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Plantain productivity: Insights from Cameroonian cropping systems

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ABSTRACT

Understanding the components of plantain productivity is important for contributing to the food security challenge in West and Central Africa. The purpose of this study was to assess how production system and cropping system characteristics affect plantain productivity. Interviews with farmers, dynamic measurements of cropped diversity, recording of management practices and characterization of the harvested bunches were used to characterize 25 plantain fields in the form of 54 factors and 5 dependent variables. The average bunch weight measured was 11.6 kg. The within-field variability of the bunch weights measured was 4.2 kg. The calculated mean plantain yield was 6.8 t/ha/year and varied between 1.1 and 18.8 t/ha/year depending on the fields studied. Harvested bunches amounted to only 34% of the field potential. Segmentation analyses (CART) of the fields studied and analyses of variance identified 12 factors strongly linked to bunch sizes and plantain field lifetime. The highest bunch weights were measured in fields belonging to farmers who participated in training and also applied herbicide and nitrogen fertilizers more frequently and at higher rates. These practices also increased within-field variability for bunch weights. Lastly, the management practices recorded showed an intensification of chemical inputs in traditional plantain-based cropping systems. These results, especially the high within-field and between-field variability for bunch weights, call for better quantify the impact of planting material quality and varietal mixture on plantain productivity into plantain-based cropping systems.

1. Introduction

The production of plantain, which is an essential component in the diet of West and Central African populations (Folefack et al., 2017), is a food security challenge. Average annual demand would appear to be above 40 kg per inhabitant (Akyeampong, 1998), while annual production, estimated at 10 million tonnes (Lescot, 2017), corresponds to an average supply of 20 kg per inhabitant. This low availability explains the high prices on urban markets, making plantain a luxury product (Mialoundama Bakouétila et al., 2016). Cameroon, which is the fourth largest plantain producer in West and Central Africa, does not escape this situation (Folefack et al., 2017). The Cameroonian plantain supply chain, comprising 650,000 growers and 50,000 middlemen (transporters, traders and processors), moves around 1.6 million tonnes annually (Lescot, 2017). The average plantain yield, as in the other producing countries of West and Central Africa, is estimated to be between 5 and 15 t/ha (Achard and Sama Lang, 1998; Akinyemi et al., 2008b; Akyeampong, 1998; Ba Kumfifutu, 1996; Dowiya et al., 2009; Dzomeku et al., 2011; Lescot, 1997; Lescot and Ganry, 2008; N'Guessan et al., 1993). Such productivity is low given the plant's potential, which can reach yields of between 20 and over 30 t/ha on experimental stations under controlled and non-limiting growing conditions (Aba and Baiyeri, 2015; Baiyeri and Ortese, 2007; Dépigny et al., 2018; Melin et al., 1976a, 1976b; Obiefuna, 1986).

Plantain is increasingly being grown in multi-variety monocultures based on an intensification of the use of fertilizers and pesticides (Akyeampong, 1998). It nonetheless principally remains a component of complex mixed cropping systems (Achard and Sama Lang, 1998;

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Hauser and Amougou, 2008), in which it is intercropped with numerous annual and perennial crops (Akyeampong, 1998; Nkendah and Temple, 2003). In Cameroon, over thirty crops intercropped with plantain have been numbered (Jacobsen et al., 2004); the annual crops identified are essential dietary components (*Arachis hypogea*, *Colocasia esculenta*, *Cucurbita maxima*, *Manihot esculenta*, *Solanum nigrum*, etc.) and the perennial crops are cash crops (*Carica papaya*, *Coffea* sp., *Elaeis guineensis*, *Theobroma cacao*, etc.). Plantain, when intercropped with perennial crops such as cacao, coffee, or rubber (Adenikinju, 1983; Jolaoso et al., 1996; Yao, 1988), is a service crop for the perennial crop. It is cropped to provide shade for young plants and to gain benefit from the land during their growth phase (food production, cashflow). It is then kept residually within the perennial crop up to its natural disappearance (Adenikinju, 1983). A plantain field is usually a varietal mixture with at least three different varieties (Hauser and Amougou, 2008).

There therefore exists a great diversity of plantain-based cropping systems. We define a plantain-based cropping system as the overall cropped diversity in the agrosystem including plantain, its organization in time and space and the management practices pertaining to each crop present. It is accepted that diversified cropping systems promote biological processes, such as facilitation and biological regulation, which can be favourable for the productivity and sustainability of the whole cropping system (Damour et al., 2015; Justes et al., 2014; Malézieux et al., 2009). It is also accepted that the production system, integrating the characteristics of the farmer (age, training, etc.), of the farm (family, area, specialization, means of production, trajectory, etc.) and of its environment (supply chain, social demand, etc.), structures the cropping system, particularly through access to the means of production, their availability and use (labour, inputs, etc.), and has an impact on its possible performance (Achard and Sama Lang, 1998; Adinya et al., 2008; Arikpo et al., 2009; Bifarin et al., 2008; Blazy et al., 2011; de Bon et al., 2014; Sonwa et al., 2008). Thus, summarizing the productivity of such a diversity of plantain-based cropping systems as a national average yield seems restrictive. Improving plantain productivity involves exploring yield heterogeneity and identifying factors that influence yield. This study aimed to explore yield heterogeneity within a panel of plantain-based cropping systems and to identify production and cropping system characteristics that affect plantain yield. Plantain yield was defined as the combination between the number of productive plantain stems and the weight of harvested bunches. Thus, this study focused on factors influencing the dynamics of the plantain stem population, the proportion of harvested bunches and the bunch weight.

2. Materials & methods

2.1. The plantain fields studied

The studied plantain fields were located in the Littoral region of Cameroon. They were part of the Mungo banana and plantain growing zone, which is the most important growing area for export bananas in Cameroon and part of the plantain supply basin for the city of Douala (Folefack et al., 2017). The soil is a rich brown andosol (Combroux, 1957). The climate is of the Equatorial Guinea type, with relatively stable, monthly mean temperatures of 26–28 °C and an average rainfall of 2300–3200 mm annually, distributed from March to November. The dry season, from December to February, is the only climatic period unsuited to banana and plantain growth when grown under rainfed conditions. The study zone was limited to a geographical area with a diameter of 20 km around the town of Njombé, in order to reduce pedoclimatic variations. The uniformity of the soils and climate were a prerequisite for observing differences in yields intrinsic to the production systems. We chose 25 plantain fields spread along a gradient of cropped diversity ranging from plantain monocultures to complex mixed cropping systems including annual and perennial crops, and some forest residues. The plantain density in each field had to be over 300 plantains per hectare; this threshold was defined from expert advice in order to select cropping systems within which plantain was a significant crop for the farmer. Another criterion for selecting the plantain fields was the motivation and ability of the farmer to take part for the duration of the study.

2.2. Data acquisition

The production system and cropping system of each plantain field were documented using three complementary methods largely involving the farmer: directed interviews with the farmer, measurement of cropped species dynamics within an experimental plot defined with the farmer, and recording by the farmer of qualitative and quantitative information about management practices and plantain production.

2.2.1. Production system data

The production system was considered as being the set of components of the farm, incorporating the decision-making system (farmer, family, etc.) and the means of production (field, equipment, labour, cashflow, etc.). The production system of each study field was characterized in an interview with the farmer. This included some data on the training and socio-professional integration of the farmer, the composition of the family and its involvement in the production system, the background of the farm, characterization of the means of production, and the land and geographical characteristics of the field. Another purpose of the interview was to specify the importance of plantain within the production system.

