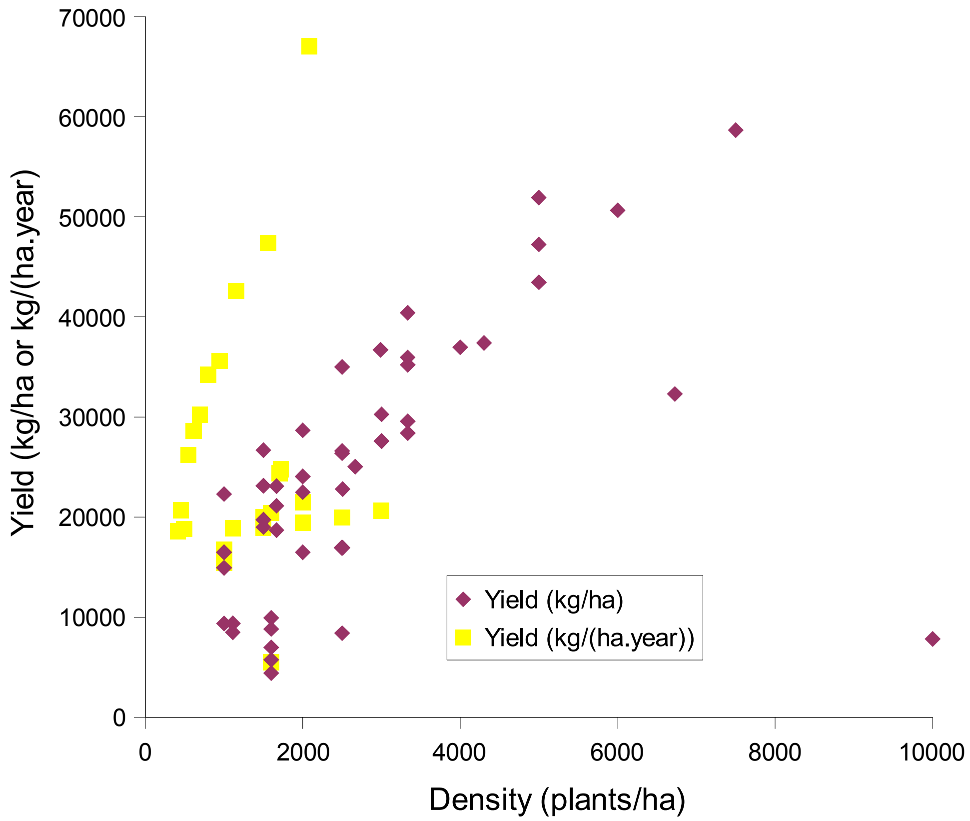


Figure 6.2: Planting density and yield of plantains (AAB group) based on a literature review

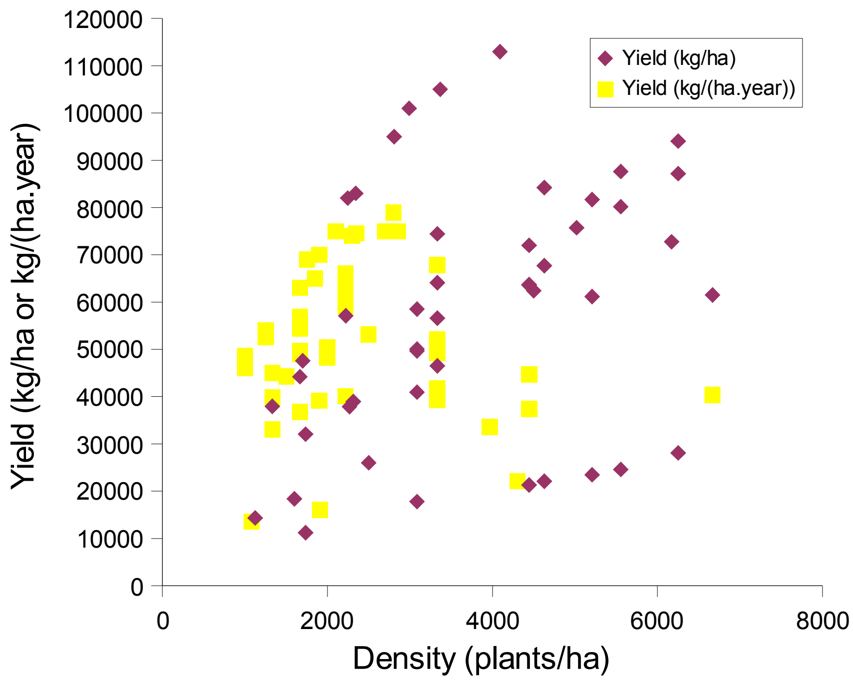


Figure 6.3: Planting density and yield of sweet bananas (AAA) based on a literature review

Figure 6.4: Different mats in a banana plantation

Fig.6.2 and Fig.6.3 show that dessert bananas can produce much more than plantains. This is because dessert bananas are generally better maintained as they are intended for export.

Also dessert bananas benefit from more intensive research and their crop husbandry practices are better known. In addition their harvest index is much superior to plantains. Nevertheless no clear correlation between plant density and yield can be observed (Fig.6.3). If all yields are considered in (kg/(ha.year)), a linear regression indicates a R^2=0.02, which is not significant (0.341). In plantains the correlation is a bit clearer (Fig.6.2) with higher planting densities leading to higher yields. If all yields are considered in (kg/(ha.year)), a linear regression indicates a $R^2=0.346$ which is significant (0.000). The lack or poor correlation in Fig.6.2 and Fig.6.3 can be due to different managerial practices and different climatic and edaphic conditions. Data of monoculture and intercropping are not separated. For example different planting material is used like suckers and in vitro plants, which can influence cycling time of the first cycle. Also the data deal with mostly the first or the first two cycles. This biases the observations towards higher density plantations, since lower interplant competition in the first cycles leads to higher yields. Once the canopy is closed, this effect tends to level off and yields decline. This prompted some authors to suggest bananas should be used as an annual arable crop (Belalcazár 2002).

Of the 39 studies (Table6.1, 6.2 and 6.3), 19 involved dessert bananas, 17 plantains (AAB) and 1 used East African highland bananas (AAA-EA). Two other articles tested varieties like Silk and hybrids, so that these data could not be linked to any other banana type.

Of all banana production worldwide, only 13% is destined for export and deals with Cavendish (AAA) bananas, the export oriented plantations are found mostly in Latin America and the Caribbean. Outside the Caribbean, commercial production is primarily on large plantations, and dominated by vertically integrated transnational trading companies whose activities include production itself but also shipping, importing, ripening, marketing and distribution. The remaining 87% of world production is done by smallholders for subsistence needs or for sale on local markets. Hence export production remains a quite separate economic activity distinct from production for local consumption (Gowen 1995). The importance of dessert bananas for export business might explain why about half of all the reported density trials dealt with dessert bananas. On the other hand 41% of bananas grown world wide are Cavendish, so they are not really overrepresented. On the other hand, only one study investigated East African highland bananas, which is quite striking, since 24% of bananas grown world-wide are East African Highland bananas (AAA-EA) and Cooking bananas (ABB). In East and Southern Africa this percentage rises to 71% (Sharrock and Frison 1999). This type of bananas is clearly underrepresented in the consulted literature. It is clear that the lack of scientific research on East African Highland bananas is due to the fact that these bananas are exclusively grown by smallscale subsistence farmers.

The studies were carried out on all continents favorable for banana cultivation, 11 among them were carried out on the African continent. But only one was conducted in East Africa (Uganda) and this was the only one using (AAA-EA) East African Highland bananas.

Most of the consulted studies applied commercial management practices such as irrigation, pesticide use and fertilization. This is reflected in very high yields and much higher than an East African subsistence framer, without aforementioned managerial practices, can afford. In literature average yields as low as 4 t/ha are mentioned in Tanzania (Gallez et al. 2004), Kagoda et al. (2005) mention average yields of 5.9 t/ha in Uganda and a general average of 6 t/ha is recorded for the whole of Africa (Sharrock and Frison 1999). These African smallholder yields equal the minima of the yields found in the aforementioned studies.

The fact that banana is a perennial crop that produces year round implies that farmers usually apply phased planting. In some cases they will inherit fields already planted with bananas. Farmers will then not easily clear a whole field and replant with a fixed spacing but, rather uproot some old mats and plant new ones in between the older ones. This is because farmers are reluctant to uproot mats even if they are rather unproductive, as clearing results in temporary production losses. This makes the application of an optimal planting density very difficult. In addition, lost stools due to uprooting or diseases are often compensated by allowing neighboring plants to produce more than one maturing sucker. In addition, the older the plantation the more suckers will have migrated from the original planting hole. Fig.6.5 shows that the youngest sucker is at some distance from the mother plant. This means that after several cycles a producing plant stays at some distance from the planting hole.

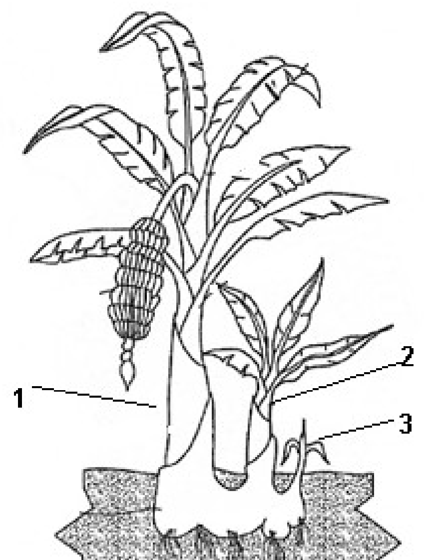


Figure 6.5: Sucker emergence in banana: 1 adult plant, 2 young sucker and 3 youngest sucker (modified from online); all plants together forming a stool or mat

It can be seen in Table6.1, 6.2 and 6.3 that all but two of the studies were conducted on-station and only two among them considered intercropping, one study allowing local farmers to execute their own management. Given all these considerations density trials on bananas under East African subsistence farmer conditions are lacking. The current study attempts to fill in this blank spot.

Table 6.1: Spacing, plant density, yield (kg/ha and kg/(ha.year) for dessert bananas.

Spacing (mxm)	Density (plants/ha)	Remarks	Variety (all dessert bananas)	Yield (kg/ha)	Yield (kg/(ha.year))	Country	Authors
2x2	2500		Cavendish (Giant governor)	26000		West Bengal	Chattopadhyay *et al.* 1978
2.5x2.5	1600			18380			
3x3	1125			14343			
2.4x1.8	2268		Robusta banana	37867		South India	Kohli *et al.* 1980
2.4x2.4	1701			47573			
5x2	1000		Williams		48600	South Africa (Eastern Transvaal)	Robinson & Nel 1989 (b)
4x2	1250				54000		
3x2	1666				63000		
3x1.5	2222				66000		
5x2	1000	Mats per ha	Williams		46100	South Africa (Eastern Transvaal)	Robinson & Nel 1986
4x2	1250	Mats per ha			52500		
3x2	1666	Mats per ha			56900		
3x1.5	2222	Mats per ha			61500		
1.5x1.5	4304	2 stems	Kabuthu (Dwarf Cavendish)		22060	Malawi	Spurling & Spurling 1975
2.3x2.3	1913	2 stems			16020		
3x3	1077	2 stems			13540		
3x2.8	2247	2 seeds per hole	Williams	82000		Israel (Jordan valley)	Israeli & Nameri 1988
3x2.8	2991	3 seeds per hole		101000			
3x2.8	4091	4 seeds per hole		113000			
3x2.8	2344	2 seeds per hole		83000			
3x2.8	2809	3 seeds per hole		95000			
3x2.8	3367	4 seeds per hole		105000			
	1750		Williams		69000	Australia (North Queensland)	Daniells *et al.* 1987
	1850				65000		
	1900				70000		
	2100				75000		
	2300				74000		
	2350				74500		
	2700				75000		
	2800				79000		
	2850				75000		
	3333		Nanicão (Cavendish)	74447	67830	Brasil	Filho & Kluge 2001
	2222			57090	59100		
	1666			44215	48972		
	1333			37937	45027		
	1500		Williams		44300	Australia (North Queensland)	Daniells et al. 2008
	1333				39800		
1.5x1.5	4444		Basrai		37420	India	Raskar 2003
0.9x2.1x2.5	3968	Triangular paired planting			33595		
2.0x3.0	1666		Nanicão (Cavendish)		49702	Brasil	Lichtemberg et *al.* 1998
2.0x2.5	2000				50497		
2.0x2.0	2500				53155		

Table 6.1 (part 2): Spacing, plant density, yield (kg/ha and kg/(ha.year) for dessert bananas.

Spacing (mxm)	Density (plants/ha)	Remarks	Variety (all dessert bananas)	Yield (kg/ha)	Yield (kg/(ha.year))	Country	Authors
3.0x3.0	3333	3 suckers per hill	Williams	56600	52100	Western Australia	Kesavan et *al.* 2002
3.0x2.0	3333	2 suckers per hill		46500	41700		
3.0x1.0	3333			64100	49200		
3.0x0.75	4444			63600	44700		
3.0x0.5	6667			61500	40300		
	1333		Williams		33100	South Africa (Natal)	Robinson & Nel 1989
	1666				36800		
	1900				39100		
	2222				40100		
	3333				39200		
	1666		Williams		54400	South Africa	Robinson & Nel 1989 (a)
	2000	2 adults allowed to grow from one seed			48300		
	2222				63400		
1.8x1.8	3086	Many spelling mistakes, some bad calculations,	Basrai	49650			Patel *et al.* 2000
1.5x1.5	4444			63720			
1.2x1.8	4629			67720			
1.2x1;5	5555			80190			
1.2x1.2x2.0	5020			75730			
1.0x1.2x2.0	6250			87170			
1.8x1.8	3086		Robusta banana	17790		India	Raveendra *et al.* 2004
1.5x1.5	4444			21310			
1.2x1.8	4629			22090			
1.2x1.5	5555			24600			
1.2x1.2x2.0	5208			23460			
1.0x1.2x2.0	6250			28100			
2.4x2;4	1736	Local check		11230			
1.8x1.8	3086		Grand naine	58510		India	Badgujar *et al.* 2004
1.5x1.5	4444			72020			
1.2x1.8	4629			84220			
1.2x1.5	5555			87630			
1.2x1.2x2;0	5208			81700			
1.0x1.2x2.0	6250			94070			
1.8x1.8	3086		Grand naine	40933		India	Badgujar *et al.* 2004 (a)
1.8x1.8	6172	2 adults allowed to grow from one seed		72763			
1.2x1.2x2.0	5208	Pair row system		61173			
1.8x3.6	4500	Three plants per hill		62419			
2.4x2.4	1736		Robusta banana	32060		India	Kotur & Mustaffa 1984
2.4x1.8	2314			38940			
1.8x1.8	3086			50070			

Table 6.2: Spacing, plant density, yield (kg/ha and kg/(ha.year) for plantains.

Spacing (mxm)	Density (plants/ha)	Remarks	Variety (all plantains)	Yield (kg/ha)	Yield (kg/(ha.year))	Country	Authors
3x1	3333		Bâtard (plantain, false horn)	28400		Cameroon (Njombe)	Kwa *et al.* 2005
3x1.33	2506			22800			
3x2	1666			18700			
3x3	1111	Square	Borodewuio (False horn plantain)	9380		Ghana	Adjei-Nsiah *et al.* 1996
3.22x3.22x3.22	1113	Triangular		9380			
4x2.5	1000	Rectangular		9380			
2x2	2500	Square		16950			
2.15x2.15x2.15	2493	Triangular		16950			
3x1.33	2506	Rectangular		16950			
2.5x2.5	1600	High tree density *Terminalia* ivoriensis	Essong (French plantainAAB)	4430		Southern Cameroon	Norgrove & Hauser 2002
2.5x2.5	1600	Low tree density		9940			
2.5x2.5	1600	Intercrop (Tannia). mulched		8830			
2.5x2.5	1600	Monocrop. mulched		7000			
2.5x2.5	1600	Monocrop. burnt		5750			
2x2	2500		Nendran (Plantain)	26380		South India	Elain Apshara *et al.* 2001
2x2.5	2000			22500			
2x3	1666			21140			
2x2	5000	2 suckers per hill		43450			
2x2.5	4000	2 suckers per hill		36960			
2x3	3332	2 suckers per hill		35950			
2x2	7500	3 suckers per hill		58650			
2x2.5	6000	3 suckers per hill		50640			
2x3	4998	3 suckers per hill		47230			
2x3	1666		Plantain	23100		Colombia (Quindio)	Belalcázar & Espinosa 2000
1.5x2	3332			40400			
2x3	4998	Several mats in planting hole		51900			
3x2	3333	2 seeds per whole	Plantain	29573		Colombia	Belalcázar & Espinosa 2000 (a)
2.5x1.5	2666			25042			
1.2x4	2083		Hartón (AAB)		67000	Venezuela	Añez *et al.* 1991
1.6x4	1562				47400		
2.16x4	1157				42600		
2.64x4	946				35600		
3.12x4	801				34200		
3.60x4	694				30200		
4.08x4	612				28600		
4.56x4	548				26200		
5.04x4	496				18800		
5.52x4	453				20700		
6x4	416				18600		

Table 6.2 (part 2): Spacing, plant density, yield (kg/ha and kg/(ha.year) for plantains.