2.2.2. Cropping system data

The cropping system was considered as being the overall cropped diversity within the studied field, its organization in time and space, and the crop management sequence applied. Inside each study field, an experimental plot of 450 m^2 was defined with the farmer as being representative of the cropping system. This was divided into 9-m^2 quadrats geographically identified and permanently marked out during the study. The aim of this experimental design was to monitor the numbers of potential productive plantains and intercrops (i.e. any associated crop with plantain during the plantain lifetime), quantify plantain production and record all the management practices applied to plantains and intercrops. Observations lasted two years.

a) Cropped diversity

Plantains are traditionally grown in mats (Melin et al., 1976a, 1976b), i.e. farmers keep several successive suckers at each new cropping cycle. The plantain mat is gradually composed of several "stems" (specifically "pseudostems" as defined by botanists, but for simplicity we shall refer to "stems"), each likely to produce a bunch (Fig. 1). The stem was chosen as the observation unit for the plantain populations in the fields studied. Each stem, kept by the farmer with a view to obtaining a bunch, was described by its cropping cycle rank in relation to the plantain planted, also called the "mother plant" and the sole stem of cycle 1 (C_1). On each observation, the number of mats and the number of stems in each cropping cycle were recorded per quadrat. On each observation, the number of plants of the other cropped species present in the quadrat were also recorded. These observations were carried out by a technical team twice a year.

Plantain production in each experimental plot over the observation period was daily (each day, any harvested bunch had to be registered) recorded by the farmer in the form of a list of bunches harvested. Each bunch was described by its harvest date and its fresh weight (kg). Bunches were harvested according to the farmer's ripeness criteria. Bunch weights were measured using identical balances distributed to each farmer taking part in the study. Each bunch was weighed with half of its peduncle, which was usually kept by the farmers to facilitate carrying.

Fig. 1. A mat with 6 stems. The stem number integrates 1 stem from the first crop cycle (C_1), i.e. the "mother-plant", and 5 stems from the second crop cycle (C_2).

b) Management practices

The management practices applied to plantains and intercrops in the experimental plot over the observation period (crop upkeep, nitrogen fertilization, pesticide applications, etc.) were recorded daily (each day, any event in the list of data to collected had to be registered); they were recorded by crop and by intervention date in a crop logbook. The quantitative and qualitative aspects of each management practice (equipment used, commercial product used, dose, work time, labour, etc.) were specified during quarterly interviews with the farmers. For fertilization, the study focused solely on nitrogen fertilizer, which was the most important for the farmers.

2.3. Data analysis

2.3.1. Characteristics of the production and cropping systems

The data gathered were transcribed in the form of 54 variables, divided into 35 quantitative variables and 19 qualitative variables (Suppl. Mat. A). The variables were grouped into seven thematic groups according to the nature of the information. The profiles of the farmers and their interactions with their socio-economic environment were summed up in the 'Farmer' group. Means of production and the geographical characteristics of the study field were assigned to the 'Production System' group. The structure of the cropped diversity of the study field was described in the 'Cropped diversity' group. The agricultural practices applied to the intercrops were summarized in the 'Intercrop Management' group. The population structure, farming practices and production data for plantains were recorded in the 'Plantain Population', 'Plantain Management' and 'Plantain Production' groups, respectively. The 'BPdyn' variable was the only estimated variable. It was obtained by modelling plantain population dynamics with a view to integrating the multiplicity of events influencing the number of stems likely to bear a bunch (new plantain plantations, plantain replacements, variable number of stems kept per plantain planted, toppling of stems or of whole mats, etc.). This modelling was established from the stem multiplication rate (SMR), an indicator of the ability of a number of stems to evolve towards the following crop cycle, calculated per quadrat according to the following formula:

$$\frac{\textit{number of cycle } C_x \textit{ stems}}{\textit{number ofcycle } C_{x+1} \textit{stems}}$$

On the scale of the experimental plot, a model of exponential decrease was fitted to the SMR values of the different quadrats depending on the crop cycles. The slope of this model was considered as a relevant indicator of plantain dynamics and was recorded in the 'BPdyn' variable (Suppl. Mat. B). It is a component of yield to be explained by the characteristics of the production system and cropping system.

2.3.2. Plantain production

Plantain production was first analysed as a sample of bunches independent of the fields studied, with a view to studying production seasonality and its consequences for bunch weight. It was then broken down into four quantitative variables per study field to better study the variability of bunch weights: the lowest bunch weight measured (BWmin), the highest bunch weight measured (BWmax), the average bunch weight calculated from the mean of all the harvested bunch weights (BWave), and the within-field variability of bunch weights calculated from the standard deviation of all the harvested bunch weights (BWstd). These descriptive variables of plantain production were used to compare the different fields and explore some effects of the production and cropping system characteristics on plantain productivity. Lastly, the yield measured for each study field was calculated by adding the harvested bunch weights in the experimental plot over the observation period and rounded off to an area of one hectare over a period of 1 year. The proportion of bunches harvested in each study field was calculated in relation to the number of harvested bunches and the average number of potential bunch-bearing stems over the study period in the experimental plot.

2.3.3. Factors explaining plantain production

Statistical exploration was undertaken to identify and quantify the effects of the 49 factors describing the studied production systems and cropping systems on the 5 dependent variables describing the dynamics of the plantain population and harvested bunch weights. Initially, 35 data segmentation analyses by the CART method were carried out (Breiman et al., 1984), based on the 'rpart' function of the 'rpart' library (Therneau et al., 2018) in R software (R-Core-Team, 2017), in order to explore interactions between factors of a different nature and the dependent variables to be explained. Each dependent variable was first analysed globally, i.e. using a model including all the factors, then using models by thematic group of factors. The factors that enabled a division of the study fields into uniform groups, reducing the Gini impurity index (Nakache and Confais, 2003), were considered significant. Then, 245 univariate analyses of variance were carried out to quantify the interaction between each factor and each dependent variable. Significant variables ($p \leq 0.05$) of the same thematic group were tested by backward variable selection to search for the best explanatory model only including variables with significant contributions (Landau et al., 2000). The factors revealed by the two analysis methods were chosen as having a demonstrated effect on the dependent variables.

Table 1
Quantitative variable values.

Variable	Short description	Unit	Data	Minimum	Mean	Median	Maximum	St. Deviation
caicqteha	Quantity of insecticide on intercrops	Kg/Ha/Year[a]	17/25	0	2.4	0	25.5	6.1
cafcqteha	Quantity of fungicide on intercrops	Kg/Ha/Year[a]	19/25	0	0.9	0	15.9	3.5
cafcnbapp	Applications of fungicide on intercrops	Application/Year	10/25	0	2.5	0	24	7.2
cafertiNkgha	Quantity of nitrogen fertilization on intercrops	Kg Nitrogen/Ha/Year	14/25	0	47.4	40.5	192.5	50.4
cafertiNnbapp	Applications of nitrogen fertilization on intercrops	Applications/Year	18/25	0	2.5	2	11	2.43
cahcqteha	Quantity of herbicide on intercrops	Kg/Ha/Year[a]	9/25	0	3.2	0	15.9	6
cahcnbapp	Applications of herbicide on intercrops	Applications/Year	10/25	0	0.4	0	2	0.7
caicnbapp	Applications of nematicide on intercrops	Applications/Year	18/25	0	0.6	0	4	1.2
pnbcaan	Number of annual crops in field	Crop	25/25	0	5.2	5	15	4
pnbcamt	Number of simultaneous intercrops in field	Crop	25/25	0	5.5	5	13	3.3
pnbcaper	Number of perenial crops in field	Crop	25/25	0	1	1	4	1.3
pnbcatot	Number of total intercrops in field	Crop	25/25	0	6.3	7	15	4.1
bpciqteha	Quantity of insecticide on plantain	Kg/Ha/Year[a]	19/25	0	2.4	0	27.7	7.3
bpfertiNkgha	Quantity of nitrogen fertilization on plantain	Kg Nitrogen/Ha/Year[a]	20/25	0	59.7	34.1	192.5	59.1
bpfertiNnbapp	Applications of nitrogen fertilization on plantain	Applications/Year[a]	21/25	0	2.6	2	11	2.2
bpicnbapp	Applications of insecticide on plantain	Applications/Year[a]	24/25	0	0.5	0	3	0.9
bpncqteha	Quantity of nematicide on plantain	Kg/Ha/Year[a]	21/25	0	20.3	7.6	135.6	31.3
bpncnbapp	Applications of nematicide on plantain	Applications/Year	22/25	0	1.4	1.5	5	1.4
bpdyn	Plantain population dynamic	–	23/25	−1.78	−0.69	−0.56	−0.15	0.41
bpnbmoypoha	Average stem density in field	Stems/Ha	25/25	511	2094	1800	5167	1110
bppotfe	Mean number of stems per mat	Stems/Mat	19/25	1.3	1.8	1.8	3.2	0.4
bpppc1	Proportion of stems from the 1st crop cycle	%	25/25	0	20	18	49	15
bpppc2	Proportion of stems from the 2nd crop cycle	%	25/25	7	35	37	57	12
bpppc3	Proportion of stems of the 3rd crop cycle	%	25/25	5	30	30	62	16
bpppc4	Proportion of stems of the 4th crop cycle	%	25/25	0	11	9	30	10
bpppc5	Proprotion of stems of the 5th crop cycle	%	25/25	0	3	1	50	10
bwstd	Standard deviation of bunch weights in field	Kg	18/25	0.9	4.2	4	8.4	1.9
bwmax	Higher bunch weight in field	Kg	19/25	7	20.3	20	39	8.8
bwmin	Lower bunch weight in field	Kg	19/25	1.5	6.1	5	17	4.2
bwave	Mean bunch weight in field	Kg	19/25	5.3	12.5	11.2	26.6	5.9
eanbparc	Number of fields in farm	Plots	25/25	1	3.6	3	12	2.4
easurftot	Cropped area in farm	Ha	25/25	0.04	4	3	13	3.1
pdist	Distance from field to farmer's house	Km	25/25	0	2.7	2.3	8.1	2.4
ploc	Field rental	CFA F/Year	24/25	0	45,833	0	300,000	69,801
psurf	Field area	Ha	25/25	0.04	0.48	0.46	1.16	0.32

[a] Commercial product quantity.

3. Results

3.1. Characteristics of the production and cropping systems

The synthetic values for the descriptive variables of the study fields are summarized in Table 1 for the quantitative variables and in Table 2 for the qualitative variables. Half of the farmers interviewed had received agricultural training (52%) and had chosen the farming profession as their main activity (60%). A third were members of a farmer group (GIC as a sort of cooperative). The production systems studied comprised 3.6 farming fields, on average, for a total cultivated area of 4 ha. Most (88%) of the farmers used casual labour, but few (16%) employed permanent farm labourers. The study fields had an average area of 0.48 ha and were located at an actual travelling distance for the farmer of between 2.7 km and 8.1 km. Few were of "home garden" status (12%). Few had a background of fallow without plantain (16%) prior to the plantains being planted. The cropping systems studied were mainly multi-species (92%) combining between 6 and 13 annual and perennial crops. The perennial crop most intercropped with plantain was cacao, and the most common annual crops were new cocoyam and taro (Suppl. Mat. C). The plantains came solely from suckers, mainly bought from neighbouring farmers and sometimes from the farmer's own field. They were planted in highly variable densities of 393–2775 plantains per hectare. They were managed with an average of 1.8 stems per mat. The densities measured varied between 511 and 5167 stems per hectare. The stems observed mainly belonged to the first (20%), second (35%) and third (30%) crop cycles, but a few stems from the fourth (11%) and fifth (3%) crop cycles were seen. The population dynamics of the stems, represented by the 'BPdyn' variable (Fig. 2), varied from −1.78 to −0.15: all the study fields showed a reduction in stem number over the crop cycles (Suppl. Mat B).

Table 2
Qualitative variable values.

Variable	Description	Yes	No
agriact	Is farming the main activity of the farmer?	60%	40%
agrigic	Is the farm attached to a cooperative?	28%	72%
agriform	Did the farmer complete agricultural training?	52%	48%
eamoet	Does the farmer use temporary labour?	88%	12%
eamoep	Does the farmer use permanent labour?	16%	84%
pprop	Does the field belong to the farm?	11%	89%
ptyp	Is the studied field a home garden?	16%	84%
pjach	Was the field fallow before plantain?	20%	80%
pforetres	Are there trees in the field?	12%	88%
caferti	Do intercrops receive fertilization?	88%	12%
cafertiorga	Do intercrops receive organic fertilization?	32%	68%
caic	Do intercrops receive insecticide?	48%	52%
cafc	Do intercrops receive fungicide?	32%	68%
cahc	Do intercrops receive herbicide?	72%	18%
bpferti	Do plantain receive fertilization?	88%	12%
bpfertiorga	Do plantain receive organic fertilization?	28%	72%
bpic	Do plantain receive insecticide?	32%	68%
bpnc	Do plantain receive nematicide?	64%	36%
bpachatmv	Do farmers buy plantlets for plantain planting?	48%	52%

Data relative to the management practices applied to plantain, classed according to their frequency in Table 3, and the management practices applied to the intercrops showed that 88% of the farmers applied inorganic nitrogen fertilization, with cumulative quantities for all crops combined that could reach 385 kg/ha/year. The average fertilization applied for all crops combined was 74.6 kg/ha/year. Herbicides were used in 72% of the study fields, applying an average of 3.2 kg/ha/year of commercial product. Insecticides were used by half of

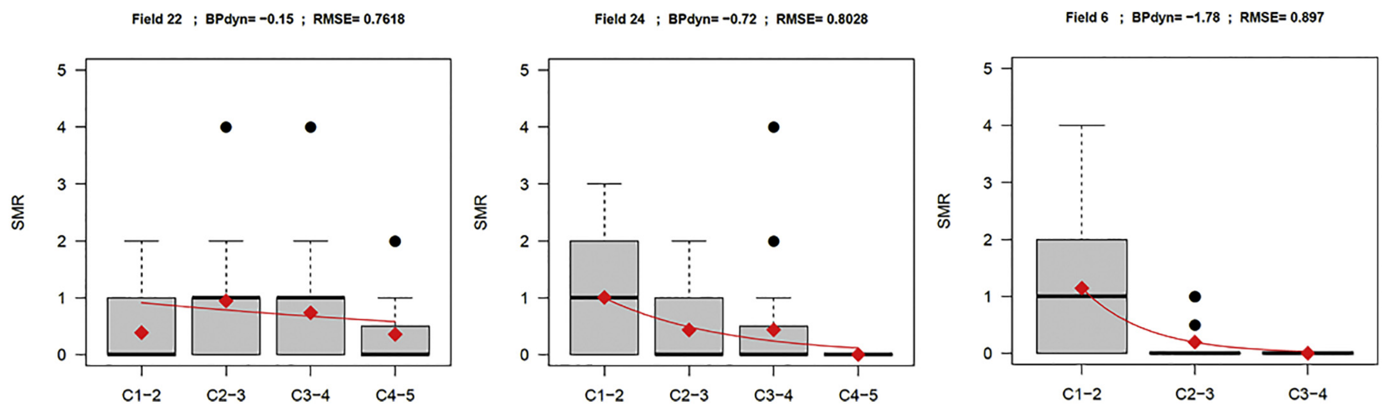

Fig. 2. Example of the 'BPdyn' indicator for three contrasted fields. For each field, the stem multiplication rate (SMR) represented the ratio between the number of stems at a given cropping cycle and the one from the previous cropping cycle. The BPdyn value is the slope of the exponential decay function of SMR across cropping cycles (e.g. C1-2 between cycles 1 and 2).

Table 3
Plantain management practices.