Spacing (mxm)	Density (plants/ha)	Remarks	Variety (all plantains)	Yield (kg/ha)	Yield (kg/(ha.year))	Country	Authors
3x3	1111		Plantain (AAB)		18920	Costa Rica	Chacon 1991
2.6x2.6	1720	Hexagonal configuration			24765		
1.4x0.92x4.57	1704	Double row configuration			24406		
3.3x2	1500		Simmonds (Dominico-Hartón)	19733	18928	Colombia	Belalcázar *et al.* 1994
3.3x2	3000	2 seeds per whole		27600	20627		
5x2	1000			14933	15408		
5x2	2000	2 seeds per whole		24066	19421		
5x4	1000			16500	16071		
5x4	1500	2 seeds per whole		23133	19480		
1.8x1.8	2989		Maricongo Plantain	36700		North-Central Puerto Rico	Irizarry *et al.* 1978
1.5x1.5	4303			37400			
1.2x1.2	6726			32300			
2x2.2	2500	Mats per ha	Dominico-Hartón	26623	19967	Colombia	Arango-Bérnal 1987
2x2.5	2000	Mats per ha		28666	21499		
2x3.3	1500	Mats per ha		26685	20013		
2x5	1000	Mats per ha		22307	16730		
	1600	Compound farm, intercrop, on-farm	Mainly Abagba (false horn plantain)		20400	Nigeria	Nweke *et al.* 1988
	1600	Non-compound farm, intercrop, on-farm			5500		
3.3x2.0	1500		Dominico-Hartón	19733		Colombia	Belalcázar et al. 1991
3.3x2.0	3000	2 seeds per hole		27600			
5.0x2.0	1000			14933			
5.0x2.0	2000	2 seeds per hole		24066			
5.0x4.0	2000	2 seeds per hole		16500			
5.0x4.0	1500	3 seeds per hole		23133			
3.0x3.0	1111		Borodewuio (False horn plantain)			Ghana	Hoisonyame 1991
3.0x3.0	1283						
2.5x2.5	1600	Triangular spacing					
2.5x2.5	1848	Triangular spacing					
3.0x2.0	3333	2 seeds per hole	Dominico-Hartón	35200		Colombia	Arcila *et al. 1998*
3.0x2.0	1500		Simmonds	19000			Belalcázar 2002
3.3x2.0	3000	2 seeds per hole		30266			
5.0x2.0	1000			14933			
5.0x2.0	2000	2 seeds per hole		24066			
5.0x4.0	1000	2 seeds per hole		16500			
5.0x4.0	1500	3 seeds per hole		23133			
3.0x3.0	1111	Management by farmers, on-farm	Hartón	8500		Venezuela	Delgado et al. 2004
2.0x2.0	2500	Management by farmers, on-farm		35000			
1.0x1.0	10000		Plantain	7840		Dominican Republic	Pound & Fernandez 1981
2.0x2.0	2500			8420			

Table 6.3 Spacing, plant density, yield (kg/ha and kg/(ha.year) for hybrids, EAHB and Silk.

Spacing (mxm)	Density (plants/ha)	Variety	Yield (kg/ha)	Yield (kg/(ha.year))	Country	Authors
	1500	Goldfinger (FHIA 1)(AAAB)		49600	Australia (North Queensland)	Daniells et al. 2008
	1333	Goldfinger (FHIA 1)		38600		
	1333	Lady Finger		23200		
2,5x2	2000	Cambur manzano (Silk Fig) (AAB) (Hartón)	27786	24032	Venezuela	Nava 1994
2,5x2,5	1600		23360	20695		
2,5x3	1333		20984	19439		
3x2	1666		24618	23339		
3x2,5	1333		20454	19291		
3x3	1111		17027	16485		
	1600	Kibuzi (AAA-EA)	14500		Uganda	Kagoda et al. 2005
	1111		11300			
	711		7500			

7. CIALCA characterization study

Here we will explore density and yield data gathered during the CIALCA characterization study. The survey was executed between October 2006 and July 2007 in Rwanda, Burundi and South Kivu (D.R. Congo). Differences in yield and density occurring in the different countries are explored, and factors influencing density and yield are examined. Special attention is given to the influence of management practices and their influence on yield. The CIALCA survey considered plant spacing as the only way to evaluate plant density. Later on in the text it will be seen that in the present study, density was evaluated using two different methods.

Results presented in the present study, sometimes differ from previous results based on the same data. This discrepancy is due to different methodological approaches. In the present study, entire fields are the basic unit. Densities and yield figures are calculated for each field separately, and extrapolated to figures per ha and per region. Another approach could be to consider individual plants and extrapolate these data to density and yield figures per ha and region. Advantages of the latter method are that some relationships will be detected more easily, since fields are heterogeneous. More data will be available for analysis, since each individual plant is considered a unit. Disadvantages of this method are that measurement errors of individual plants are greatly enlarged during extrapolation per hectare. Another objection is that extrapolation to a hectare based on individual plants is not realistic.

7.1 Results and discussion from the CIALCA study

For the sake of completeness, we present all data gathered in the CIALCA characterization study (Tab7.1), but we will discuss the data of Rwanda in more detail (see section 8.3.13 Plant density in Rwanda).

Table 7.1: Spacing, plant density and yield data collected in the CIALCA characterization study

		Spacing (m)			Plant density (mats/ha)			Bunch weight estimation (kg)			Yield (kg/ha)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Country	District												
Rwanda	Bugesera	2.82	1.66	4.05	1389	611	3645	11.0	3.9	18.0	15535	5325	35107
	Kibungo	2.92	2.35	3.33	1211	899	1811	20.4	10.6	31.9	24250	16423	39422
	Karongi (Kibuye)	2.83	2.35	3.36	1290	884	1815	18.0	11.4	29.9	23752	12894	54233
	Rusizi (Cyangugu)	2.42	1.63	3.38	1891	875	3764	14.9	6.8	24.1	27697	9416	50754
	Ruhango	2.91	1.73	4.22	1352	563	3351	13.2	3.4	21.8	17932	1927	37317

		Spacing (m)			Plant density (mats/ha)			Bunch weight estimation (kg)			Yield (kg/ha)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Country	Commune												
Burundi	Giheta	2.50	1.78	3.32	1724	910	3148	10.4	5.2	15.6	17974	6413	35513
	Mutaho	2.88	1.79	5.10	1463	385	3130	11.5	5.8	17.3	16511	4367	34776
	Busoni	2.19	1.14	3.88	2932	664	7654	12.5	6.7	16.7	38118	7025	92219
	Kirundo	2.47	1.49	3.50	1941	816	4491	11.9	7.2	19.1	24006	6472	62217
	Mugina	3.02	1.56	5.04	1527	393	4091	13.7	8.7	18.6	20977	5421	60791

		Spacing (m)			Plant density (mats/ha)			Bunch weight estimation (kg)			Yield (kg/ha)		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Country	Site												
Congo	Kabamba	2.28	1.73	3.64	2072	754	3328	17.6	10.4	33.4	36409	11811	73291
(South Kivu)	Luhihi	2.54	1.78	3.42	1660	856	3144	23.7	8.7	42.9	39687	14038	81627
	Lurhala	1.93	1.45	2.71	2939	1359	4740	11.8	4.5	18.9	33299	8027	64685
	Burhale	1.92	1.24	3.31	3039	911	6469	18.5	8.2	29.2	54067	18786	106290

Plant densities are lowest in Rwanda (1211-1891). In Burundi plant densities are higher (1463-2932) and highest densities are recorded in South Kivu (1660-3039). Yields are similar in Rwanda and Burundi, whereas they are highest in South Kivu. As the CIALCA annual report of 2007 states that cycling times are on average 1 year, data on yields can be compared between different sites. The CIALCA annual report (2007) also provide additional data on plant density and yield for Uganda and North Kivu and concludes that highest yields and plant densities are realized near the Albertine rift (Fig.7.1), were soils are young and rainfall is high (>1400 mm/year). Lower yields and densities are encountered on more weathered soils with a lower rainfall (<1100 mm/year). Pest and disease pressure decline with rising altitude, contributing to higher yields near the Albertine rift (Fig.7.2). The CIALCA data of Rwanda were pooled with data gathered in the current study. A more detailed discussion of the resulting analysis is given below (see section 8.3.13 Plant density in Rwanda). In what follows now, only data gathered in the CIALCA characterization study are analyzed.

Figure 7.1: Albertine rift (on line)

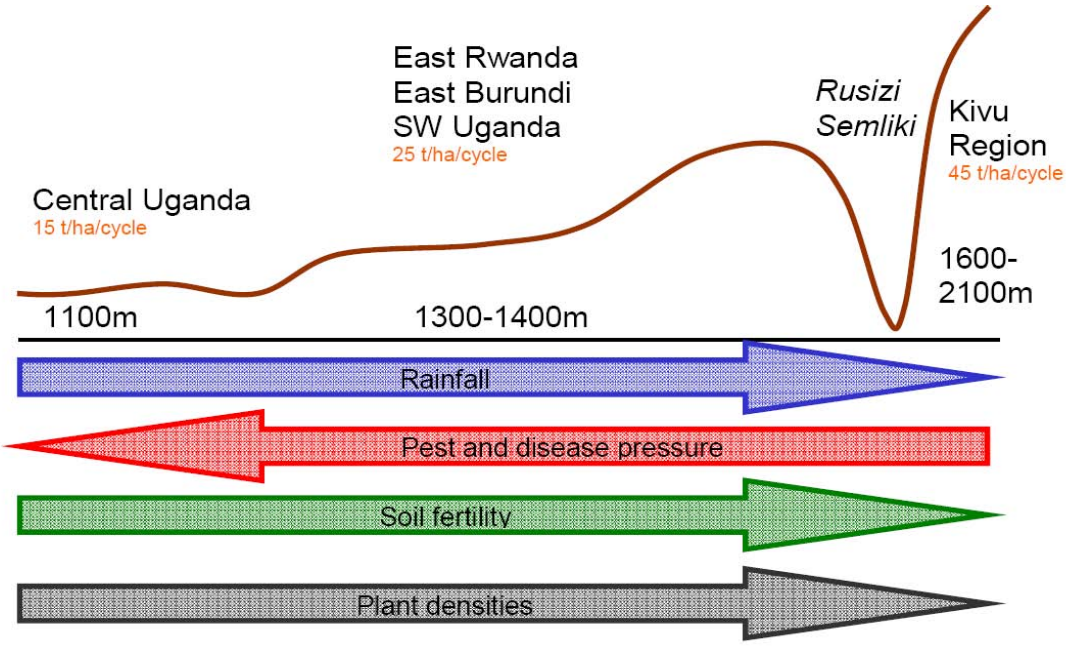


Figure 7.2: Rainfall, pest and disease pressure, soil fertility and plant density gradients in Eastern Africa (CIALCA 2008)

7.1.1 Plant density and bunch weight

It is expected that fields with a lower plant density will produce higher bunch weights. However Fig.7.3 illustrates that this relationship does not exist (linear regression R^2=0.001). Hence it is suggested that individual plant spacing and bunch weight should be considered instead of whole fields.

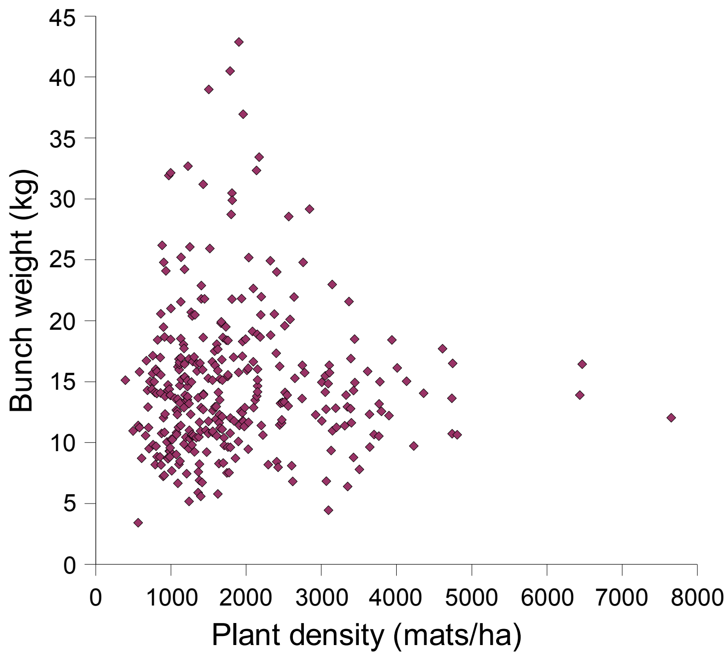


Figure 7.3: Plant density vs. bunch weight

7.1.1.1 Individual plant spacing and bunch weight

Since average field spacing and bunch weight did not produce a satisfactory correlation, individual plant spacing and bunch weight were examined. The results are presented in Fig.7.4. A linear regression produced a R^2=0.05 which is not satisfactory. The relation between individual plant spacing and bunch weight was also investigated in each site separately. It did not produce satisfactory results, as highest R^2 value was reached in Lurhala (R^2=0.095). Thus it is assumed that climatic, managerial and intercrop effects are more pronounced than plant spacing on bunch weight. Thus to find a correlation between plant spacing and bunch weight, all growing conditions should be standardized throughout the different farms, but then we cannot anymore consider such research as on-farm research.

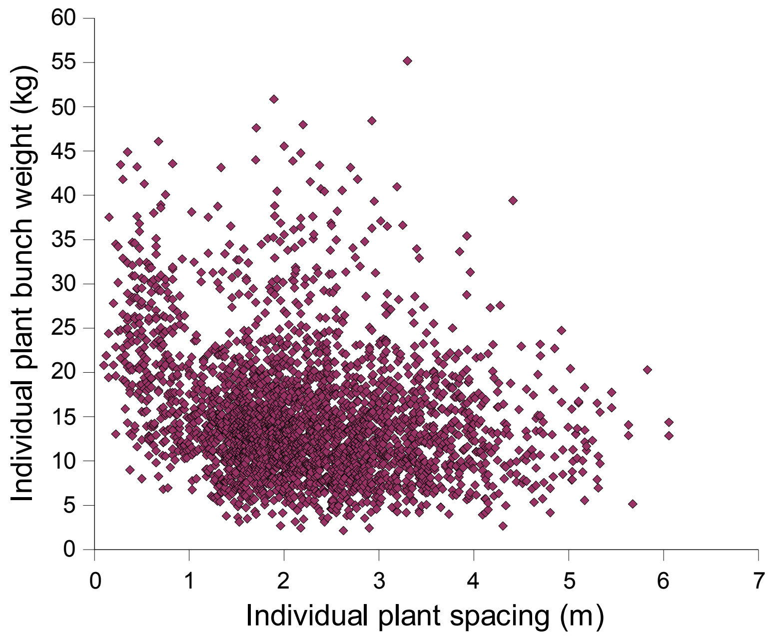


Figure 7.4: Individual plant spacing and bunch weight

7.1.2 Plant density and yield

It is expected that yield is positively correlated to plant density, up to a certain maximum, after which yield increments start decreasing. Results are presented in Fig.7.5. A linear regression obtained a R^2= 0.628, but the values in the x and y-axis are not independent. A linear regression is not possible, since assumptions of linear regressions are not respected. The R^2 is only indicative of the variance in the data. It is seen that plant density is positively correlated to yield. Yield was calculated by multiplying average plant density with average bunch weight.

A drawback in calculating yield in this way is that when density increases, less plants will actually flower and cycling time will increase, but these effects are not accounted for. Yet it can be concluded from the data that higher densities lead to higher yield. The CIALCA annual report (2007) indicates that higher densities are found in regions with higher soil fertility and rainfall. These results thus imply that farmers adapt management to prevailing conditions. On-station density trials will have to point out if high densities are optimal under low fertility and rainfall regions.

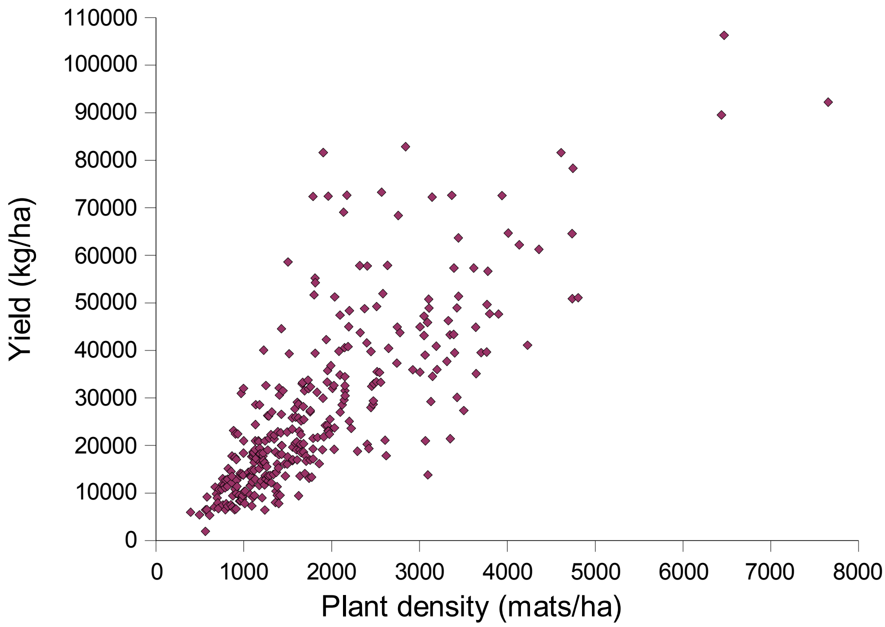


Figure 7.5: Plant density and yield

7.1.3 Plantation age

7.1.3.1 Influence of plantation age on density

Two different effects of plantation age on plant density can be expected. First one can expect that plantation density will increase with plantation age. Indeed, farmers in general allow more than one sucker to follow the mother plants. Second plant density will decrease because of loss of plants due to pests and diseases. These cropping trends are brought together in Fig.7.6

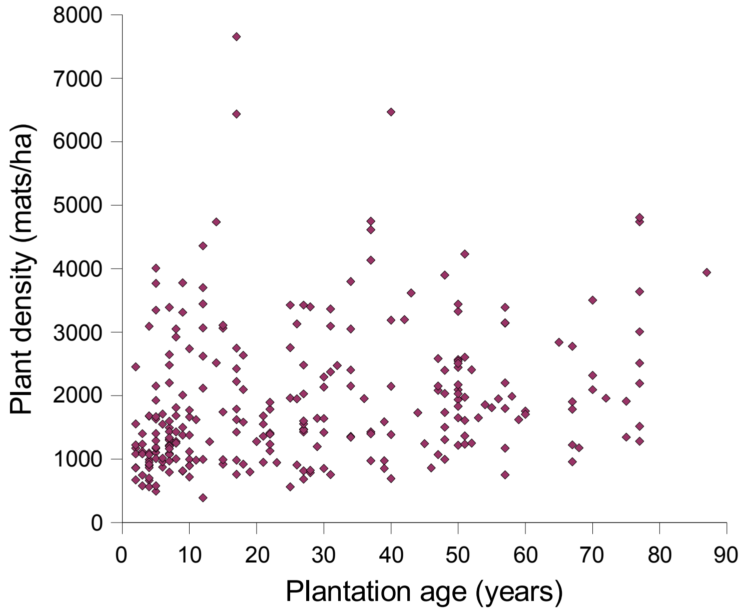


Figure 7.6: Influence of plantation age on plant density

A linear regression obtained a $R^2 = 0.046$. Thus none of the hypotheses' is respected, and plant density is not correlated to plantation age. It is striking to observe that some plantations are between 30 and 90 years old. This suggests that farmers manage density, and replace dead plants by planting new ones.

7.1.3.2 Influence of plantation age on yield

It is expected that plantation age is negatively correlated to yield, as older mats have longer cycles and produce smaller bunches. The influence of plantation age on yield is depicted in Fig.7.7.

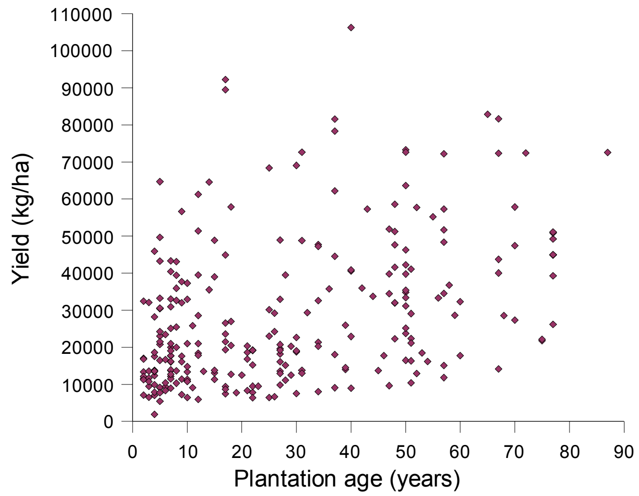


Figure 7.7: Plantation age and yield

The linear regression with a $R^2= 0.133$ shows that there is no clear relationship between plantation age and yield. The Fig.7.7 also shows that some old plantations can still be very productive. This should be the combined effect of productive plantations being kept, whereas less productive ones are replanted. Besides farmers apply phased planting, thus plantation age as a whole is rather the period during which a field was kept under bananas than simply the age of banana stools as for example a plantation of 40 years may have mats of 40 years, while other mats were replanted long time ago or very recently.

7.1.4 Plantation altitude

7.1.4.1 Influence of altitude on density

It is observed in Fig.7.8 that no clear correlation prevails between altitude and yield. A linear regression gave a $R^2 = 0.065$. Noteworthy is that bananas are cultivated up to altitudes of 2000 m.a.s.l..

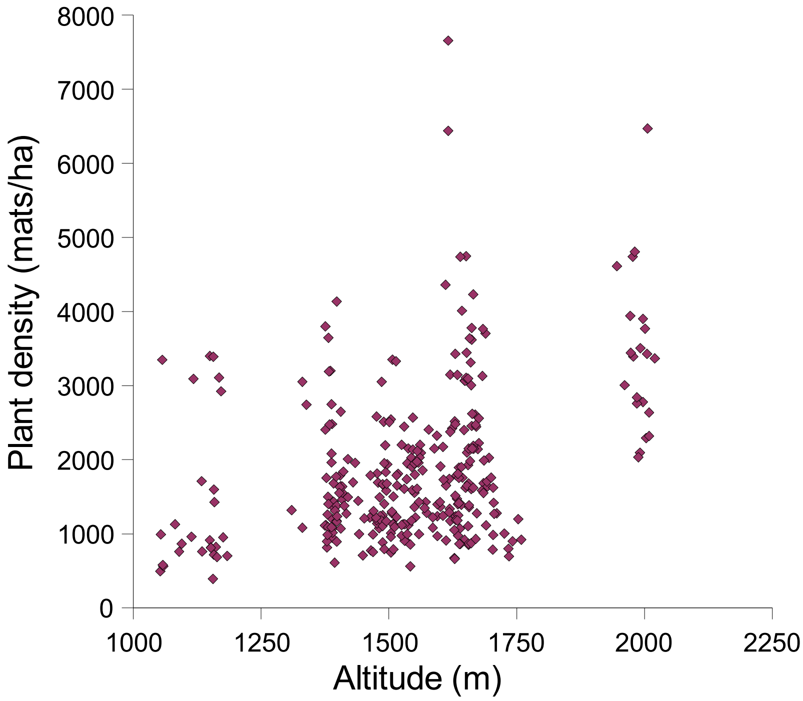


Figure 7.8: Influence of altitude on plant density

7.1.4.2 Influence of altitude on yield

Fig.7.9 shows that there is no correlation between altitude and yield. Indeed the linear regression gave a $R^2= 0.074$.

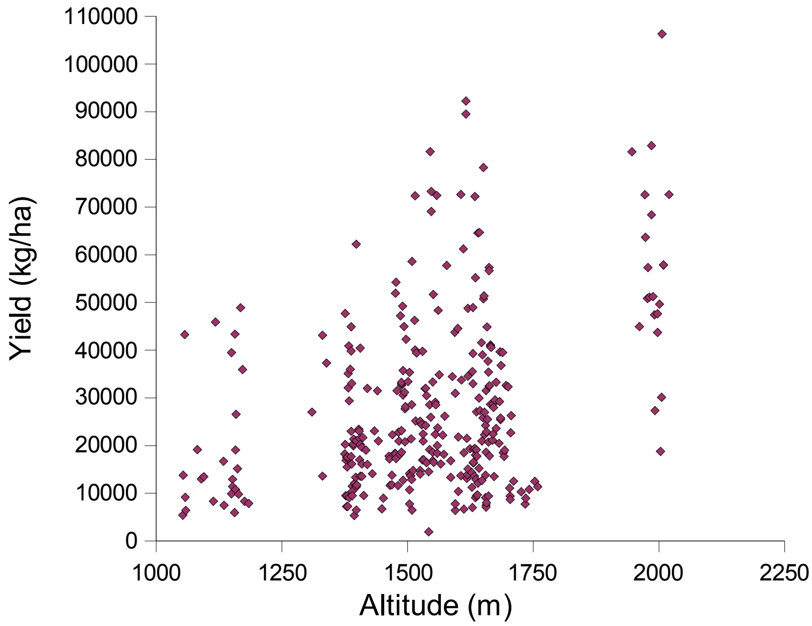


Figure 7.9: Influence of altitude on yield

Yet Fig.7.9 shows that yield can be very high at high elevations. Therefore we divided the measurements in four groups (Tab.7.2).

Table 7.2: Altitude and yield

Altitude (m)	Yield (kg/ha) Mean	Min	Max
1000 < < 1300	18801 a	5421	48901
1300 < < 1600	25367 a	1927	81627
1600 < < 1900	27440 a	6413	92219
1900 < < 2200	56375 b	18786	106000

Different letters next to the mean yield indicate significant differences, obtained with a one-way ANOVA Tamhane T2 test at significance 0.05

Variances of yields were not homogeneous, thus an one-way ANOVA Tamhane T2 test was executed. This showed that only yields in locations between 1900 and 2100 m.a.s.l. are significantly higher from other yields. However these data came from one location in South Kivu, thus a general trend between altitude and yield is refuted. It is suggested that more measurements should be done on altitudes between 1000 and 1300 m.a.s.l. and altitudes higher than 1800 m.a.s.l., as most measurements were on altitudes between 1300 and 1800 m.a.s.l.. This range of altitude is probably too small to find relationships, between altitude and other variables.

7.1.5 Field size

7.1.5.1 Field size versus density

Field size was assessed visually in the CIALCA survey. A distinction was made between fields larger than 1 hectare, those between 1 and 0.4 ha and those smaller than 0.4 ha (Fig.7.10). As variances are not homogeneous, an one way ANOVA, Tamhane T2 test indicated that none of the differences are significant. Thus to find a relationship between field size and plant density, if it exists, the fields size should be measured more accurately.

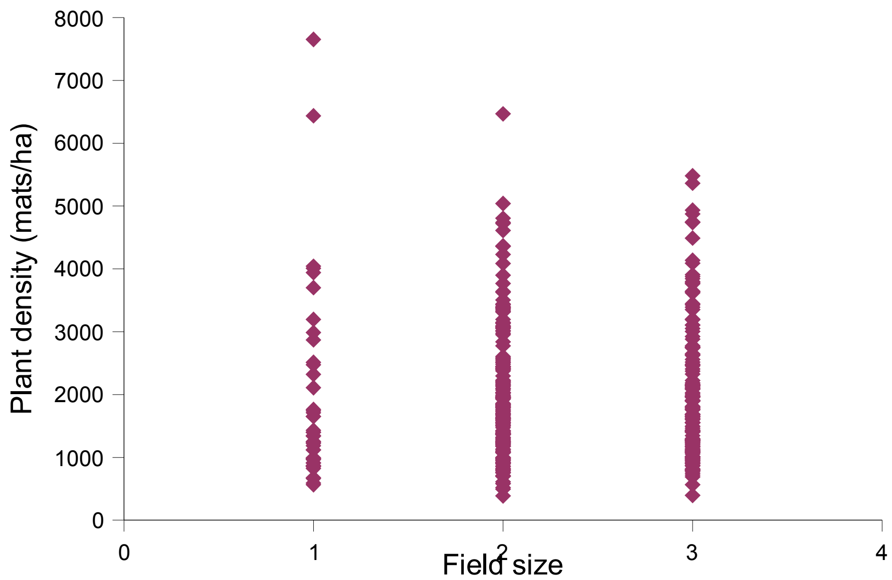


Figure 7.10: Field size versus plant density. (1) larger than 1 ha, (2) between 1 and 0.4 ha and (3) smaller than 0.4 ha

7.1.5.2 Field size versus yield

The relationship between field size and yield is examined here. Fig.7.11 shows that no clear relationship exists between these two parameters. An one-way ANOVA Tamhane T2 test indicated that yield is not influenced by field size. Again it is suggested that the field size should be measured more accurately in the future.

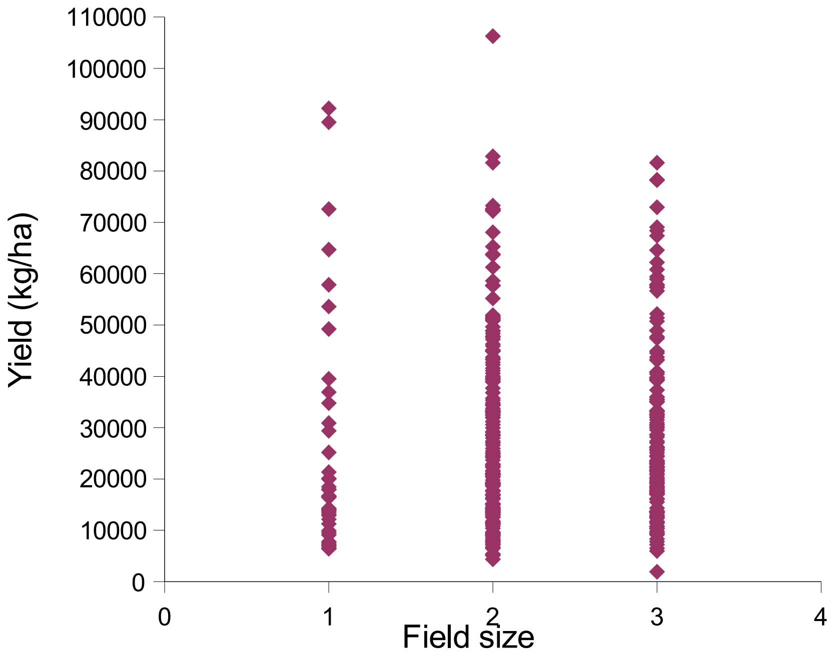


Figure 7.11: Field size versus yield. (1) larger than 1 ha, (2) between 1 and 0.4 ha and (3) smaller than 0.4 ha

7.1.6 Influence of management on yield

It is expected that fields that are more intensively managed produce higher yields. Farmers were asked about frequency of weeding, application of manure, etc... . Yield was divided in three groups. Less than 10 t/ha is considered a bad yield, whereas yields between 15 and 25 t/ha are considered good yields for subsistence farmers. Yields higher than 30 t/ha are considered very good for low input farms.

Results are depicted in Table 7.3, it is remarkable that fields producing most, suffer the most from erosion. It is suggested that although altitude did not influence yield significantly, (Table 7.2) highest yields were encountered in fields at higher altitude, which are more prone to erosion. In accordance with the erosion data, it is observed that erosion control measures occur least in the most productive fields. Another observation is that superficial weeding accompanies high yields, whereas deep weeding accompanies low yields. It is suggested that deep weeding will usually be executed in order to plant intercrops. This deep weeding will damage banana roots and reduce yields.

None of the respondents reported the use of mineral fertilizer. Most fields are mulched, but a higher percentage of the most productive fields are mulched. The most productive fields are mostly self mulched. No large differences in application of compost and manure are observed. In the most productive fields manure is often applied more than twice a year, in other fields this is not observed.

Table 7.3: Management practices and yield

		Y = Yield (kg/ha)		
		Y < 10 000 N= 46	15 000< Y <25 000 N= 111	Y > 30 000 N= 151
Erosion				
None	1	80%	75%	59%
Some (rills)	2	16%	21%	40%
Moderate (small gullies)	3	4%	4%	1%
Severe (large gullies)	4	0%	0%	0%
(No response)		(2%)	(2%)	(0%)
Soil & water conservation measures				
None	1	25%	35%	57%
Mulch material perpendicular to slope	2	4%	6%	8%
Grass bunds	3	30%	23%	12%
Stone rows	4	0%	2%	0%
Soil bunds-retention system	5	4%	11%	2%
Live mulch	6	0%	0%	0%
Terracing	7	0%	0%	0%
Mulch not perpendicular to slope	8	37%	23%	21%
(No response)		(4%)	(18%)	(9%)
Weeding				
By hand	1	2%	8%	2%
Superficial with hand & hoe	2	41%	64%	83%
Deep with hand & hoe	3	55%	26%	11%
Herbicides	4	0%	0%	0%
Cut with machete	5	0%	0%	0%
Superficial and deep with handhoe	6	2%	2%	4%
(No response)		(2%)	(4%)	(0%)
Mineral fertilizer use				
None	1	99,00%	98%	96%
Application	2	1%	2%	4%
(No response)		(22%)	(48%)	(66%)
Mulch				
None	1	18%	18%	8%
Application	2	82%	82%	92%
(No response)		(4%)	(6%)	(3%)
Origin of mulch				
Self mulch	1	62%	73%	80%
External mulch	2	7%	10%	5%
Self & external mulch	3	10%	2%	0%
Others	4	21%	15%	14%
(No response)		(4%)	(6%)	(3%)
Frequency of mulching				
Once a year	1	40%	63%	63%
Twice a year	2	52%	33%	35%
More then twice a year	3	8%	4%	2%
(No response)		(50%)	(53%)	(70%)
Compost/manure				
No application	1	48%	40%	40%
Application	2	52%	60%	61%
(No response)		(12%)	(37%)	(51%)
Origin of compost/manure				
Cow manure	1	17%	22%	5%
Compost	2	35%	45%	39%
Compost and manure	3	48%	33%	56%
(No response)		(12%)	(37%)	(51%)
Frequency of manuring				
Once a year	1	28%	54%	32%
Twice a year	2	72%	46%	43%
More then twice a year	3	0%	0%	25%
(No response)		(56%)	(67%)	(70%)
Way of application of manure				
Surface application around mat	1	15%	18%	25%
Scattering all over field at ground surface	2	36%	25%	29%
Incorporate into soil around mat	3	27%	26%	29%
Incorporate into soil all over field	4	9%	8%	0%
Applied in patches in field	5	4%	0%	0%
Surface application around several mats	6	9%	18%	16%
Applied at base of mat	7	0%	5%	1%
(No response)		(56%)	(66%)	(68%)

It can be concluded that fields are not intensively managed, as no mineral fertilizer is applied, weeding is done by hand and hoeing and manuring is done only twice a year in almost all fields. In sloping and montaneous regions with tropical concentrated rainfall, erosion fighting structures are very important but are not widely adapted. Nevertheless very appreciable yields are realized.

7.2 Conclusion

It can be concluded that banana plantations in the region can be very old, and up to 90 years of age. Nevertheless they are still very productive (up to 70 t/ha). Higher planting density leads to higher yields, however under the current conditions plant density does not influence bunch weight. It is suggested that managerial, intercrop, edaphic and climatic factors are more important in determining bunch weight.

Before high densities can be recommended, further research should point out if there is a causal relationship, or if high densities are applied in regions most fit for it. Contrary to the results of CIALCA (2008), no correlation was found between altitude and density or yield. Most production is done on small fields without modern management practices and little erosion control structures. None of the respondents reported fertilizer use. Deep hoeing affects banana yields negatively, probably due to root damage, which leads to lower nutrient uptake and hence lower vigor and yield. As population will increase and pressure on land will increase, raising of land and labor productivity will become more necessary. On-farm research will have thus to come up with input modifications of farming systems, that are readily applicable by smallholders.

8. On-farm assessment of plant density

8.1 Introduction

In Rwanda many different banana varieties, intercrops and planting densities occur. Fig.8.1 depicts two different fields with greatly differing densities. Most literature on banana planting densities deal with on-station experimentation and investigate one single variety grown as a monocrop. In contrast not much data are available on planting densities, varietal mixtures and intercrops used by Rwandan subsistence farmers. Consequently no clear guidelines can be given to farmers.

In this chapter we will further elaborate the factors influencing planting density. As in other crops, it is expected that soil fertility, rainfall, and field management will be positively correlated with planting density, but field size will be negatively correlated with plant density. Presences of intercrops and occurrence of banana varieties will also be examined.

Figure 8.1: Banana fields in Rwanda

8.2 Materials and methods

8.2.1 Sites studied

The present study was conducted in three Rwandan districts (Ruhengeri, Butare and Kibungo (Fig2.1)) each located in a different agro-climatic zones (Table8.1). In each district, two villages were surveyed. In each village, the farms included in the study were chosen randomly dependent on willingness of farmers to cooperate. The altitude and rainfall for the considered agro-climatic zones are presented in Table8.2. In each village 15 farms were visited, and only fields owned by the farmer and planted with bananas were considered.

Table 8.1: Surveyed sites and respective agro-climatic zones.

	Ago-climatic zone
Ruhengeri (Musanze)	Birunga
Butare (Huye)	Central Plateau
Kibungo (Ngoma)	Eastern Plateau

Table 8.2: Agro-climatic zones (ACZ) included in the survey. Modified from (Verdoodt and Van Ranst 2003)

ACZ		Altitude (m)			Mean temperature (C°)	
	Mean	Max	Min	Mean	Max	Min
Birunga	1960	2500	1460	17	20	14
Central plateau	1749	2110	1400	19	22	17
Eastern plateau	1575	2200	1370	20	21	18

ACZ		Total rainfall (mm/year)			Dry period (days)	
	Mean	Max	Min	Mean	Max	Min
Birunga	1317	1678	1110	15	62	0
Central plateau	1298	1993	1025	59	123	0
Eastern plateau	1038	1255	891	86	123	31

It is observed in table8.2 that the agricultural zone of Birunga at 1960 m.a.s.l. receives the highest rainfall, has the shortest dry season and lowest mean temperature. The Central plateau at 1749 m.a.s.l. has about the same rainfall as Birunga. However the dry season is a lot longer, consequently rains are more concentrated. The mean temperature in the Central plateau is higher than in Birunga. The Eastern plateau at 1575 m.a.s.l. has the highest temperature, longest dry season and lowest rainfall.