Cultural practice	Frequency
Inorganic fertilization	88%
Herbicide application	72%
Nematicide application	64%
Leaf pruning	60%
Sucker removal for plantlet	48%
Manual weeding	36%
Insecticide application	32%
Ridging	28%
Stem cleaning	28%
Organic fertilization	28%
Additional plantain planting	20%
Toppled plantain cutting	12%
Desuckering	12%
Toppled plantain replacement	8%
Wiring	8%
Harvested plantain cutting	8%
Staking	4%
Bunch marking with paint	4%

the farmers interviewed to control black banana weevil in plantains and other insect pests in intercrops. Fungicides were used in 38% of the study fields, solely against fungal diseases of the intercrops. Nematicides were used in 64% of the study fields to control plantain endoparasitic nematodes, applying an average of 20.3 kg/ha/year of commercial product. Some management practices alternative to pesticide use were also recorded, such as removing leaves affected by Black Sigatoka leaf spot (60%) and manual weeding (36%).

3.2. Plantain production

The harvest data for 19 study fields were usable. They amounted to a sample of 525 bunches (Fig. 3). Bunch weights varied from 1.5 to 39 kg for an average weight of 11.6 kg. The harvests for July, August and September cumulated over the length of the study exceeded 80 bunches, while they varied between 20 and 50 bunches during the other months, and only reached 7 bunches in February. The monthly average bunch weight varied between 9.4 kg (January) and 14.5 kg (December). The monthly standard deviation for bunch weight varied from 5.1 kg (June) to 8.1 kg (December). Fig. 4 shows the bunch weight distribution per study field. The average bunch weight per field varied from 5.3 kg (5) to 26.6 kg (25). The standard deviation for bunch weight per field varied from 0.9 kg (12) to 8.4 kg (2). The yields recorded (Table 4) varied from 1.1 t/ha/year (19) to 18.8 t/ha/year (7). The average yield recorded for the study fields as a whole was 6.8 t/ha/year. The proportion of potential bunches that farmers harvested (Table 4) varied from 11% to 94% depending on the study fields.

3.3. Factors determining plantain production

The data segmentation analyses revealed 11 discriminant factors for the study fields (Suppl. Mat. D). They belonged to the set of defined thematic groups of variables, apart from the 'Cropped diversity' group, and discriminated between study fields for the descriptive variables of plantain production (BWmin, BWave, BWmax, BWstd). The analyses of variance identified 6 factors with at least one significant effect on one of the five variables studied (Suppl. Mat. E). The synthesis of the results from the two types of analysis identified 12 factors for plantain production and for plantain population lifetime. Fig. 5 summarizes these factors according to their thematic group and their effect on the variables studied. Plantain population lifetime was slightly improved in recently planted fields composed of a few residual trees. In addition, herbicide use was a factor linked to plantain stem numbers. The management practices applied to plantain and to the intercrops, particularly herbicide use and nitrogen fertilizer application, were positively correlated with high bunch weights, and also with within-field variability for bunch weight. The fact that a farmer had received agricultural training and did not practise any other activity was also positively correlated with higher bunch weights.

4. Discussion

4.1. Plantain productivity

4.1.1. Very high pre-harvest losses

The proportion of harvested bunches, a major component of yield, was under 50% of the number of potential bunch-bearing stems in most of the study fields. This result made it possible to objectify the discourse of the farmers describing very high pre-harvest losses during interviews. The main cause would appear to be the toppling of a large number of plantain stems prior to harvest due to damage caused by black banana weevils (*Cosmopolites sordidus*) and nematodes (*Radopholus similis* and *Pratylenchus* sp.). Many authors have explained these two major constraints in plantain cultivation due to which losses by toppling can exceed 50% of potential bunches (Banful et al., 2000; Banful et al., 2008; Iratcher, 1998; Speijer et al., 1993) (Achard and Sama Lang, 1998; Akinyemi et al., 2008a; Dankii et al., 2007; Hauser and Amougou, 2008; Pierrot et al., 2002). The second cause would appear to be bunch thefts before harvesting, which would seem to reach 20–30% of the potential number of bunches (Desdoigts et al., 2005; Folefack et al., 2017; Iratcher, 1998). Another possible explanation, which we could not completely rule out given our experimental design, is that farmers varied in how well they recorded the data despite the

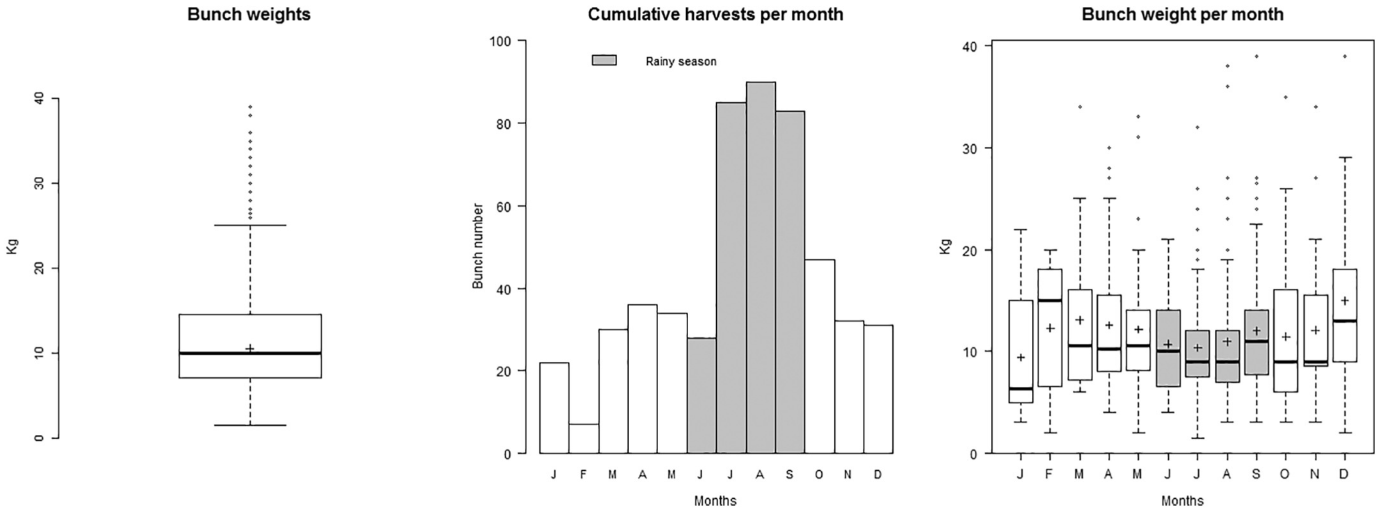

Fig. 3. The left-hand figure shows bunch weight distribution throughout the study fields. The centre figure shows harvest distribution over a year: harvests doubled during the rainy season (in grey). The right-hand figure shows bunch weight distribution per month: bunch weights decreased during the rainy season. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

follow-up of the technical team. Nevertheless, this study made it possible to put values on a probably relevant, but worrying, picture of production in traditional plantain-based cropping systems in the Littoral region of Cameroon: a farmer would seem to plant 100 plantains to harvest just 30 or so bunches. It would be interesting to check whether this context is similar in other plantain production areas in West and Central Africa.