8.2.2 Plant spacing

Subsistence farmer's fields are usually quite heterogeneous (Fig.8.2 and Fig.8.3) and not planted in rows. To evaluate plant spacing, five mats were chosen randomly in each field. The distance from the center of the mat to the center of the nearest mat was measured. A mat (Fig.6.4) consists of all plants originating from the same planting material and still being connected underground.

Figure 8.2: Farmer's field in the sector of Save,central plateau, with intercropping of bananas, sorghum and sweet potato

Figure 8.3: Farmer's field in the sector of Cyuve, Birunga agro-climatic zone, with intercropping of banana and cocoyam

8.2.3 Plant density

Plant density in mats/ha was evaluated in two ways. The first method implied delineating a plot of 10*10 m, the location of this plot was chosen at random. In this plot the number of mats was counted. If the number of mats in a 10*10 m square is known, the number of mats in one hectare can be calculated. We will refer to this as the plant density based on plots (PPD: plot plant density).

The second procedure used the average spacing between mats. The distance between the center of one mat and the center of the four closest mats was measured. This procedure was repeated five times. The average of these measurements was called the average field spacing. It was assumed that the surface occupied by each mat was equal to the square of the average field spacing. If the fraction of the surface of 1 ha and the surface occupied by one mat is made, this results in the plant density (mats/ha). We will refer to this as the plant density based on spacing (SPD: Spacing plant density)

SPD = Number of mats/ha = $10000/As^2$

with

As = average field spacing (m),

As^2 = surface occupied by one mat (m^2)

1ha = 10,000 m^2

All subsequent calculations using plant density will be executed twice, once with SPD and once with PPD.

8.2.4 Bunch weight estimates

As few bunches could be harvested and weighed, most bunch weights needed to be estimated according to the formula below. Thus the girth at the base of the pseudostem was measured as well as the girth at 1m. The number of hands on the bunch and number of fingers on the lowest row of the second lowest hand were counted (Wairegi *et al*. 2009).

$$\ln(B_{wt}) = -9.071 + [\,0.949*\ln(\text{Volume})\,] + [\,0.554*\ln(\text{Hands})\,] + [\,0.433*\ln(\text{Fingers})\,]$$

with

B_{wt} = bunch weight estimate

Volume = $\pi h/2$ ($r^2_{\text{pseudostem at base}} + r^2_{\text{pseudostem at 1m}}$)

Hands = number of hands on the bunch

Fingers = number of fingers in the lowest row of the second lowest hand

A limitation of the used method is that the bunch weight was only assessed in a time span of one month in each location. This is a drawback as the season of harvest greatly influences the bunch weight, but this variation could not be accounted for in the study (Robinson & Nel 1989). The weighed average of the measured bunch weights and the estimated bunch weights was made. In all equations involving average bunch weight, this figure was used.

8.2.5 Yield estimates

8.2.5.1 Farmer estimation of yield

A first method depended on farmers estimating the number of bunches they harvest in an 'average year'. This figure was then multiplied by the average bunch weight, calculated as the weighed average of both estimated and measured bunch weights. This was then divided by the surface of a farmer's field and multiplied by the surface of one hectare.

Yield (kg/year.ha) = (Fe*Bw*10000)/Sp

with

Fe = farmers estimate of number of bunches for a given field in one year

Bw = average bunch weight (both weighed and estimated)

Sp = surface of a farmer's field in m^2

10,000 m^2 = 1 ha

This method led to yields ranging from 760 kg/year.ha to 312,000 kg/year.ha, the latter value not being realistic and possibly due to the unreliable estimates by the farmers.

8.2.5.2 Calculated estimate of yield

It is assumed that one mat produces one bunch every cycle. Thus the plant density was multiplied with the bunch weight. This yields (kg/ha) refers to the yield per cycle, a cycle being the time span between two harvests on the same mat. Since two methods were used to evaluate plant density, yield is also calculated two times.

8.2.6 Surface measurements of farmers' fields

The size of the surveyed fields was measured with a GPS (Global Positioning System). As fields rarely have a geometric form, fields were divided in virtual triangles. The size of these triangles can be calculated if the length of all sides is known. Measurement of the sides was done with a GPS with a 3m precision. Distances measured usually ranged from 10 to 15m.

8.2.7 Leaf area index calculations

The term leaf area index (LAI) was coined by Watson in 1947 and is used to express the area of the leaf surface (one surface only) covering an unit area of land surface (Zetlich 1971). To calculate the LAI, plants were divided into three groups, i.e. those that are higher than 2m, those that have a height between 1 and 2m and those that are smaller than 1m. The logic behind this is that plants smaller than 1m do not contribute significantly to LAI and those between 1 and 2m differ greatly in leaf surface from those that are higher than 2m. Plants smaller than 1m are thus excluded from the LAI calculations.

In each field a plot of 10*10 m was delineated. In this plot, the number of mats was counted and grouped according to the three plant size categories. In bananas the lowest and oldest leaf has the smallest area and the highest and youngest leaf has the biggest area (Blomme *et al.* 2008). Hence we measured, the middle leaf considering it as an average for the entire canopy. To obtain the surface of that leaf, the length and width were multiplied by 0.80 (Murray 1960, sited by Kumar *et al.* 2002). Then the surface of the leaf was multiplied by the number of leaves on the plant, resulting in an estimate for the total leaf area of one plant. This procedure was repeated five times for plants higher than 2m and five times for those between 1 and 2m. The average surface of these five plants was then multiplied by the number of plants in the given category in the plot. This was then divided by the surface of the plot.

LAI = ($P_2s*Sp_2 + P_1s*Sp_1$) / Ss

with

P_2s = number of plants higher than 2m in the plot

Sp_2 = average foliar surface of plants higher than 2m

P_1s = number of plants between 1 and 2m in plot

Sp_1 = average foliar sample of plants between 1 and 2m

Ss = surface of the plot

8.3 Results and discussion

8.3.1 Correlation of two plant density assessment methods

As was mentioned (see section 8.2.3 Plant density), the plant density was evaluated in two ways. Here we will investigate the correlation between the two methods. In the x-axis, plant density was calculated using plant spacing and in the y-axis, plant density was calculated using the number of mats in the plot (Fig.8.4).

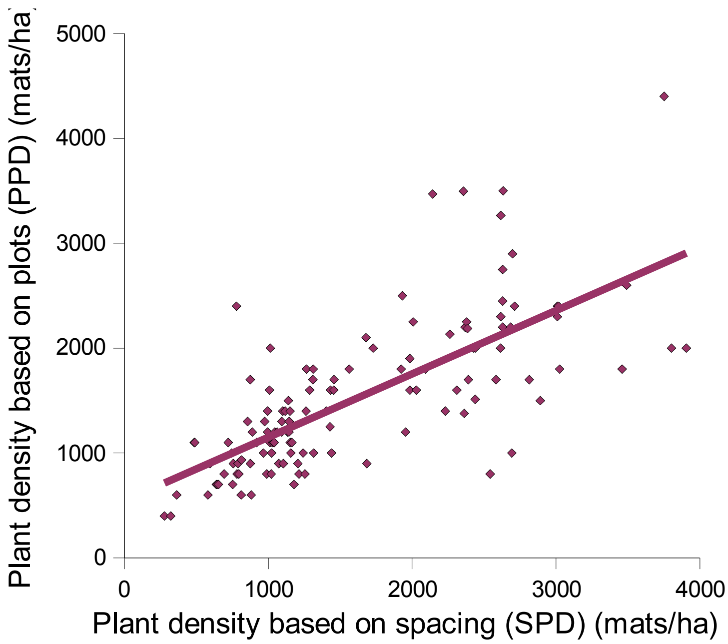


Figure 8.4 Correlation between plant density assessing methods

The linear regression indicates that the correlation is quite good, with a $R^2 = 0.521$ and a level of significance of 0.000. It can be expected that both estimation methods will lead to similar results.

8.3.2 Plant density

Plant density was evaluated in two different ways (see section 8.2.3 Plant density) accordingly, results of the two different methods will be presented separately. It is observed in table8.3 that Ruhengeri has the lowest spacing and accordingly highest plant density. Butare has a intermediate plant density whereas Kibungo has the lowest plant density.

Table 8.3: Plant spacing and densities in 3 Rwandan agro-climatic zones

	Plant spacing (m)			Plant density based on plot (PPD) (mats/ha)		
	Mean	Min	Max	Mean	Min	Max
Ruhengeri (Musanze)	2.17 a	1.63	4.15	2157 a	600	4400
Butare (Huye)	2.98 b	1.60	6.00	1248 b	400	2600
Kibungo (Ngoma)	3.23 b	2.64	5.57	1143 b	400	1800

Table 8.3 (second part): Plant spacing and densities in 3 Rwandan agro-climatic zones

	Plant density based on spacing (SPD) (mats/ha)		
	Mean	Min	Max
Ruhengeri (Musanze)	2325 a	581	3752
Butare (Huye)	1490 b	278	3906
Kibungo (Ngoma)	1006 c	322	1432

Data with different letters in the same column are significantly different in an one-way ANOVA Tuckey test at $\alpha = 0.05$

As the variances are homogenous, a Tuckey-test was executed. It is observed that plant spacing in Ruhengeri differs significantly from plant spacing in Butare (0.000) and Kibungo (0.000). Plant spacing in Butare and Kibungo do not differ significantly. The data on plant density based on plots (PPD) suggest that Ruhengeri differs significantly from Butare (0.000) and Kibungo (0.000). Butare and Kibungo no longer differ significantly. Plant density based on spacing (SPD) differs significantly in all three districts. Ruhengeri differs from Butare (0.000), and Kibungo (0.000). Kibungo and Butare differ significantly as well (0.003).

It is concluded that in the Birunga agro-climatic zone (ACZ), high rainfall and short dry season allow close plant spacing and high plant density. SPD decreases with decreasing rainfall and increasing dry season, and the highest SPD is recorded in the Birunga ACZ followed by the Central plateau ACZ and the Eastern plateau ACZ respectively.

8.3.3 Bunch weight

If we have a look at mean bunch weights in the 3 agro-climatic zones (Table 8.4) it is seen that Kibungo produces the heaviest bunches. In Butare bunches are a lot lighter than in the rest of the country, despite the low plant densities.

Table 8.4: Mean bunch weights in 3 Rwandan agro-climatic zones

	Bunch weight (kg)		
	Mean	Min	Max
District			
Ruhengeri (Musanze)	15.7 a	5.7	32.0
Butare (Huye)	11.9 b	7.3	22.3
Kibungo (Ngoma)	20.8 c	9.5	37.4

Data with different letters in the same column are significantly different according to a one-way ANOVA Tamhane T2 test

A Levene test pointed out that bunch weight variances were not homogeneous, thus a Tamhane T2 test was executed. This test pointed out that bunch weights differ significantly in the different agro-climatic zones. Bunches in Kibungo are significantly heavier than in Ruhengeri (0.000) and Butare (0.000). Bunch weight in Ruhengeri differs significantly from that in Butare (0.001).If we have a closer look at the relationship between plant spacing and bunch weight, we can conclude that our data do not suggest a correlation between these two parameters (Fig.8.5). A linear regression indicates a R^2= 0.059 between SPD and bunch weight and a R^2= 0.007 between PPD and bunch weight.

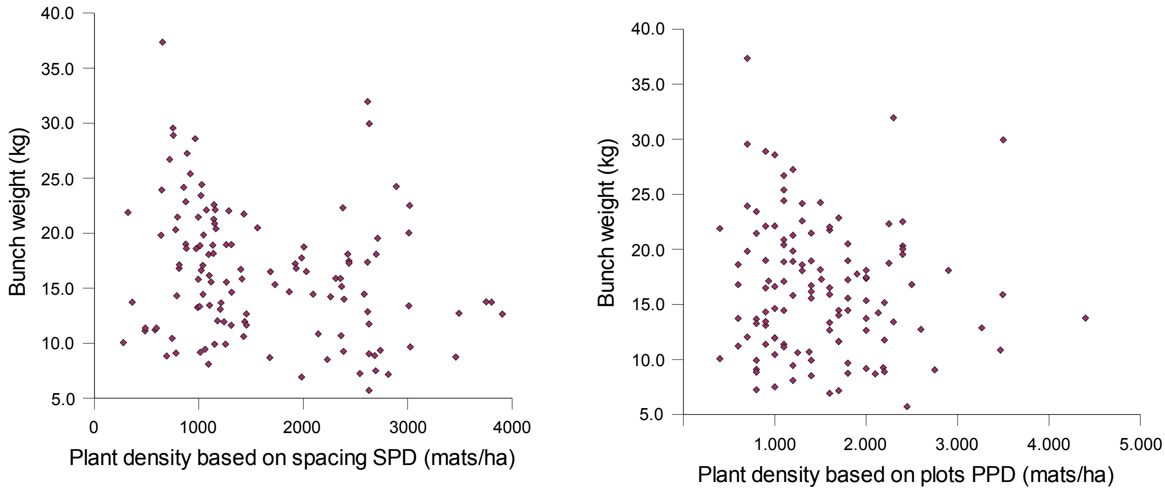
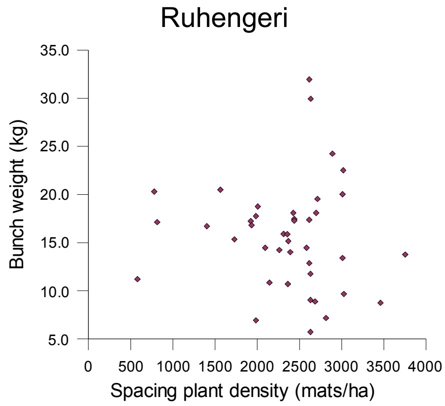
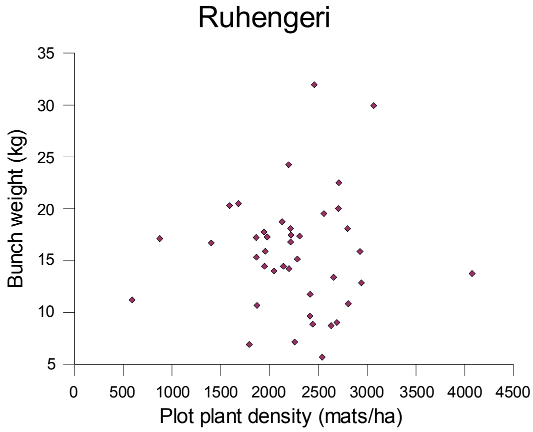


Figure 8.5 Plant density vs. bunch weight

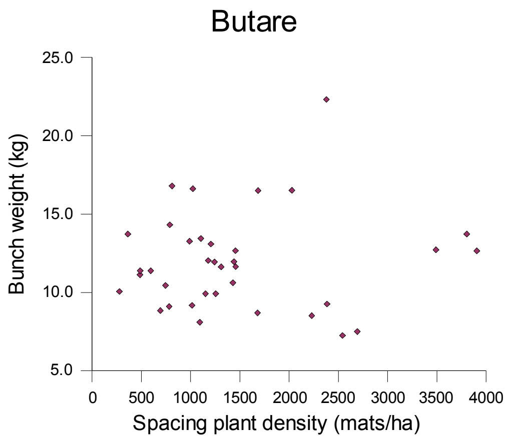
The relationship between plant density and bunch weight was investigated separately in each agro-climatic zone, the results are presented in Fig.8.6. It is observed that only in Kibungo the linear regression was significant (R^2=0.223 and R^2=0.178). It is suggested that: good management practices such as uniform spacing and mulching, explain why the relationship holds in Kibungo and not in Butare and Ruhengeri. It is observed that plant density in Kibungo ranges from 500 to 1500 mats/ha, whereas in Ruhengeri and Butare it ranges from 500 to 4000 mats/ha. Within fields plant spacing is also more uniform in Kibungo than in the other sites studied.



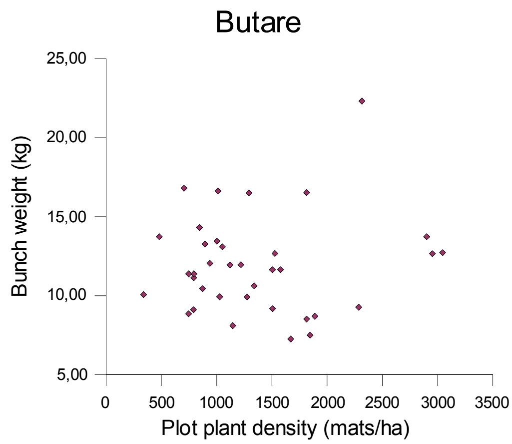
$R^2 = 0.005$



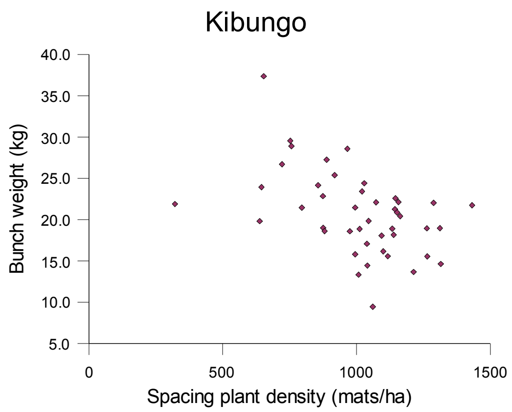
$R^2 = 0.002$



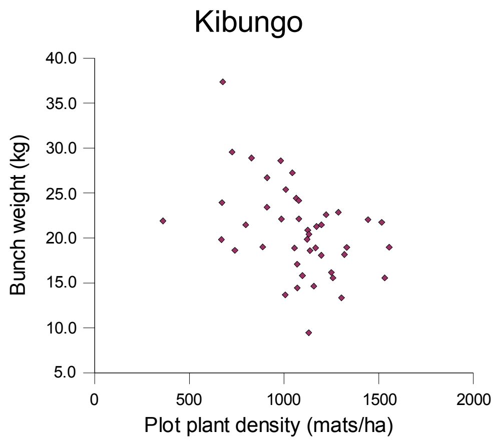
$R^2 = 0.005$



$R^2 = 0.009$



$R^2 = 0.223$ (0.001)



$R^2 = 0.178$ (0.004)

Figure 8.6: Spacing plant density and plot plant density versus bunch weight in 3 agro-ecological zones. R^2 and significance values, obtained through a linear regression

It is suggested that factors other than plant density e.g. soil fertility, are more important in determining bunch weight.

8.3.4 Yield

The most important characteristic of a banana plantation is its yield, but on-farm it is nearly impossible to measure it. Following the method explained (see section 8.2.5 Yield estimates) we calculated yields (Table 8.5). It is seen that highest yields are realized in Ruhengeri, followed by Kibungo. Lowest yields are obtained in Butare.

Table 8.5: Banana yield in 3 Rwandan agro-climatic zones

	Yield based on spacing (kg/ha)			Yield based on plots (kg/ha)		
	Mean	Min	Max	Mean	Min	Max
Ruhengeri (Musanze)	35761 a	6513	83608	35953 a	6730	104829
Butare (Huye)	17810 b	2795	53094	15072 b	4025	50203
Kibungo (Ngoma)	20396 b	7051	31131	23222 c	8758	38854

Data with different letters in the same column are significantly different according to ANOVA Tuckey test $\alpha = 0.05$

It is seen in Table8.5 that yields calculated using SPD are significantly higher in Ruhengeri than in the other agro-climatic zones. Ruhengeri differs from Kibungo (0.000) and Butare (0.000), yields in Butare and Kibungo do not differ significantly.

If we have a look at yields calculated using PPD it is observed that all differences are significant. Ruhengeri differs from Kibungo (0.000) and Butare (0.000), Kibungo and Butare differ significantly as well (0.013).

Kibungo is traditionally considered a banana growing area. It is observed that despite the fact that heaviest bunches are produced in Kibungo, yields are not highest. This confirms the hypothesis that high bunch weights are often wrongly linked with high yield per ha. An on-station trial executed in Rwanda from 1960 to 1969, pointed out that yields are highest in the period August-October, 4-5 months after the peak rainfall. Average number of harvested bunches and bunch weight increased in the period June-September (Delepierre, 1970 sited by Gowen, 1995). This variation is not accounted for in the present study.

8.3.5 Influence of density on yield

As was mentioned before (see section 6.2 Plant density), yield is expected to rise with rising density up to a certain maximum. We investigated this relationship in our own data. The result is presented in Fig.8.7.

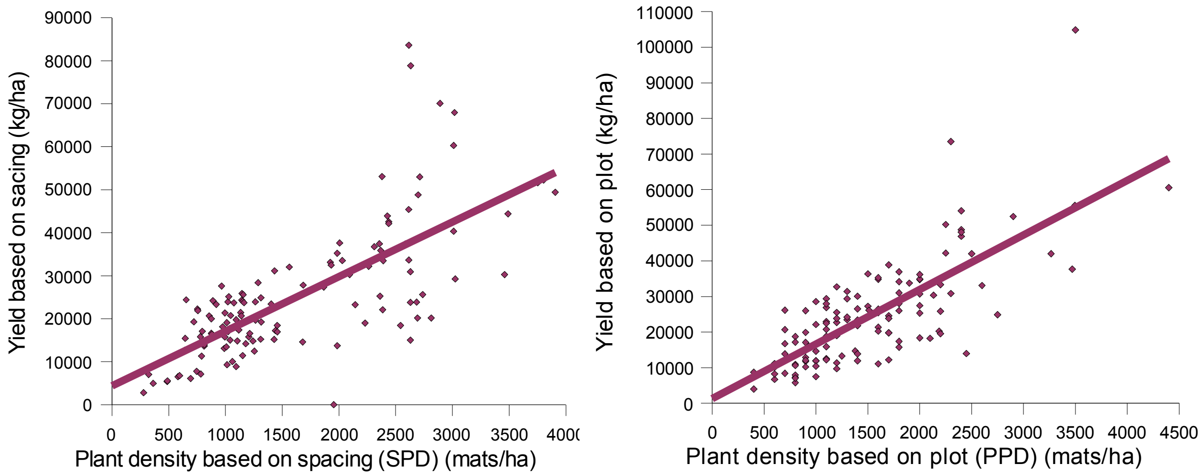


Figure 8.7: Influence of plant density on yield

As can be observed, the correlation is quite good, but we cannot express this statistically. Indeed variables in the x and y-axis are not independent, since yield is a function of density. If we would execute a regression, we would see that about half of the variation is accounted for by the regression, SPD has a R^2= 0.521 and PPD a R^2=0.563. We cannot make any statements on the significance of the model, since assumptions of regression models are not respected.

It can be concluded from the data that higher densities lead to higher yield. But caution must be taken on advising farmers to plant at higher densities. It is suggested in the CIALCA annual report (2007) that higher densities are linked to a higher soil fertility and rainfall. These results imply that farmers adapt management to prevailing conditions. On-station density trials will have to point out if high densities are optimal in low fertility and rainfall regions as well.

8.3.6 Farmers' estimate of yield versus calculated yield

Yield was estimated using three different methods (see section 8.2.5 Yield estimates). Here we will compare farmers' estimates of yield and the calculated yield. Four outliers were removed from farmers' estimates, as they were higher than 200,000 (kg/(ha.year)) which is impossible. Fig.8.8 depicts farmers estimates of yield versus calculated yield. Both relationships are not pronounced, yield based on plots and farmers' estimate has a R^2= 0.102 and yield based on spacing has a R^2= 0.049. These R^2 values indicate that care should be taken when evaluating yield figures given by farmers.

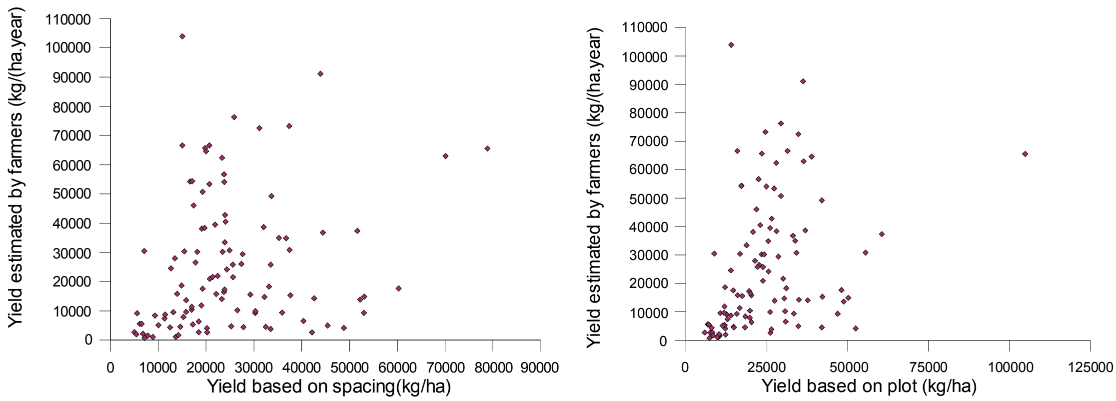


Figure 8.8: Farmers' estimated yield versus calculated yield

8.3.7 Leaf area index (LAI)

It is observed in Table8.6 that highest LAI is realized in Ruhengeri, followed by Butare and Kibungo. It is noted that LAI is very low compared to the optimal LAI of 4.5 to 6 as suggested by Turner (2007) and Robinson and Nel (1989). Most fields are intercropped which could explain why farmers want to have light passing between the plants.

Table 8.6: Leaf area index in three Rwandan districts

	LAI		
	Mean	Min	Max
Ruhengeri (Musanze)	2.1 a	0.4	5.3
Butare (Huye)	1.4 b	0.3	4.2
Kibungo (Ngoma)	1.2 b	0.7	1.8

Data with different letters in the same column are significantly different according to a one-way ANOVA Tuckey test α = 0.05

An one-way ANOVA pointed out that differences between Ruhengeri and Butare are significant (0.000) as is the difference between Ruhengeri and Kibungo (0.000). Butare and Kibungo do not differ significantly.

A limitation of the applied procedure is the short period of time during which the survey was executed. Indeed Turner (1998) mentioned that the LAI of a plantation changes significantly throughout different seasons. Hence we could not take this variation into account.

8.3.8 Influence of altitude on yield

It is expected that altitude has an impact on yield as fields at a higher altitude should produce less, due to a lower temperature. It is also possible that lower temperature leads to lower disease and pest pressure, which has a positive effect on yield. It is seen in Fig.8.9 that no clear correlation is present in our data. Yield calculated using PPD obtains a R^2= 0.039 and yield calculated using SPD obtains a R^2= 0.111.

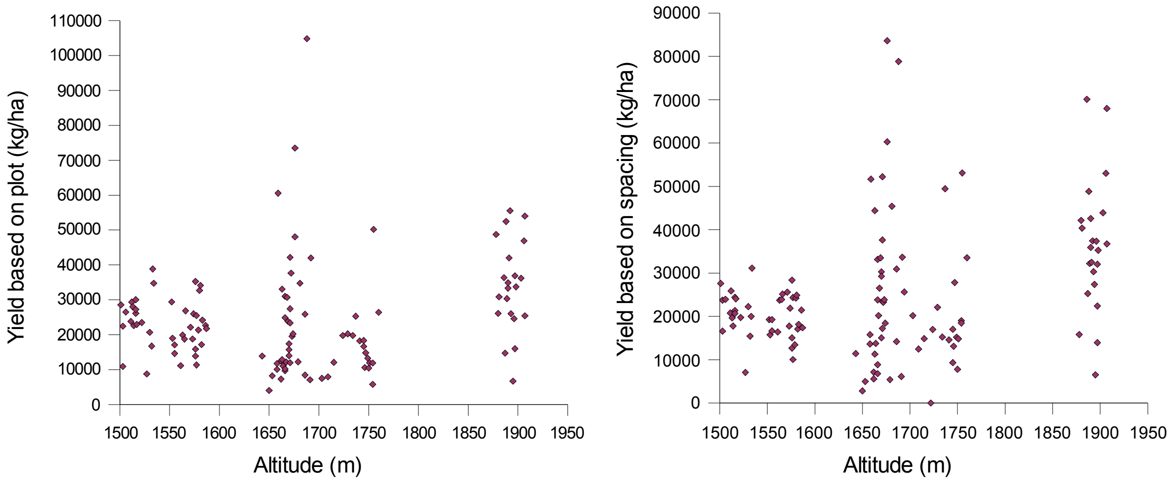


Figure 8.9: Influence of altitude on yield

8.3.9 Intercropping and banana yield

Most agriculture in Rwanda is subsistence agriculture and fields are intercropped. We examined if intercrops influence banana density, bunch weight and yield. Therefore we divided the intercrops in 5 arbitrary groups. Crops that were encountered in less than five fields (e.g. coffee), were not considered. It should be taken into account that in the present study, intercropping is considered as a static land use. Crop rotations are not considered e.g. monocrops might be intercropped in the next season. Variances of none of the data depicted in table 8.7 are homogenous, thus a Tahmane T2 test was executed to verify if differences were significant.

Table 8.7: Intercropping and plant density

		Plant density based on spacing (SPD) (mats/ha)	Plant density based on plots (PPD) (mats/ha)	Observations
	Monocrop	1269 b	1311 b	N= 31
Banana &	Beans	1325 b	1222 b	N= 9
	Cocoyam	2339 a	2148 a	N= 26
	Beans with cocoyam	1735 ab	1525 b	N= 15
	Cassava	1059 b	1117 b	N= 18

Data with different letters in the same column are significantly different according to a one-way ANOVATamhane T2 test with α = 0.05

Table 8.7 indicates that highest SPD is encountered in fields intercropped with Cocoyam (*Colocasia esculenta*). Cocoyam plant densities significantly differ from bean intercrops (0.001), monocrops (0.000), and cassava (*Manihot esculenta*) intercrops (0.000). Cocoyam SPD does not differ significantly from cocoyam with beans. Beans with cocoyam intercrops SPD do not differ significantly from any other SPD. Monocropping and bean intercropping do not differ significantly from densities involving cassava as an intercrop.

If we have a look at PPD, it is observed that only Cocoyam PPD differs significantly from the other PPD. Cocoyam PPD is higher than cocoyam with bean (0.012), monocrop (0.001), bean intercrops (0.001) and cassava intercrops (0.000).

Table 8.8: Intercropping and banana yield

		Bunch weight (kg)	Yield based on spacing (kg/ha)	Yield based on plot (kg/ha)	Observations
	Monocrop	21.1 a	25116 ab	26687 a	N= 31
Banana &	Beans	15.7 abc	20499 bc	19857 ab	N= 9
	Cocoyam	15.4 b	35342 a	32709 a	N= 26
	Beans with cocoyam	16.5 ab	27001 ab	25642 a	N= 15
	Cassava	11.8 c	12101 c	12924 b	N= 18

Data with different letters in the same column are significantly different according to a one-way ANOVA Tamhane T2 test with α = 0.05

Table 8.8 shows that highest bunch weights are realized in monocropping. Bunch weights from monocropping differ significantly from bunch weights of cocoyam intercrops (0.007) and cassava intercrops (0.000). Bunch weights of bean with cocoyam intercrops differ significantly from cassava intercrops (0.015), and cocoyam intercrops differ significantly from cassava intercrops (0.044). It is noted that bean intercrop bunch weights do not differ significantly from any other treatment. It is suggested that this is due to the low number of measurements available for bean bunch weights.

Yield calculated with SPD is highest in cocoyam intercrops. Cocoyam SPD differs significantly from bean intercrop yield (0.011) and cassava intercrop yield (0.000). Monocrop SPD yield differs from cassava intercrop (0.002), and bean cocoyam intercrop also differs from cassava intercrop SPD yield (0.005).

Yield calculated using PPD is highest in cocoyam intercrops, however it only differs significantly from cassava intercrops (0.000). Monocrop PPD yields differ significantly from cassava (0.004), and bean and cocoyam intercrops differ from cassava as well (0.004).

When interpreting these figures from intercropped fields, one should realize thatadditional yield is realized from the accompanying plants. In the present study, only the banana yield is considered and no predictions can be made on the yield of the accompanying crops. Besides these intercrops have their own specific climatic requirements so that their effect should be tested per agro-climatic zone.

Fig.8.10 illustrates the occurrence of different intercrops, throughout the different agro-climatic zones. Only fields planted with bananas were considered. It is observed that cocoyam intercrops occur most in Ruhengeri, cassava intercrops on the other hand occur most in Butare and Monocrops occur most in Kibungo. The occurrence of monocropping is more linked to management than to climatic conditions. Cocoyam occurs most in the high rainfall area. Cassava is a crop which is very often cultivated in poor soils like the region around Butare, which is also reflected in the banana yield (Table 8.8). As Verwimp (2002) noted, households with smaller fields will tend to intercrop them, whereas households with larger fields will readily apply monocropping. Most monocropped fields are found in Kibungo, where largest fields were encountered (Fig.8.10 and table 8.10).

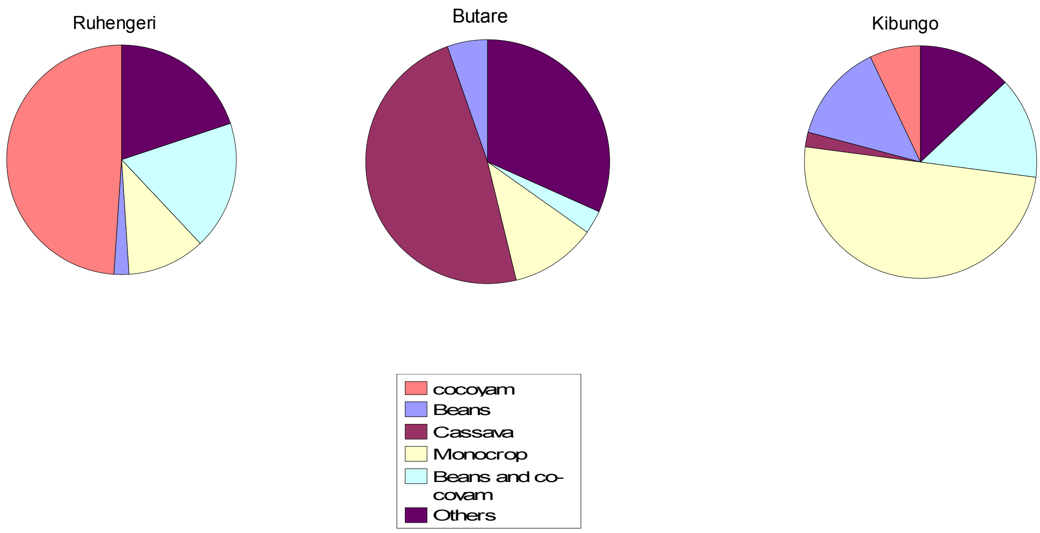


Figure 8.10: Occurrence of different banana intercrops in 3 Rwandan districts

8.3.10 Distance to the homestead and plant density

Table 8.9: Distance to the homestead and plant density

	Distance to homestead		
	Close	Far	Significance
Plant density (mats/ha)	1588	1500	Not significant
Plant density (adult plants/ha)	2064	1544	0.02
Number of adult plants per mat	1.25	1.11	Not significant
Bunch weight (kg)	16.8	15.7	Not significant
Yield (kg/ha)	26116	22462	Not significant
	N = 73	N = 48	

Results obtained with a T-test at significance 0.05

It is assumed that fields closer to the homestead receive more manure and household wastes and thus have more organic matter in the soil, leading to higher bunch weight and yield. Fields are considered close to the homestead if they border the house, if they do not border the homestead, they are considered as far away.

A T-test was applied, since only two treatments are compared. The results are presented in table 8.9. It is seen that plant density measured in mats/ha does not differ significantly in fields close to the homestead and those further away. If the plant density is measured in adult (higher than 2 m) plants/ha, differences become significant.

One would think that fields close to the homestead thus have a larger number of adult plants per mat, oddly enough this is not confirmed by our data. Bunch weight and yield figures do not differ significantly across fields close to the homestead and further away. It is suggested that to discover differences in densities and yields, only mats close to the homestead should be considered, as household wastes are expected to be thrown only around the house.

8.3.11 Field size

It is observed in table8.10 that field size are very small in Rwanda (note that not the farm size is evaluated; a farm being all the fields cultivated by one household). All fields are a lot smaller that 1 ha.

Table 8.10: Field size in three Rwandan districts

	surface of field (m²)		
	Mean	Min	Max
Ruhengeri (Musanze)	331 a	67	1307
Butare (Huye)	1155 b	106	3938
Kibungo (Ngoma)	1694 c	355	4623

Data with different letters in the same column are significantly different according to a ANOVA Tukey test $\alpha = 0.05$

According to the Tuckey test, all differences are significant, Ruhengeri differs significantly from Butare (0.000) and from Kibungo (0.000). Butare and Kibungo also differ significantly from each other (0.019).

If we have a look at the correlation between altitude and field size (Fig.8.11), it is observed that smallest fields are encountered at the highest altitudes. A non-linear inverse regression obtained a $R^2 = 0.215$. More research will be needed to elucidate this relationship. It is suggested that higher fields are located at the feet of volcanoes and thus profit from fertile soils. This allows high yields and smaller fields are needed to support a high population. As population rises, field sizes decline, as moving fields even higher is then no longer an option in Rwanda. It is also observed that a smaller field size results in a reduced food security and it is suggested that smaller plots will be accompanied by higher population density.