4.1.2. *Very variable bunch weights*

The average bunch weight recorded (11.6 kg) corresponded to the values described in other studies carried out in the traditional cropping systems of Cameroon (Achard and Sama Lang, 1998; Banful et al., 2008; Pierrot et al., 2002). This value was close to half of the average bunch weights obtained by different natural plantain varieties on experimental stations with non-limiting agricultural management (Dépigny

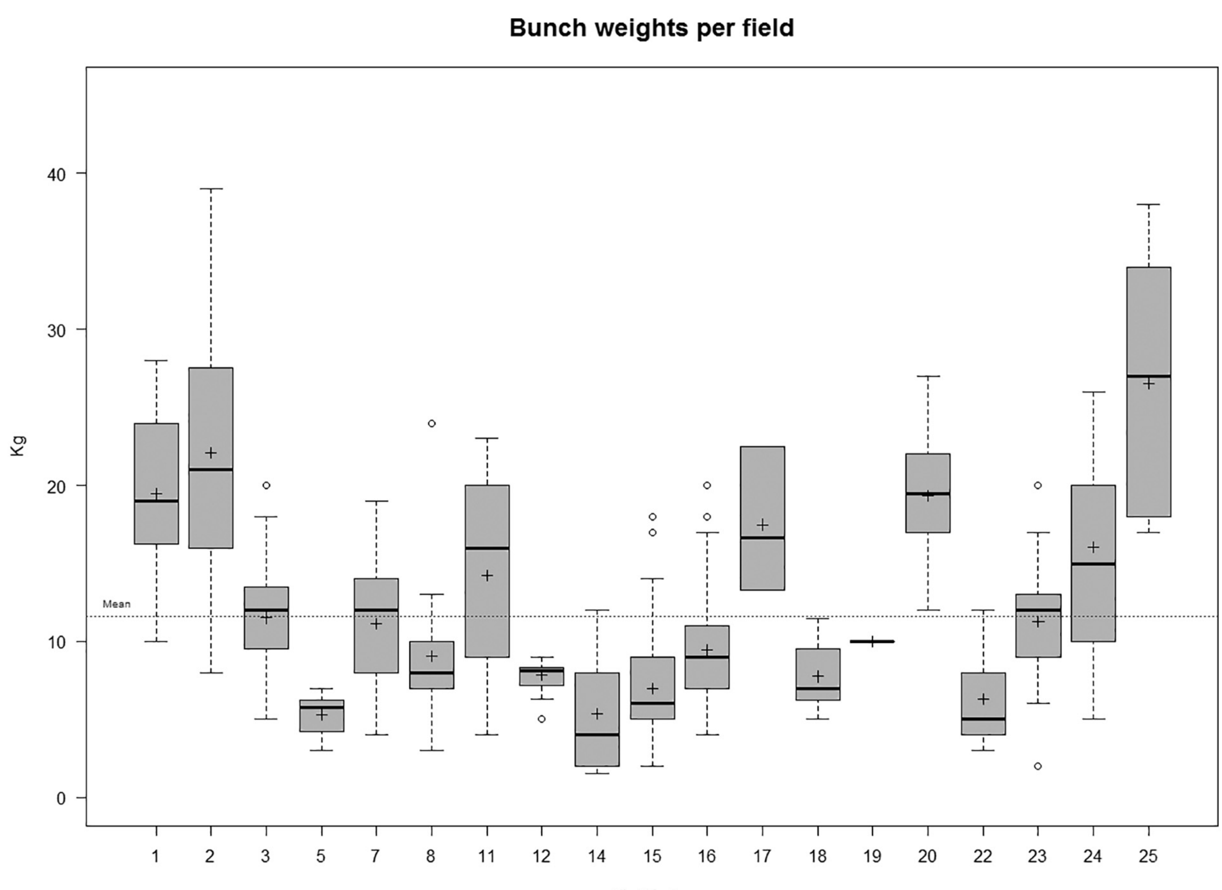

Fig. 4. Bunch weight distribution per study field. The average bunch weight of each field is marked with (+) in the boxplot. The average bunch weight of all harvested bunches is drawn as a horizontal dotted line. Outlier values are represented by small circles.

Table 4
Harvest proportion and measured yield.

Field	Harvested stem proportion		Measured yield
1	17%	17%	14.0
2	36%	36%	11.7
3	40%	40%	6.3
5	36%	36%	3.3
7	89%	89%	18.8
8	26%	26%	3.5
11	13%	13%	3.9
12	94%	94%	7.2
14	30%	30%	4.2
15	44%	44%	4.6
17	21%	21%	4.2
18	44%	44%	2.1
19	14%	14%	1.1
20	14%	14%	7.1
22	27%	27%	3.7
23	24%	24%	8.3
24	35%	35%	11.6
25	11%	11%	7.1
Area	40%	34%	6.82

et al., 2018; Melin et al., 1976a, 1976b). The results showed seasonal variability in plantain production, marked by both the doubling of the number of bunches harvested in the rainy season and a sharp drop in the dry season, along with a 5% drop in average bunch weight and a rise of 7% in the dry season. These results went against the literature: plantain is usually scarce on urban markets during the rainy season (Bikoï and Yomi, 1998; Dzomeku et al., 2011; Ndubizu and Okafor, 1976; Osseni et al., 1998; Temple and Engoya Oyep, 1998; Yao et al., 2014). We put forward the hypothesis that we observed harvested production seasonality, whereas the literature mainly speaks about the seasonality of plantain availability and prices on urban markets. We described the ability of the plantain to produce under climatic conditions that could be improved by choosing less drought-susceptible varieties and applying management practices that limit water stress (planting date, plantain population management, fertilization, etc.), and the literature describes market supply chains that depend on infrastructure enabling bunches to be moved from production fields to local markets.

The bunch analysis on a field scale also revealed strong within-field variability for bunch weights, which had rarely been identified and quantified in the literature before. The average within-field variability recorded was 4.2 kg, i.e. over a third of the average bunch weight measured in this study. The cropped diversity of plantain varieties could be an explanation of the variability in bunch weights, in line with the various bunch structures and sizes among plantain groups (De Langhe, 1961; Tezenas du Montcel et al., 1983). We did not collect any varietal data in our study, but it would be interesting to link plantain field productivity and heterogeneity with varietal mixture. Nevertheless, the explanation we would opt for would be the existence of high variations in the initial quality of the planting material, which consists almost solely of suckers taken from other plantain fields. Many authors have identified the poor quality of planting material as being a factor in declining plantain productivity (Banful, 1998; Ocimati et al., 2013; Tenkouano et al., 2006) and a vector of diseases (Cote et al., 2008; Ndungo et al., 2008). It has been demonstrated that choosing healthy (Niere et al., 2014) or sanitized (Coyne et al., 2010) plantain material improves growth and yields. Variations in the quality of sucker-type planting material may be linked to multiple factors (variety, type of sucker, physiological status and sanitary condition at the time of sampling, sampling method, etc.), and could be the main factor of within-field variability for bunch weights. It would be worth taking a more in-depth look at the relation existing between planting material quality and pre-harvest losses, particularly in terms of plantain population lifetime, and quantifying the financial impact for farmers.

4.1.3. Yields difficult to estimate

We came up against a known difficulty (Hauser and van Asten, 2008) of estimating and interpreting the yield of traditional mixed plantain-based cropping systems. The first expected yield component was a number of potential bunch-bearing stems per unit area and time.

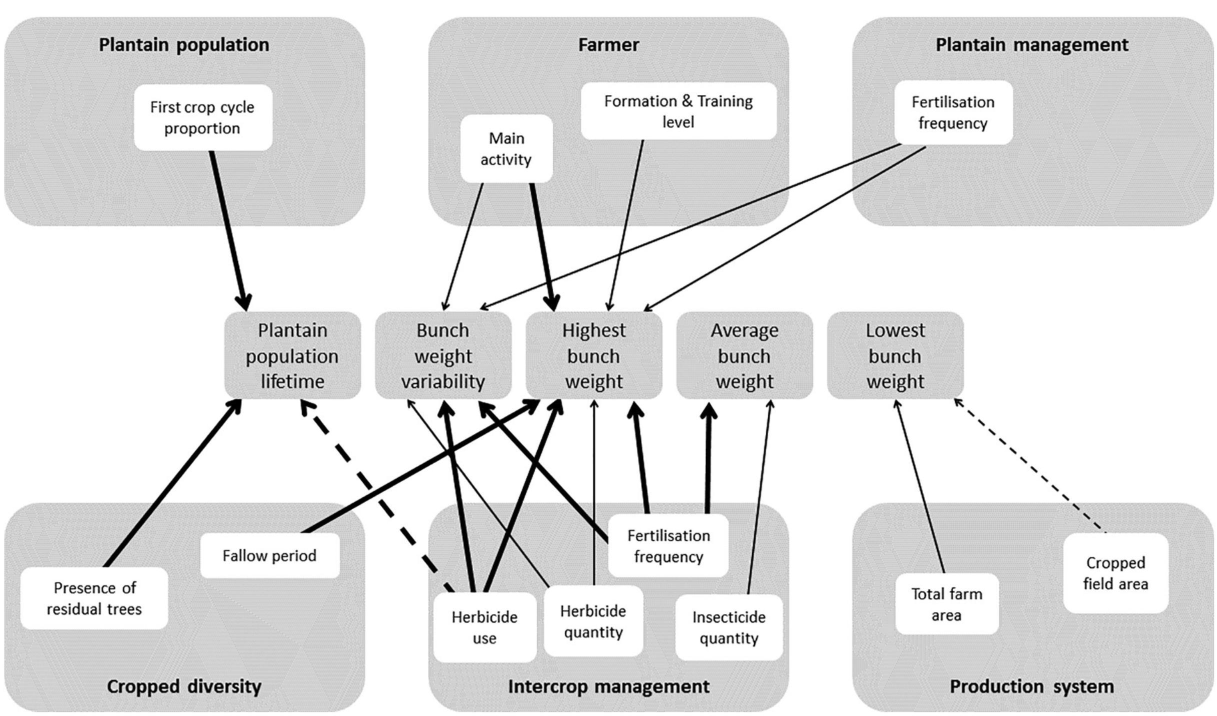

Fig. 5. Summary of the links between studied variables and factors (organized in thematic groups) established with ANOVA and CART analyses. Bold and thin lines represent significant effects of factors from both ANOVA (See Supp. Mat. E for details) and CART analyses and only CART analyses, respectively. Solid and dotted lines represent positive and negative effects, respectively.

The dynamics of the plantain population, characterized by a variable density of mats (planting, replanting, replacements and toppling), a variable density of potential bunch-bearing stems (grown in mats, variable number of stems kept per mat) and by variable crop cycle durations depending on the nutritional and health status of the plantains (Ndubizu and Okafor, 1976), led to an uncertain estimation of this first yield component, which only a more meticulous and time-consuming exploration of all the plantains in each study field would have been able to improve. The size and variability of the measured pre-harvest losses also showed that this yield component should be weighted by an estimation of the risk of toppling before harvest, as we attempted to do with the 'BPdyn' variable. The second expected yield component was the average bunch weight. The high measured within-field variability for bunch weights raised doubts about its value as a yield component. Nevertheless, with a view to comparing between study fields, we adopted yield modelling incorporating these limits. The mean measured yield (6.8 t/ha/year) was within the average of 5–12 t/ha/year for overall yields (Lescot, 1997) described in West and Central Africa (See Introduction). However, our results also showed that this value displayed very high variability between cropping systems (1.1–18.8 t/ha/year). They highlighted the low representativeness and the difficult interpretation of average yields established by the literature and the lack of knowledge regarding the true productivity of traditional plantain-based cropping systems.

4.2. Factors affecting plantain productivity

Some characteristics of the production and cropping systems were identified as having a significant effect on bunch weight and plantain field lifetime. The small number of fields studied did not enable a generalization of the formalized rules, but the factors that were brought to light suggested some study options for enhancing the understanding of plantain productivity. Bunch weights were highest in the production systems with the greatest means of production, in particular those with access to chemical inputs. The high cost of plantain growing, particularly due to the inputs needed, is often put forward by farmers as a reason for the limited success of this crop. Most of the farmers achieving high bunch weights had received agricultural training, with farming as their main activity, and were not members of a farmer group. The fields involved were usually far from homes, located on the edge of forest zones where less land pressure would appear to allow fallow periods; the fertility of their soil could also be better due to more recent deforestation. All the analyses identified fallow as a factor improving bunch weights, corresponding to an already demonstrated improvement in health status (Chabrier et al., 2010). Nitrogen fertilizer application, either directly on the plantains, or on the interrops, was also correlated positively with bunch weight. These aspects tally with the importance of nitrogen nutrition for plantain growth (Anjorin and Obigbesan, 1983), which would be worth looking into more closely by variety, to assist farmers in their bunch weight objectives. The highest average bunch weights were observed in the fields with the greatest cropping diversity. There may exist some facilitation between the plantains and their intercrops in agroforest systems (Zake et al., 2015), but within the environment studied, where abiotic stress was very present, the hypothesis would rather be that the fertilization and herbicides applied to the intercrops made a favourable contribution to plantain growth. In addition, a large number of insecticide applications on the intercrops was analysed as being detrimental to bunch weight, the hypothesis being that chemical control destructures the trophic networks harbouring predators of black banana weevils (Dassou et al., 2015). Lastly, a plantain comprising a maximum of two stems would seem to bear the heaviest bunches; this would confirm that the selection of a single successor would promote bunch weight more (Vargas et al., 2005). The plantain field lifetime was maximized in small fields, with a limited number of annual crops intercropped with plantains, through the use of organic fertilization and the absence or only very limited use of insecticides. The use of organic fertilization is known for its positive overall effects on plantain growth and yields (Ndukwe et al., 2009; Obiefuna, 1991) and the low use of insecticide could be beneficial to trophic networks rich in weevil predators, limiting toppling (Dassou et al., 2015).

4.3. Insights for plantain cropping

The crop management sequences seen in the study fields revealed major use of chemical inputs that positively influenced bunch weights. The highest yields were achieved by cropping systems integrating nitrogen fertilization and pesticides. The three agricultural practices most frequently implemented by the interviewed farmers were inorganic fertilization, along with herbicide and nematicide applications. In addition, the average doses applied cannot be considered negligible, corresponding to around half the rates recommended by experts in a plantain monoculture based on input intensification. These results were quite surprising, because it is generally accepted that traditional plantain-based cropping systems in West and Central Africa would seem to use very few or no inputs (RTB, 2013). Despite that pesticides were not only applied on plantain, we cannot rule out possible technology transfer or an imitation phenomenon related to export banana agro-industries located in the area. It would be interesting to compare these data with other plantain production contexts. However, farmers are increasingly seeing the specialization of plantain crops with monoculture based on chemical inputs as a financial opportunity. This trend can be considered worrying given some other observations during farmer interviews: as already described by Hauser and Amougou (2008) we found that farmers lacked knowledge of the main pests and diseases of plantain and their impacts, the nutritional requirements of the different varieties grown depending on their development, and the chemical inputs applied. While the effects of fertilization and the use of herbicides to limit competition from weeds were shown in this study on the gain in bunch weight, it would be worth studying the effectiveness of chemical input applications in these cropping systems, as they have a heavy cost for farmers and also a major social and environmental cost (de Bon et al., 2014). Furthermore, our results showed that the lowest yields did not systematically correspond to the absence of, or minimalist use of inputs. It would be worth taking a more in-depth look at the relation existing between plantain productivity and the level of specialization and chemical intensification in cropping systems on the scale of a larger production zone, particularly in the current context of a lack of quality planting material. Thus, in a food security and environmental protection context (Temple et al., 2015), and faced with many alternatives to chemical inputs that have currently developed for export bananas (Cote et al., 2008; De Lapeyre de Bellaire et al., 2016), we need to recall the surge for agronomic research to support the development of agroecological and productive plantain-based cropping systems.