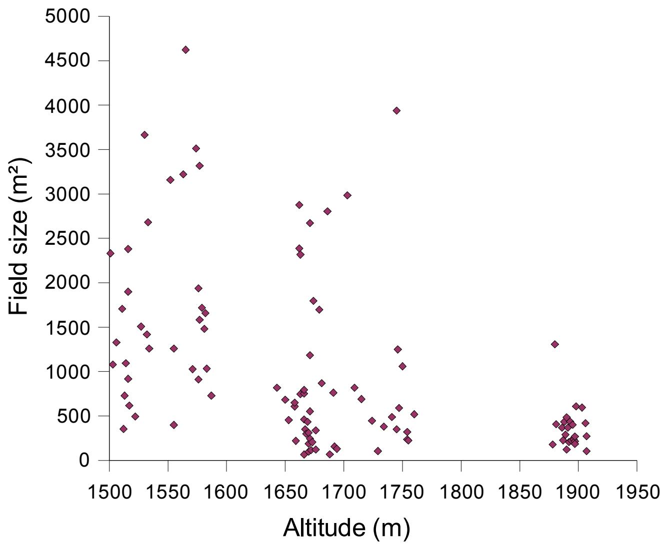


Figure 8.11: Influence of altitude on field size

8.3.11.1 Field size and density

It is expected that smaller fields will be managed more intensely, and thus have a higher density. Fig.8.12 depicts plant density as a function of field size.

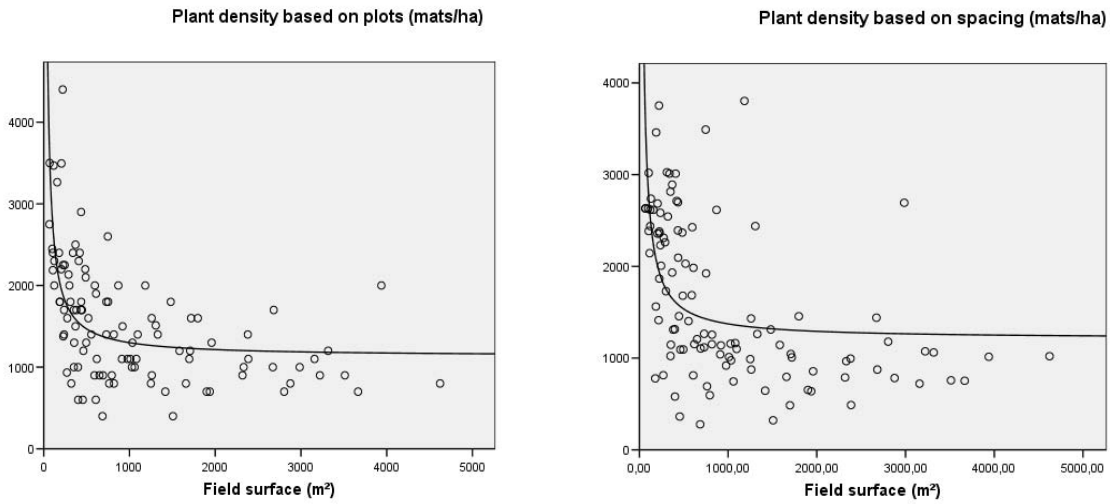


Figure 8.12: Influence of field size on plant density

It is observed in Fig.8.12 that an inverse relation occurs between PPD and field size. A non-linear inverse regression obtained a R^2= 0.396 with a significance of 0.000. The same observations are made for SPD and field size, here a non-linear inverse regression obtained a R^2=0.277 with a significance of 0.000. These data suggest that fields smaller than 500 m² will be very densely planted, whereas plots bigger than 500 m² will all be planted at roughly the same density.

8.3.11.2 Field size and yield

Previous results pointed out that smaller fields are more densely planted; therefore it is expected that yields will also be higher. Fig.8.13 depicts yield as a function of field size.

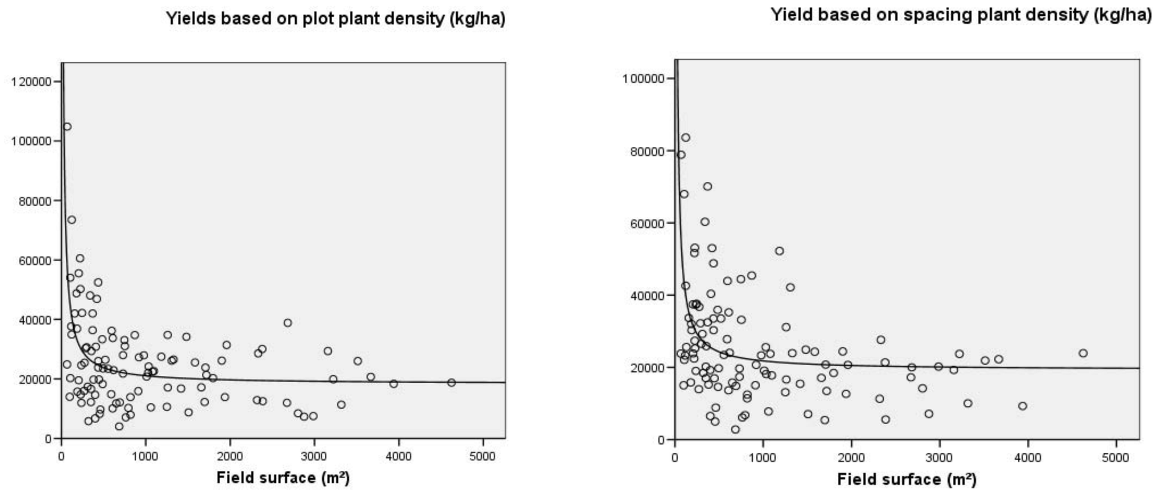


Figure 8.13: Yield as a function of field size

It is observed in Fig.8.13 that an inverse relationship between yield and field size prevails. A non-linear inverse regression between PPD yield and field size obtained a R^2 = 0.247, with a significance of 0.000. The same regression on SPD yield and field size obtained a R^2=0.190, with a significance of 0.000. It is suggested that households dependening on small plots will manage their fields more intensively. However if plots are large enough to provide enough food for the family, incentives to intensify their management will be less.

8.3.12 Farmer perception on plant density

A questionnaire was designed to interview farmers on banana plant density. Farmers were asked about what they perceived as constraints to banana production, and why certain plant spacing is applied. Answers differed according to regions. In the current study, only about 10 min were spent per farmer. Nevertheless results of the questionnaires are here summarized.

Major constraints to banana production throughout the country are: the small size of fields, diseases and lack of organic fertilizer. In Ruhengeri it was mentioned that most mats are old, thus limiting production. In Butare it was mentioned that irregularity of rainfall was a constraint to banana production. The wind was mentioned as a constraint to production in Kibungo (Fig.8.14).

Figure 8.14: The wind as a constraint to banana production

When asked why a certain plant density was applied, answers were not straightforward. In Ruhengeri it was often mentioned that the same spacing was applied as farmers' parents had previously applied. In one of the villages surveyed near Butare, it was mentioned that the presence of intercrops was important in determining spacing and in one of the villages near Kibungo it was mentioned that bunch size was important in determining plant spacing with a larger spacing leading to bigger bunches. It was mentioned by some farmers that varieties producing more suckers were planted at larger spacing (e.g. Gisubi) to allow the suckers to mature under minimal competition. It was also mentioned that initial plant spacing was lost due to plantation age and formation of suckers. Farmers are quite aware of the fact that smaller spacing leads to smaller bunches. Therefore they often stated that if they owned larger fields, they would plant at larger spacings to have bigger bunches. This is confirmed by our observations, which indicate that smaller fields are planted more densely. These results suggest that maximal production (kg/ha) is not the main objective of farmers. It was further stated by farmers, that spacing applied to beer bananas is the same as spacing applied to cooking bananas. It is suggested that accessibility of markets is of importance in determining management practices. Okech *et al.* (2005) observed that choice of banana type (beer, cooking or dessert) depended on socio-economic factors. They found that in Kibungo cooking bananas dominated, due to better accessibility of markets. In our survey, farmers in Kibungo stated that they applied certain spacing in order to have big bunches, this suggests that big cooking type bunches are more easily marketable. These results should be used to direct future research rather than as sound conclusions.

8.3.13 Plant density in Rwanda

Here the data gathered in Rwanda during CIALCA characterization survey and data gathered during the current survey are combined. Table 8.11 indicates plant densities, it is observed that Ruhengeri has highest density, followed by Cyangugu, Butare and Bugesera. Lowest planting density is encountered in Kibuye, Kibungo and Ruhango.

Table 8.11: Plant densities in Rwanda

Site	Plant density based on spacing (SPD) (mats/ha)		
	Mean	Min	Max
Bugesera	1389 ab	611	3645
Butare	1490 ab	278	3906
Cyangugu	1890 bc	875	3764
Kibungo (our data)	1006 a	322	1432
Kibungo (CIALCA data)	1211 a	899	1811
Kibuye	1290 a	884	1815
Ruhango	1352 a	563	3351
Ruhengeri	2326 c	581	3752

Data with different letters in the same column are significantly different in an one-way ANOVA Tuckey test at α = 0.05

Table 8.12 depicts yield data of different sites studied. It is seen that highest yield is realized where highest densities occur. Highest yield is realized in Ruhengeri, followed by Cyangugu, Kibungo and Kibuye. Lowest yields are realized in Bugesera, Butare and Ruhango. Fig. 8.15 depicts the spatial distribution of density.

Table 8.12: Banana yields in Rwanda

Site	Yield based on spacing (kg/ha)		
	Mean	Min	Max
Bugesera	15535 a	5325	35107
Butare	17810 a	2795	53094
Cyangugu	27697 bc	9416	50754
Kibungo (our data)	20397 ab	7051	31131
Kibungo (CIALCA data)	24250 ab	6423	39422
Kibuye	23752 ab	2894	54233
Ruhango	17932 a	1927	37317
Ruhengeri	35731 c	6513	83608

Data with different letters in the same column are significantly different in an one-way ANOVA Tuckey test at α = 0.05

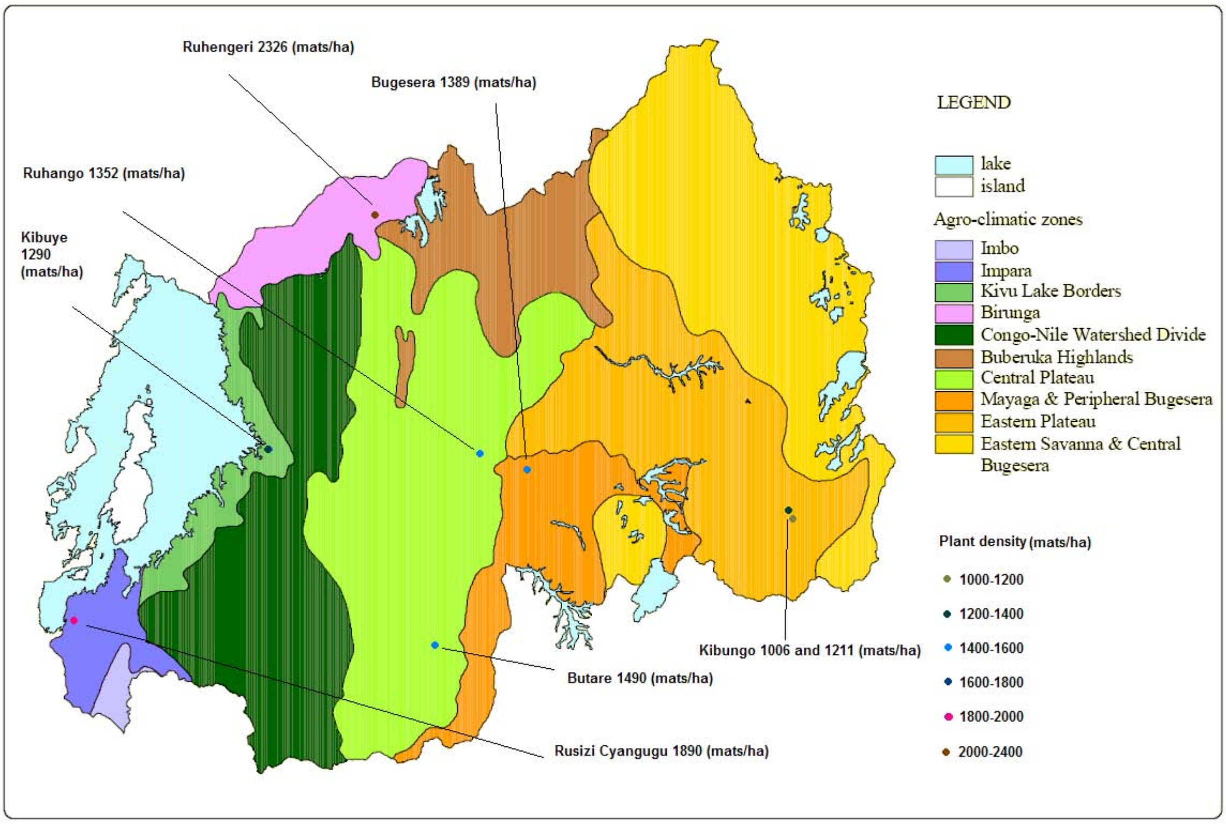


Figure 8.15: Plant density distribution across agro-ecological zones in Rwanda (modified from Van Ranst and Verdoodt 2003)

It is observed that highest plant density is encountered in Birunga and the Impara agro-climatic zone (ACZ). Altitude in Impara ACZ ranges between 1400 and 1900 m.a.s.l., as altitude increases, rainfall increases from 1300 to 2000 mm while temperature decreases from 22°C to 19°C. Soils are very fine and clayey, developing from basalt and having a very high agricultural potential, if not leached out by abundant rainfall. The Birunga ACZ ranges from 1900 to 2500 m.a.s.l.. It is comprised of fertile volcanic soils, and has a regularly distributed rainfall, varying between 1300 and 1600 mm.

Other densities are not differing significantly, they are spread over the ACZ of Kivu lake border, Central plateau, Mayaga and peripheral Bugesera and the Eastern plateau. Kivu lake border ACZ has moderately fertile soils developing on shales and granites on gently sloping hillsides, while abrupt slopes are strongly eroded, leaving skeletal soils. Rainfall varies between 1150 and 1300 mm, but it is not evenly spread throughout the ACZ, the Kibuye region, where our measurements were taken, is driest. Altitude ranges between 1460 and 1900 m.a.s.l. and temperatures ranges between 19 and 22.5°C. The central plateau mainly consists of two soils developed on granitic material, if the humus containing layers are retained, cultivation of a whole range of crops is possible. Average altitude is 1746 m.a.s.l., mean temperature is 19°C and annual rainfall is 1298 mm. Mayaga and peripheral Bugesera ACZ has a very variable soilscape. In Mayaga rock outcrops characterize the hill tops. But humus-rich, gravelly soils are found on the upper slopes, while younger soils of the footslopes generally have higher productivity. The Bugesera part is characterized by deep strongly weathered soils, intersected by dry valleys with very gentle slopes. Altitude is 1403 m.a.s.l., mean temperature is 21°C and average annual rainfall is 1101 mm. The Eastern plateau ACZ is characterized by low rainfall of 900 to 1000 mm. Hilltops are covered with deep humus-rich soils. On convex upper slopes, outcropping laterite crusts and gravelly soils have been reported. The fields on the steep slopes are strongly eroded and are mainly used as pasture land. In the East, shallow degraded soils dominate the soilscape and only the soils of the footslopes have some agricultural potential.

It can be concluded from the above that highest plant density is applied on fertile soils with high rainfall. The above is even more clear if plant densities are placed on a rainfall distribution map (Fig.8.16). It is observed that high rainfall (>1400 mm) is accompanied by high plant densities (>1800 plant/ha) while low rainfall (between 1000 and 1200 mm) is accompanied by lower plant densities (between 1000 and 1500 mats/ha).

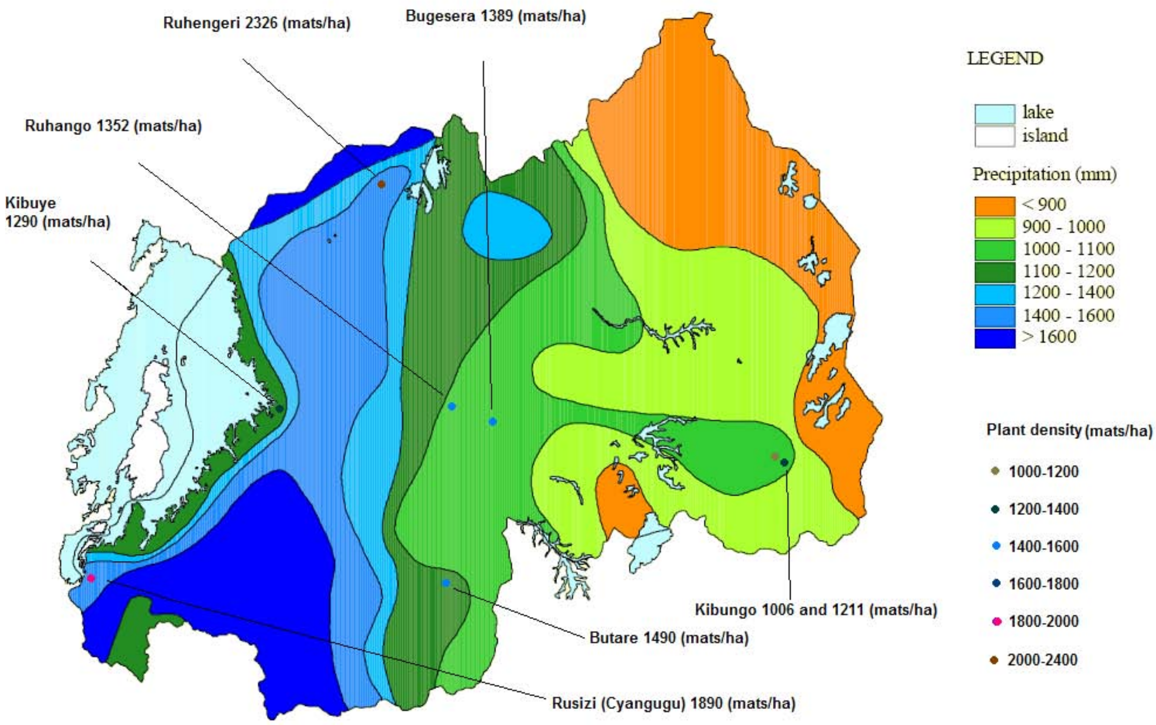


Figure 8.16: Banana plant density and rainfall distribution in Rwanda (modified from Van Ranst and Verdoodt 2003)

8.4 Conclusion

It can be concluded that spacing and plot plant density assessment gave similar results. No correlation was found between spacing and bunch weight, as treatments across different farms vary too much. Yield (kg/ha) rises with rising density but caution should be taken to advise high plant densities to farmers as no causal relationship has yet been proven. It is noted that average yields are higher than one might expect in low input subsistence farmers fields, ranging between 15.4 and 35.7 t/ha. Caution should be taken when using such yield data estimated by farmers, as they differ greatly from the calculated yields. Yields in fields bordering the homestead do not differ significantly from yields in fields not bordering the homestead. It is suggested that to find a relationship, if any, individual mats should be considered, and not whole fields. The importance of intercrops is reflected in the low LAI found (1.2-2.1) in banana plantations, as enough light needs to pass to the accompanying crops. Cassava and cocoyam are good indicators of density and yield of banana plantations. This is seen in their geographical distribution, cocoyam occuring in wet highlands with high density plantations and cassava occuring in drier, lower areas with lower plant density. It is observed that a small field size leads to a higher plant density, but the relation is not as clear for yield. Plant densities in Rwanda are low and vary little, however high plant densities are encountered in areas with high rainfall and fertile soils.

9. Varieties encountered in 3 Rwandan districts

In each surveyed field, farmers were asked to identify all varieties, and indicate their main uses (beer, cooking or dessert). The results are presented here. Previous work in Uganda pointed out that East African highland bananas can be divided in 5 clone sets namely: Beer, Musakala, Nakabululu, Nakitembe and Nfuuka (Karamura, 1998). Nsabimana and van Staden (2005) suggested that this classification can be used for Rwandan cultivars as well. It is assumed that names of varieties are the same all over the country and that farmers can distinguish them.

9.1 Banana varieties encountered in Rwanda

It is observed in Table9.1 that 49 different varieties were identified by farmers. Only six of those were not known in literature. In Table9.1 they are further subdivided in different uses, groups, sub-groups and clone sets. Of the 49 different varieties, 30 are classified as East African highland bananas. Next to each variety name, the use as indicated by farmers is depicted. It is observed that the varieties not belonging to the East African highland bananas, are exclusively used as dessert or brewing bananas. East African highland bananas are used either for cooking of for brewing. It can be observed that uses cited by farmers do not always coincide with those found in literature.

Table 9.1: Varieties encountered in Rwanda (Classification: Karamura and Nsabimana, personal communication);*Beer, **Cooking and ***Dessert

Rwanda

Variety	Use	Group	Sub-group	Clone-set for EAHB
Gisubi*	Beer	AB	Ney Poovan	NA
Gisukari*,***	Beer/dessert	AAA	Red/Green Red	NA
Gros Michel*,***	Beer/dessert	AAA	Gros Michel	NA
Henja*	Beer	ABB	?	NA
Imbotabota*	Beer	AAA	Ibotabota	NA
Indaya*	Beer	AAA	Ibotabota	NA
Ingurube*,***	Beer/dessert	AAA	Cavendish	NA
Inkonywa**	Cooking/roasting	AAB	Plantain	NA
Kamaramadam*,***	Beer/dessert	?	Prata	NA
Kamaramasenge***	Dessert	AAB	Sukali-Ndizi	NA
Kayinya*	Beer	ABB	Pisang Awak	NA
Mbogoya*	Beer/dessert	AAA	Gros Michel	NA
Fhia 25*	Beer	AAAA		NA
Poyo*,***	dessert	AAA	Cavendish	NA
Sultan*	Beer	AAA	?	NA
ImpudekazI**	Cooking	AAA	Lujugira-Mutika	?
Ingomba*	Beer	AAA	?	?
Inhira*	Beer	AAA	?	?
Intude**	Cooking	AAA	Lujugira-Mutika	?
Kibuye*	Beer	?	?	?
Mushantere*	Beer	?	?	?
Injagi**	Cooking	AAA	Lujugira-Mutika	Musakala
Inshakara**	Cooking	AAA	Lujugira-Mutika	Musakala
Inyoya**	Cooking	AAA	Lujugira-Mutika	Musakala
Mujuba**	Beer/cook	AAA	Lujugira-Mutika	Musakala
Intama**	Cooking	AAA	Lujugira-Mutika	Nakabululu
Intobe**	Cooking	AAA	Lujugira-Mutika	Nakabululu
Inyabutembo**	Cooking	AAA	Lujugira-Mutika	Nakabululu
Nyakitengwa**	Cooking	AAA	Lujugira-Mutika	Nakabululu
Umugumira*	Beer	AAA	Lujugira-Mutika	Nakabululu
Ingagara**	Cooking	AAA	Lujugira-Mutika	Nakitembe
Inyarwanda**	Cooking	AAA	Lujugira-Mutika	Nakitembe
Mbaziruma*	Beer/cook	AAA	Beer	Nakitembe
Nyiruhuni**	Cooking	AAA	Lujugira-Mutika	Nakitembe
Icyerwa*	Beer	AAA	Lujugira-Mutika	Nfuuka/Nakabululu
Icyerwa**	Cooking	AAA	Lujugira-Mutika	Nfuuka/Nakabululu
Indenge*	Beer	AAA	Lujugira-Mutika	Nfuuka
Ingaju **	Cooking	AAA	Lujugira-Mutika	Nfuuka
Ingote*	Beer	AAA	Lujugira-Mutika	Nfuuka
Insatsi **	Cooking	AAA	Lujugira-Mutika	Nfuuka
Intokatoke*	Beer	AAA	Lujugira-Mutika	Nfuuka
Intsikira**	Cooking	AAA	Lujugira-Mutika	Nfuuka
Intuntu*	Beer	AAA	Lujugira-Mutika	Nfuuka
Inyamico**	Cooking	AAA	Lujugira-Mutika	Nfuuka
Inyamunyo**	Cooking	AAA	Lujugira-Mutika	Nfuuka
Inyonza**	Cooking	AAA	Lujugira-Mutika	Nfuuka
Inyumbu*	Beer	AAA	Lujugira-Mutika	Nfuuka
Inzilabushera*	Beer/cook	AAA	Lujugira-Mutika	Nfuuka
Isha*	Beer	AAA	Lujugira-Mutika	Nfuuka

In Fig.9.2 the distribution of the different varieties across the country is depicted. It is noted that the unknown varieties occur fairly little, except Ingomba that occurs in 15% of the fields. Ingomba was known in literature to be a cooking type but is here considered as a beer banana, which might question its identification.

Fields have a given variety if it is mentioned by farmers. If one mat of a given variety is present, the field is considered as having the variety. It is observed that Kamaramasenge occurs most (50%). It is a sweet apple flavored dessert banana that is sold in local markets. It can be further observed that no variety is dominating Rwandan banana fields, on average 5.6 varieties are encountered in each field. Many varieties are very site specific, as 21 varieties occur in less than 5% of farmer's fields.

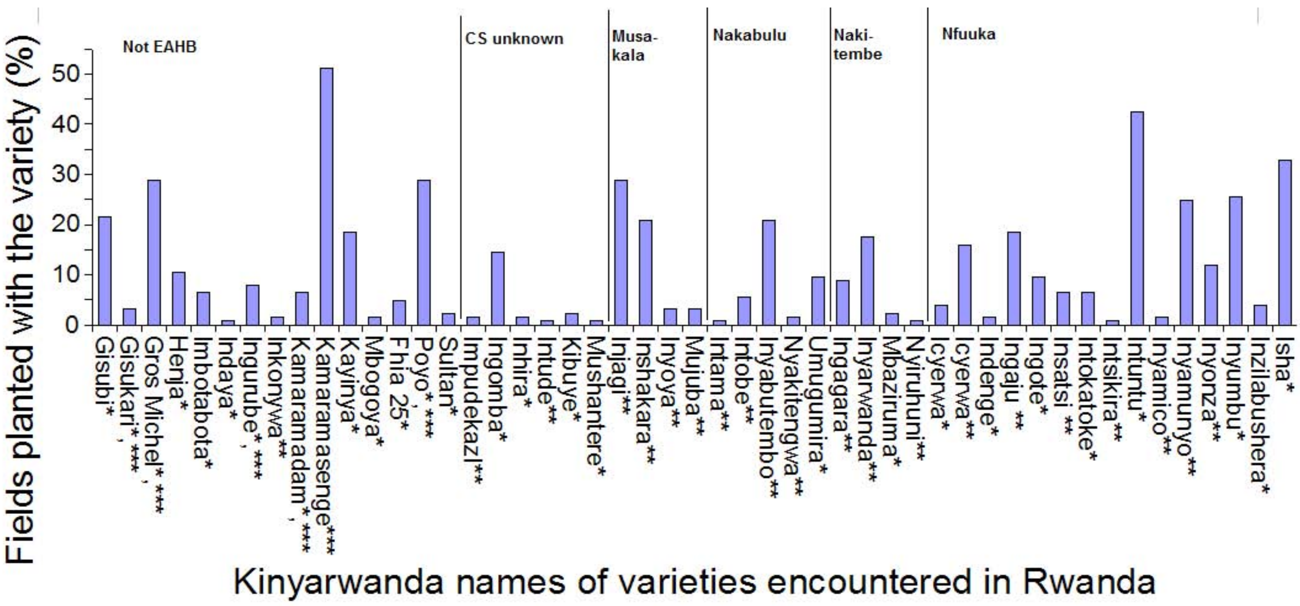


Figure 9.1: Different varieties of bananas encountered in Rwanda, classified according to the clone-set (CS). *Beer bananas, **Cooking bananas, ***Dessert bananas

Nsabimana et al. (2008) note that Gisubi multiplies very fast and outcompetes other varieties in banana stands. This leads to lower number of other varieties in fields having Gisubi but a correlation between the occurrence of Gisubi and the number of varieties in the field was not found in our data. Nsabimana et al. (2008) further state a negative correlation between altitude and amount of varieties encountered in fields. This correlation was not found in our data, fields bordering the homestead and those further away also had similar amounts of banana varieties.

9.2 Banana varieties encountered in Ruhengeri

In the district of Ruhengeri (Musanze) in the Birunga agro-climatic zone, two villages were surveyed, Cyuve and Muko. We will refer to them as the sectors Cyuve and Muko. Cyuve is located at an altitude of 1893 m.a.s.l. at the foot of the Birunga volcanoes. Muko is located in a valley close to the town of Ruhengeri, at an altitude of 1673 m.a.s.l.. The varieties encountered in both sectors are depicted in Fig.9.2 and Fig.9.3.

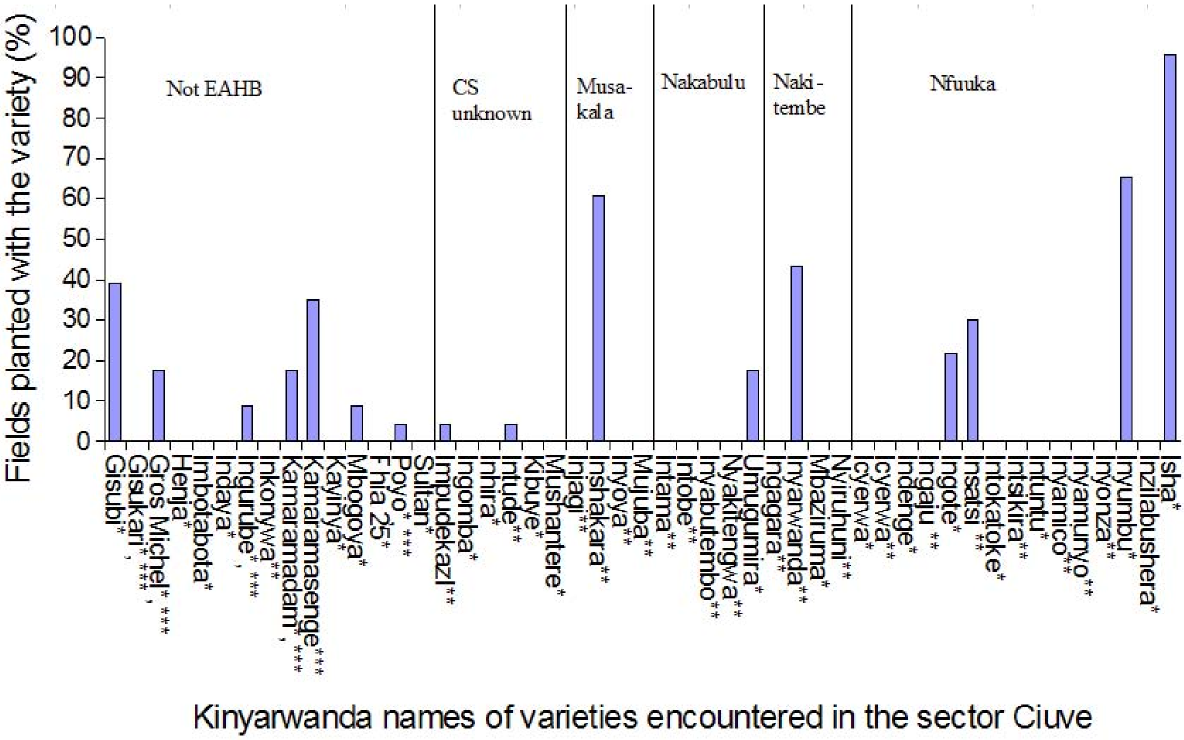


Figure 9.2 Different varieties of bananas encountered in Cyuve, classified according to clone-set (CS). *Beer bananas, **Cooking bananas, ***Dessert bananas

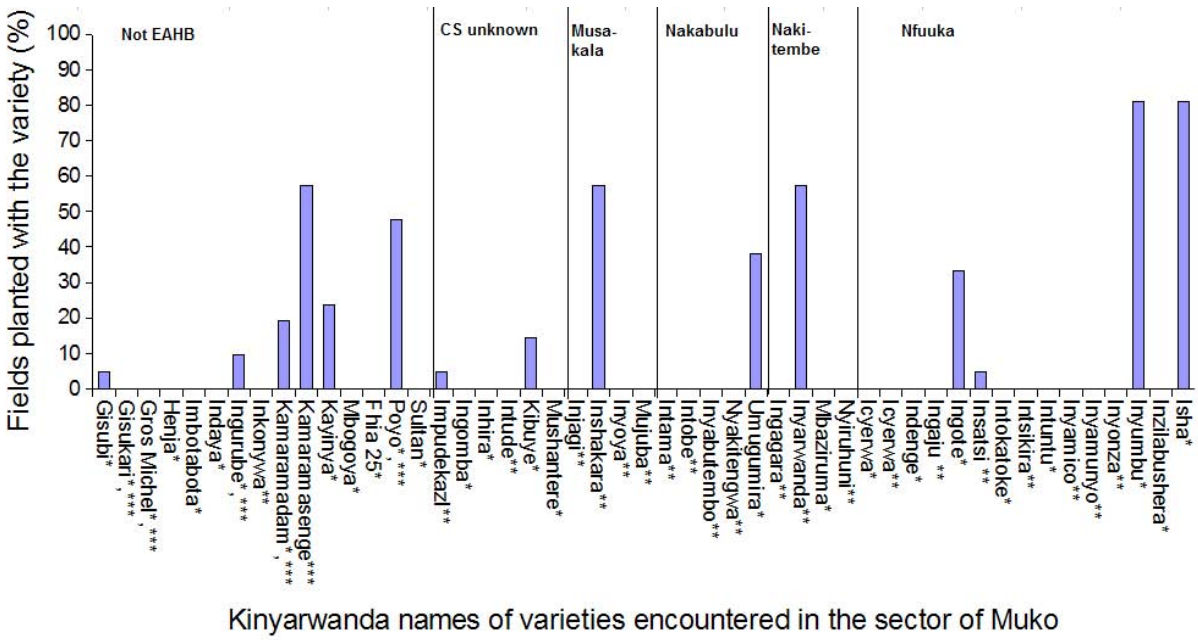


Figure 9.3: Different varieties of bananas encountered in Muko, classified according to clone-set (CS). *Beer bananas, **Cooking bananas, ***Dessert bananas

It is observed that all clone sets are present, and varieties encountered most are Isha and Inyumbu which both belong to the Nfuuka clone set.

9.3 Banana varieties encountered in Butare

In Butare (Huye) located in the agro-climatic zone of the central plateau, two villages were surveyed, Save and Rusatira. We will refer to them as the sectors Save and Rusatira. Save is located at an altitude of 1738 m.a.s.l. and Rusatira at an altitude of 1665 m.a.s.l. Varieties encountered in both sectors are depicted in Fig.9.4 and Fig.9.5.