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References

Aba, S.C., Baiyeri, K.P., 2015. Nitrogen and potassium fertilizer influenced nutrient use efficiency and biomass yield of two plantain (< i > Musa < /i > spp. AAB)

genotypes. Afr. J. Agric. Res. 10, 458–471.
Achard, R., Sama Lang, P., 1998. Description des systèmes de production du sud-ouest du Cameroun : quels enseignements pour l'intervention de la recherche? In: Picq, C., Fouré, E., Frison, E.A. (Eds.), Bananas and Food security. Les productions bananières: un enjeu économique majeur pour la sécurité alimentaire. INIBAP, Douala (Cameroun), pp. 649–666.
Adenikinju, S.A., 1983. L'importance du plantain pour la production du cacao et pour les paysans. Fruits 38, 348–350.
Adinya, I.B., Awoke, M.U., Enun, E.E., Arikpo, J.D., 2008. Analysis of resource use efficiency of small scale plantain (Musa sp. aabcv.agbagba) mono cropping system in Cross River state, Nigeria. J. Agric. Forest. Soc. Sci. 6 (n.p.).
Akinyemi, S.O.S., Aiyelaagbe, I.O.O., Akyeampong, E., 2008a. Plantain (MUsa spp.) cultivation in Nigeria: a review of its production, marketing and research in the last two decades. In: Dubois, T., Hauser, S., Staver, C., Coyne, D. (Eds.), International Conference on Banana and Plantain in Africa: Harnessing International Partnerships to Increase Research Impact. Acta Horticulturae, Mombasa (Kenya), pp. 211–218.
Akinyemi, S.O.S., Staver, C., Aiyelaagbe, I.O.O., Kintomo, A.A., Babalola, S.O., 2008b. Perspectives of small-scale Musa processing firms in Nigeria. In: Dubois, T., Hauser, S., Staver, C., Coyne, D. (Eds.), International Conference on Banana and Plantain in Africa: Harnessing International Partnerships to Increase Research Impact. Acta Horticulturae, Mombasa (Kenya), pp. 257–263.
Akyeampong, E., 1998. Plantain production, marketing and comsuption in West and Central Africa. In: Picq, C., Fouré, E., Frison, E.A. (Eds.), Bananas and Food Security. Les productions bananières: un enjeu économique majeur pour la sécurité alimentaire. INIBAP, Douala (Cameroun), pp. 353–359.
Anjorin, H.O., Obigbesan, G.O., 1983. Influence de la fertilisation azotée sur la croissance et le développement précoces du plantain (musa paradisiaca). Fruits 38, 300–302.
Arikpo, J.D., Adinya, I.B., Angba, A.O., Agbogo, E.A., Ahong, E.A., Nyienakuna, M.G., Eze, A.N., Anyaorah, N.C., Ogar, N.E., 2009. Economic analysis of variables affecting the plantain (Musa sp) mono cropping system of production by small-scale farmers in central Cross River State, Nigeria. J. Agric. Forest. Soc. Sci. 7 (n.p.).
Ba Kumfifutu, B., 1996. La culture de la banane au Zaïre. In: Ortiz, A.V., Akoroda, M.O. (Eds.), Plantain and Banana: Production and Research in West and Central Africa. Ibadan, Nigeria, pp. 103–108.
Baiyeri, G.T., Ortese, E., 2007. Variation in growth, dry matter production, nitrogen and potassium uptake by six Musa genotypes in a soiless culture. J. Appl. Hortic. 9, 84–88.
Banful, B., 1998. Production of plantain, an economic prospect for food security in Ghana. In: Picq, C., Fouré, E., Frison, E.A. (Eds.), Bananas and Food Security. Les productions bananières: un enjeu économique majeur pour la sécurité alimentaire. INIBAP, Douala (Cameroun), pp. 151–160.
Banful, B., Dzietror, A., Ofori, I., Hemeng, O.B., 2000. Yield of plantain alley cropped with Leucaena leucocephala and Flemingia macrophylla in Kumasi, Ghana. Agrofor. Syst. 49, 189–199.
Banful, B., Hauser, S., Kanga, F.N., Kumaga, F., Ofori, K., 2008. Soil population of Helicotylenchus multicinctus under Pueraria phaseoloides, Flemingia macrophylla and natural bush fallows and their effect on plantain yield in the humid forest zone of southern Cameroon. Biol. Agric. Hortic. 25, 209–221.
Bifarin, J.O., Alimi, T., Baruwa, O.I., Ajewole, O.C., 2008. Determinants of technical, allocative and economic efficeincies in the Plantain (Musa spp.). Production industry, ondo state, Nigeria. In: Dubois, T., Hauser, S., Staver, C., Coyne, D. (Eds.), International Conference on Banana and Plantain in Africa: Harnessing International Partnerships to Increase Research Impact. Acta Horticulturae, Mombasa (Kenya), pp. 199–209.
Bikoï, A., Yomi, G., 1998. Origine et gestion de l'instabilité sur les marchés des produits vivriers: le cas de la filière plantain à Douala, Cameroun. In: Picq, C., Fouré, E., Frison, E.A. (Eds.), Bananas and Food Security. Les productions bananières: un enjeu économique majeur pour la sécurité alimentaire. INIBAP, Douala (Cameroun), pp. 497–506.
Blazy, J.-M., Carpentier, A., Thomas, A., 2011. The willingness to adopt agro-ecological innovations: application of choice modelling to Caribbean banana planters. Ecol. Econ. 72, 140–150.
Breiman, L., Friedman, J., Olshen, R., Stone, C., 1984. Classification and Regression Trees. Wadsworth & Brooks.
Chabrier, C., Tixier, P., Duyck, P.F., Carles, C., Queneherve, P., 2010. Factors influencing the survivorship of the burrowing nematode, Radopholus similis (Cobb.) Thorne in two types of soil from banana plantations in Martinique. Appl. Soil Ecol. 44, 116–123.
Combroux, J., 1957. Atlas du Cameroun.
Cote, F., Tomekpe, K., Staver, C., Dépigny, S., Lescot, T., Markham, R., 2008. Agro-ecological intensification in banana and plantain (Musa spp.): an approach to develop more sustainable cropping systems for both smallholder farmers and large-scale commercial producers. In: Dubois, T., Hauser, S., Staver, C., Coyne, D. (Eds.), International Conference on Banana and Plantain in Africa: Harnessing International Partnerships to Increase Research Impact. Acta Horticulturae, Mombasa (Kenya), pp. 457–464.
Coyne, D., Wasukira, A., Dusabe, J., Rotifa, I., Dubois, T., 2010. Boiling water treatment: a simple, rapid and effective technique for nematode and banana weevil management in banana and plantain (Musa spp.) planting material. Crop Prot. 29, 1478–1482.
Damour, G., Garnier, E., Navas, M.L., Dorel, M., Risede, J.M., 2015. Using functional traits to assess the services provided by cover plants: a review of potentialities in banana cropping systems. Adv. Agron. 81–133.
Dankii, A.A., Dzomeku, B.M., Anno-Nyako, F.O., Adu-Appiah, A., Gyamera-Antwi, 2007. Plantain production practices in the Ashanti, Brong-Ahafo and Eastern regions of Ghana. Asian J. Agric. Res. 1, 1–9.
Dassou, A., Carval, D., Depigny, S., Fansi, G., Tixier, P., 2015. Ant abundance and Cosmopolites sordidus damage in plantain fields as affected by intercropping. Biol. Control 81, 51–57.
de Bon, H., Huat, J., Parrot, L., Sinzogan, A., Martin, T., Malézieux, E., Vayssières, J.-F., 2014. Pesticide risks from fruit and vegetable pest management by small farmers in sub-Saharan Africa. A review. Agron. Sustain. Dev. 34, 723–736.
De Langhe, E., 1961. La taxonomie du bananier plantain en Afrique équatoriale. Journal d'Agriculture Tropicale et de Botanique Appliquée 8, 417–449.
De Lapeyre de Bellaire, L., Bachelier, B., Dorel, M., Goebel, F.R., Guibert, H., Husson, O., Jagoret, P., Marnotte, P., Risède, J.M., Scopel, E., 2016. Conception des systèmes de culture et intensification écologique. In: Biénabe, E., Rival, A., Loeillet, D. (Eds.), Développement durable et filières tropicales. Quae, pp. 125–138.
Dépigny, S., Tchotang, F., Talla, M., Fofack, D., Essomé, D., Ebongué, J.-P., Kengni, B., Lescot, T., 2018. The 'Plantain-Optim' Dataset: Agronomic Traits of 405 Plantains every 15 Days from Planting to Harvest. (Data in Brief).
Desdoigts, E., Kwa, M., Fogain, R., Temple, L., Lang, P.S., Bikoï, A., Achard, R., 2005. A multidisciplinary monitory centre by smallholders in Cameroon to identify factors limiting plantain production. Fruits 60, 237–244.
Dowiya, N.B., Rweyemamu, C.L., Maerere, A.P., 2009. Banana (Musa spp. Colla) cropping systems, production constraints and cultivar preferences in eastern Democratic Republic of Congo. J. Anim. Plant Sci. (JAPS) 4, 341–356.
Dzomeku, B.M., Dankyi, A.A., Darkey, S.K., 2011. Socioeconomic importance of plantain cultivation in Ghana. J. Anim. Plant Sci. 21, 269–273.
Folefack, D.P., Fongang Fouepe, G.H., Adamou, K.M., Ebongue, J.-P., Bikoi, A., Noupadja, P., 2017. Analysis of the plantain supply system of markets in the city of Douala. J. Econ. Sustain. Dev. 8 (6). http://www.iiste.org (ISSN 2222-1700 (Paper) ISSN 2222-2855 (Online)).
Hauser, S., Amougou, D., 2008. Plantain (Musa spp.) cropping systems of southern Cameroon. In: Dubois, T., Hauser, S., Staver, C., Coyne, D. (Eds.), International Conference on Banana and Plantain in Africa: Harnessing International Partnerships to Increase Research Impact. Acta Horticulturae, Mombasa (Kenya), pp. 495–508.
Hauser, S., van Asten, P., 2008. Methodological considerations on banana (Musa spp.) yield determination. In: Dubois, T., Hauser, S., Staver, C., Coyne, D. (Eds.), International Conference on Banana and Plantain in Africa: Harnessing International Partnerships to Increase Research Impact. Acta Horticulturae, Mombasa (Kenya), pp. 433–444.
Iratcher, B., 1998. UN outil pour orinter la recherche et apporter des réponses aux problèmes des producteurs de bananes plantains dans le sud-ouest du Cameroun : l'exemple de l'observatoire agro-phytosanitaire.
Jacobsen, K., Fogain, R., Mouassom, H., De Waele, D., 2004. Musa-based cropping systems of the Cameroon highlands: a case study of the West and Northwest provinces of Cameroon, with emphasis on nematodes. Fruits 59, 311–318.
Jolaoso, M.A., Ojeifo, I.M., Aiyelaagbe, I.O.O., 1996. Productivity of plantain (Musa AAB) melon mixtures in South Western Nigeria. Biol. Agric. Hortic. 13, 335–340.
Justes, E., Bedoussac, L., Corre-Hellou, G., Fustec, J., Hisinger, P., Jeufroy, M., Journet, E., Louarn, G., Naudin, C., Pelzer, E., 2014. Les processus de complémentarité de niche et de facilitation déterminent le fonctionnement des associations végétales et leur efficacité pour l'acquisition des ressources abiotiques. Innov. Agron. 40, 1–24.
Landau, S., Mitchell, R.A.C., Barnett, V., Colls, J.J., Craigon, J., Payne, R.W., 2000. A parsimonious, multiple-regression model of wheat yield response to environment. Agric. For. Meteorol. 151–166.
Lescot, T., 1997. Culture du bananier plantain et durabilité des systèmes de production. Fruits 52, 233–245.
Lescot, T., 2017. La diversité génétique des bananiers. Fruitrop Focus Banane 208–212.
Lescot, T., Ganry, J., 2008. Plantain (Musa spp.) cultivation in Africa: a brief summary of developments over the previous two decades. In: Dubois, T., Hauser, S., Staver, C., Coyne, D. (Eds.), International Conference on Banana and Plantain in Africa: Harnessing International Partnerships to Increase Research Impact. Acta Horticulturae, Mombassa (Kenya), pp. 445–455.
Malézieux, E., Crozat, Y., Dupraz, C., Laurans, M., Makowski, D., Ozier-Lafontaine, H., Rapidel, B., de Tourdonnet, S., Valantin-Morison, M., 2009. Mixing plant species in cropping systems: concepts, tools and models. A review. Agron. Sustain. Dev. 29, 43–62.
Melin, P., Plaud, G., Tezenas Du Montal, H., 1976a. Influence du mode de conduite du bananier plantain sur l'intensification de la culture. Fruits 31, 669–671.
Melin, P., Plaud, G.T.D.M., Hugues, 1976b. Potentiel de productivité de deux cultivars de French plantain. Fruits 31, 655–657.
Mialoundama Bakouétila, G., Berton Ofuémé, Y., IR, T., Boukoulou, H., Folefack, D., Mbemba, F., Loubelo, A., Makouya, H., Mboungou, Z., 2016. Analyse des déterminants de la consommation de la banane (Musa sp.) à Brazzaville, République du Congo. J. Anim. Plant Sci. 31.
Nakache, J.-P., Confais, J., 2003. Statistique explicative appliquée. In: Analyse discriminante, Modèle logistique, Segmentation par arbre. Technip, Paris.
Ndubizu, T.O.C., Okafor, E.I., 1976. Growth and yield patterns of nigerian plantains. Fruits 31, 672–677.
Ndukwe, O.O., Muoneke, C.O., Baiyeri, K.P., Tenkouano, A., 2009. The effects of organic and inorganic fertilizers on growth, yield and black Sigatoka disease reaction of some plantain (Musa spp. AAB) genotypes in south-eastern Nigeria. Agro-Sci. 8, 151–161.
Ndungo, V., Fiaboe, K.K.M., Mwangui, M., 2008. Banana Xanthomonas wilt in the DR Congo: impact, spread and management. J. Appl. Biosci. 1–7.
N'Guessan, A., Yao, N., Kehé, M., 1993. La culture du bananier plantain en Côte d'Ivoire. Fruits 48, 133–143.
Niere, B., Gold, C., Coyne, D., Dubois, T., Sikora, R., 2014. Performance of tissue-cultured versus sucker-derived East African highland banana (Musa AAA-EA) under high and low input systems in Uganda. Field Crop Res. 156, 313–321.
Nkendah, R., Temple, L., 2003. Pression démographique et efficacité technique des producteurs de banane plantain de l'Ouest-Cameroun. Agriculture 12, 333–339.
Obiefuna, J.C., 1986. The effect of monthly planting on yield, yield patterns and yield