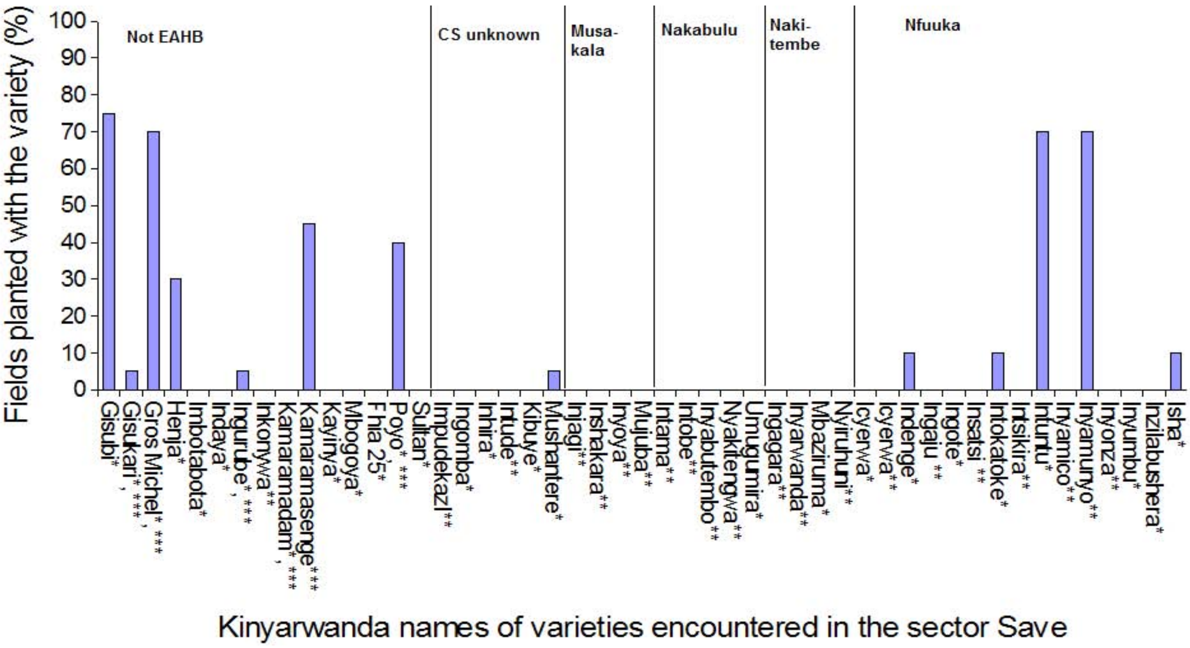


Figure 9.4: Different varieties of bananas encountered in Save classified according to clone-set (CS). *Beer bananas, **Cooking bananas, ***Dessert bananas

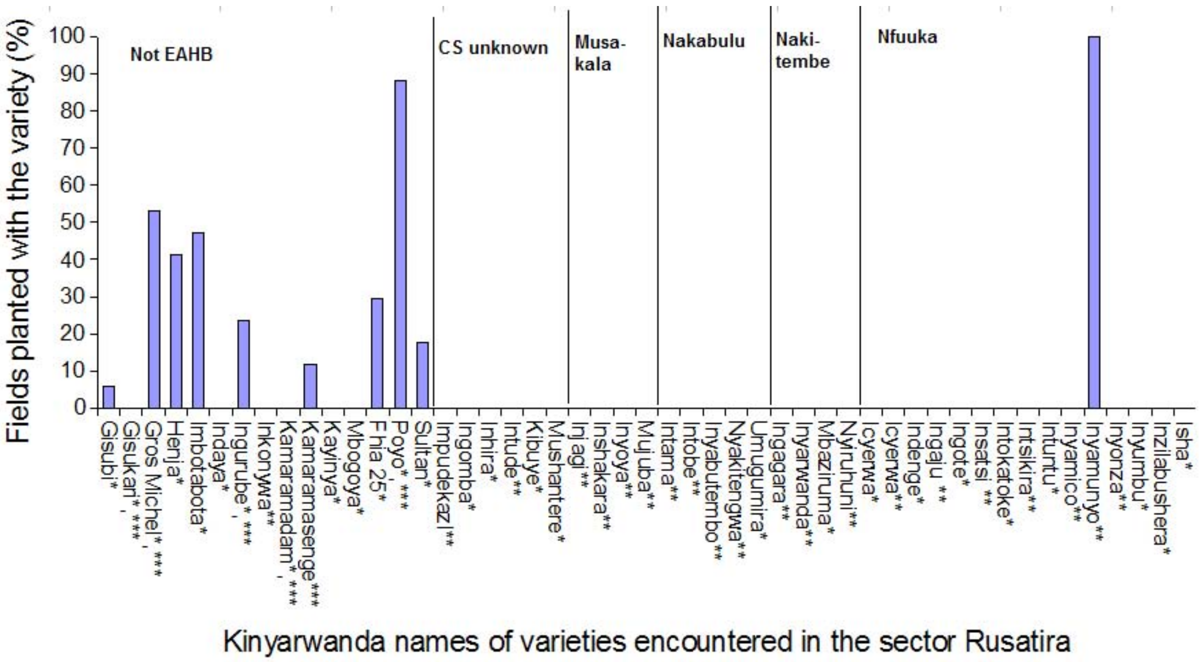


Figure 9.5: Different varieties of bananas encountered in Rusatira classified according to clone-set (CS). *Beer bananas, **Cooking bananas, ***Dessert bananas

It is observed that only the clone set of Nfuuka and non East African highland bananas are present. The banana varieties not belonging to the East African highland bananas, dominate in the two sites. Inyamunyo occurs most, but differences occur between the two sites, e.g. Gisubi (75%) and Intuntu (70%) occur frequently in Save, but are almost absent in Rusatira. Nsabimana et al. (2008) mention that Gisubi multiplies very fast and tolerates poor soils. The abundance of Gisubi in Save may be an indicator of soil quality there, as is the occurrence of cassava intercrops.

9.4 Banana varieties encountered in Kibungo

In the agro-climatic zone of the Eastern plateau, two villages were surveyed, Gatore and Mushikiri. Gatore is located at 1514 m.a.s.l. and Mushikiri at 1570 m.a.s.l.. Varieties encountered are depicted in Fig.9.6 and Fig.9.7.

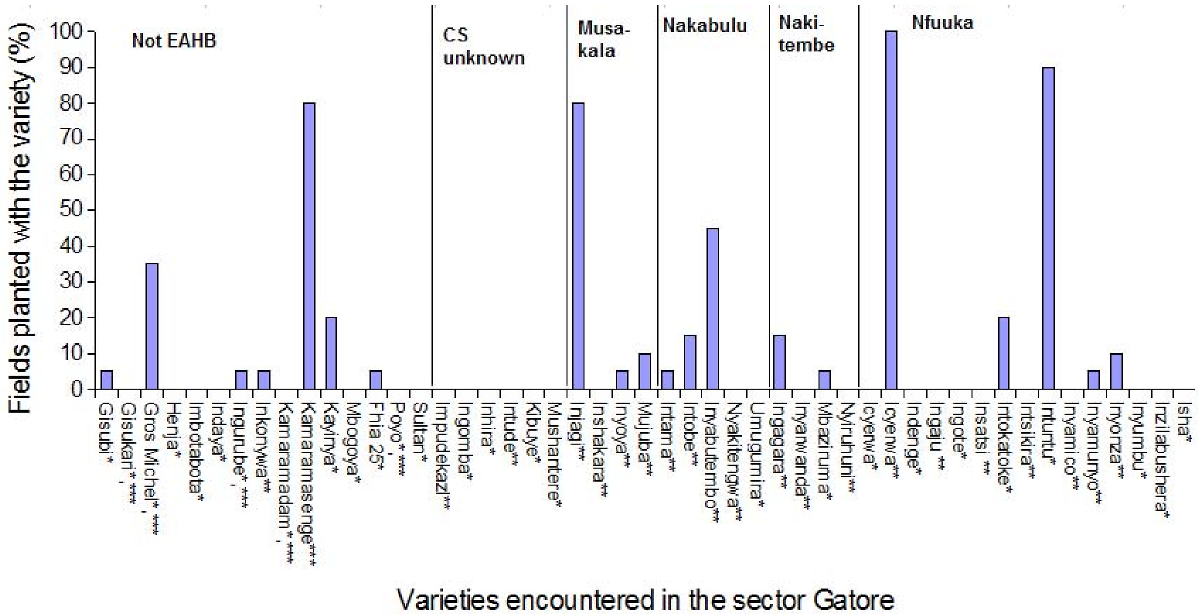


Figure 9.6: Different varieties of bananas encountered in Gatore classified according to clone-set (CS). *Beer bananas, **Cooking bananas, ***Dessert bananas

It is observed that all clone sets are represented. East African highland bananas are more abundant than non East African highland bananas. It is also noted that Mushikiri is richest in varieties, on average 7.7 varieties occur in each field.

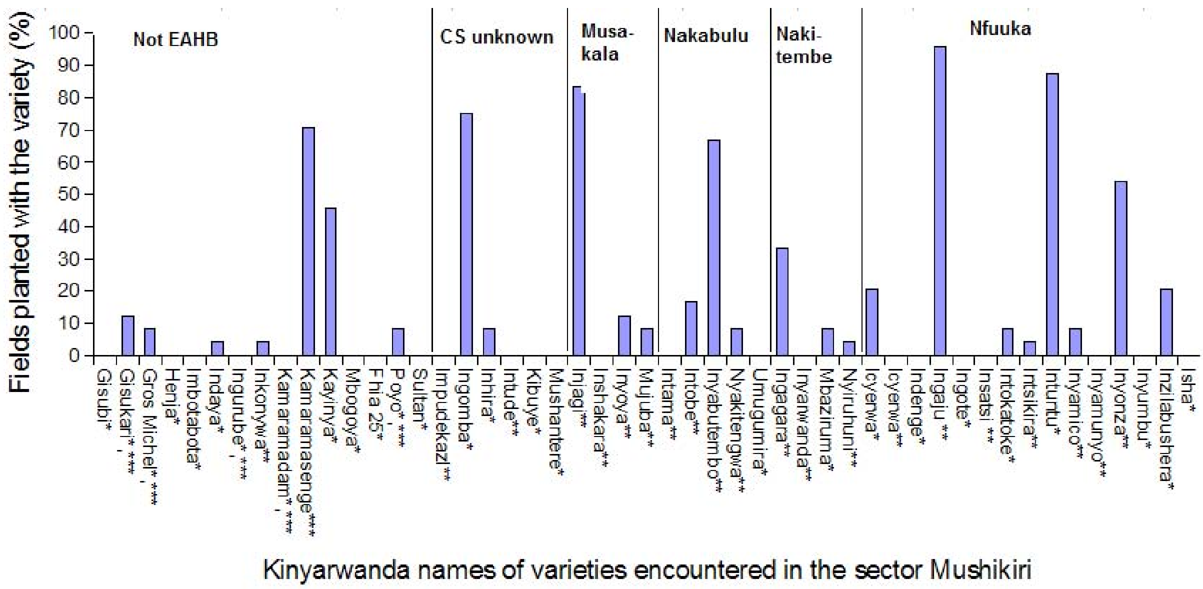


Figure 9.7: Different varieties of bananas encountered in Mushikiri classified according to clone-set (CS). *Beer bananas, **Cooking bananas, ***Dessert bananas

9.5 Occurrence of different banana types in Rwanda

Bananas have three main uses in Rwanda. They are used for cooking, brewing or as dessert bananas. It is suggested by Okech et al. (2005) that the distribution of the three types of bananas throughout the country is dependent on socio-economic factors e.g. distance to markets (see section 4.5 Distribution of bananas in Rwanda). The distribution of different banana types throughout the country is depicted in Fig.9.8 and Fig.9.9.

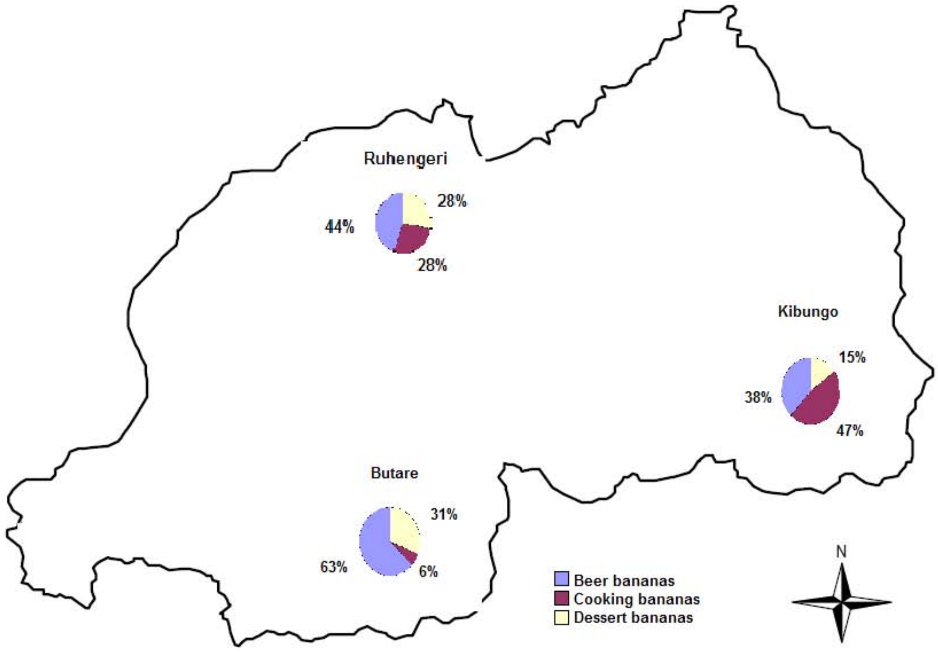


Figure 9.8: Distribution of banana types in Rwanda

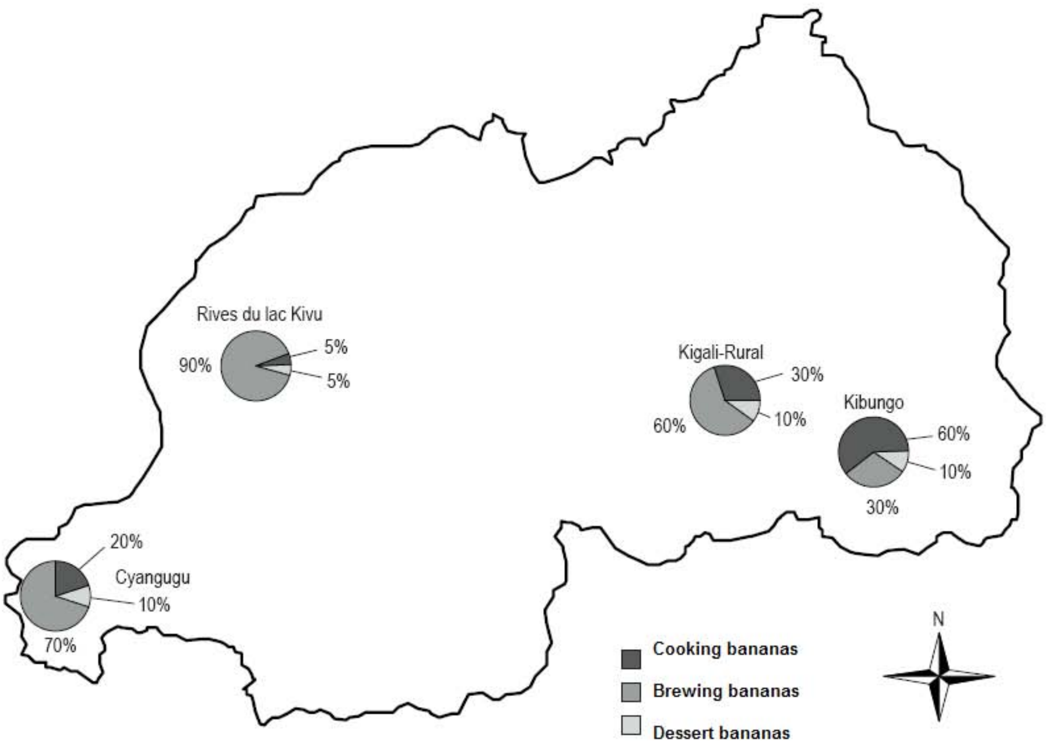


Figure 9.9: Distribution of banana types in Rwanda (Okech *et al.* 2005)

It is observed (Fig.9.8) that in Kibungo cooking bananas are cultivated most, but in the other two sites beer bananas dominate. In Butare almost no cooking bananas are cultivated, in accordance with the observation that most of the varieties encountered there are not East African highland bananas. Our results are in accordance with Okech et al. (2005) (Fig. 9.9), who state that the occurrence of cooking bananas is linked with the accessibility to markets. Kibungo and Kigali-rutal are better connected to the main market of the country, the capital Kigali. Butare, Ruhengeri, Cyangugu and Kivu lake border mainly produce for local markets, as such beer bananas are preferred. Our data suggest that dessert bananas are cultivated in at least 15% of the fields, and these results are a lot higher than sited by Nsabimana et al. (2008). This is due to differing appraisal methods, because in the present survey a field has a given variety if at least one mat is present, whereas Nsabimana et al. (2008) considered the coverage of different varieties in one field. This discrepancy suggests that many fields have dessert type bananas, but never in large amounts.

9.6 Conclusion

Many varieties are cultivated in Rwanda, as farmers distinguished 49 different varieties. Most varieties present are East African highland bananas. However varieties may differ with the region, and the same names may be given to the different varieties. On average 5.6 varieties are present in one field, making it very hard to formulate an optimal planting density as each variety should have its own optimal density.

Many varieties are very site specific, as 21 varieties occur in less than 5% of the fields. Climatic factors influence the occurrence of varieties, and exotic varieties occur most under harsh conditions. It is suggested that among the EAHB the clone set of Nfuuka is most resistant to drought and poor soil fertility.

No correlation between altitude, distance to the household and number of varieties was found in our data. Our data support the findings of Okech *et al*. (2005), that the occurrence of cooking, brewing and dessert bananas is also dependent on socio-economic factors like distance to markets.

10. General conclusion

It is concluded that areas with high rainfall (>1400mm) are planted more densely (>1800 mats/ha) and areas with a lower rainfall (between 1000 and 1200 mm) are planted at lower densities (between 1000 and 1500 mats/ha). Thus farmers adapt their cropping practices according to prevailing climatic conditions. This is also reflected in the intercrops grown between the bananas. Indeed cocoyam is cultivated in the high rainfall areas and cassava under more adverse conditions.

Fields with a higher density yield more. It is noted that the widest spacing is applied in one site only, here a significant positive correlation exists between spacing and bunch weight. In all other sites, no correlation was found between spacing and bunch weight. Therefore it is suggested that fields over the whole country should be planted more densely, in order to increase banana production (kg/ha). However trials will have to point out if higher planting densities are useful in low rainfall areas.

It has to be noted that high banana production (kg/ha) is not the main objective of farmers as farmers also value the yield of intercrops and thus of the entire farming system. The yield of intercrops will drop when the banana plant density is increased. Hence subsistence farmers might be unwilling to increase banana plant density as that would also increase risks and reduce production diversification

Results also show that fields can be cultivated with bananas for a very long time. Maximum records go up to 90 years, without a negative effect on yield. Probably these fields are continuously replanted with bananans. Another outcome is that smaller fields are planted more densely, and thus gave higher yields. This is important because the acreage per capita will decrease further in the country due to the rising population. On average a field contains 5.6 varieties but the total number of varieties can go up to 14. Given the mixture of different varieties, and mixture being dependent on the site, the prediction of an optimal plant density becomes very hard, since it is varietal dependent. In addition 43% of the varieties are encountered in only 5% of the fields. Lastly an inverse relationship between the occurrence of exotic varieties and East African highland bananas is suggested, exotic varieties seem to occur in more adverse conditions.

List of errata

p. 4, 1st alinea, 5th line: (between 1000 and 1200 mats/ha) => (between 1000 and **1500** mats/ha)

p. 4, 2nd alinea, 5th line: (tussen 1000 en 1200 mats/ha) => (tussen 1000 en **1500** mats/ha)

p. 61, Table 7.3:

Mineral fertilizer use					
	None	**1**	**99%**	98%	96%
	Application	**2**	**1%**	2%	4%
	(No response)		(22%)	(48%)	(66%)

p. 76, Table 8.6:

		LAI	
	Mean	Min	Max
Ruhengeri (Musanze)	2.1 a	0.4	5.3
Butare (Huye)	1.4 b	0.3	4.2
Kibungo (Ngoma)	1.2 **b**	0.7	1.8

p. 98, 1st alinea, 3d line: (between 1000 and 1200 mats/ha) => (between 1000 and **1500** mats/ha)

p. 98, 2nd alinea, 2nd line: a significant negative correlation => a significant **positive** correlation

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