decline of plantains (Musa AAB). Sci. Hortic. 29, 47–54.
Obiefuna, J.C., 1991. The effect of crop residue mulches on the yield and production pattern of plantain (Musa-Aab). Biol. Agric. Hortic. 8, 71–80.
Ocimati, W., Karamura, D., Rutikanga, A., Sivirihauma, C., Ndungo, V., Ntamwira, J., Kamira, M., Kanyaruguru, J.P., Blomme, G., 2013. Agronomic Practices for Musa Across Different Agro-Ecological Zones in Burundi, Eastern Democratic Republic of Congo and Rwanda. pp. 175–190.
Osseni, B., Séry, Z., N'Guessan, A., Yao, N.T., 1998. Evolution des circuits de commercialisation de la banane plantain à l'échelle d'une petite localité du sud forestier de la Côte d'Ivoire. In: Picq, C., Fouré, E., Frison, E.A. (Eds.), Bananas and Food Security. Les productions bananières : un enjeu économique majeur pour la sécurité alimentaire. INIBAP, Douala (Cameroun), pp. 555–564.
Pierrot, J., Achard, R., Temple, L., Abadie, C., Fogain, R., 2002. Déterminants de la production de plantain dans le sud-ouest du Cameroun: intérêt d'un observatoire. Fruits 57, 75–86.
R-Core-Team, 2017. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
RTB, 2013. Workshop Report: Tools for Improved Cropping Systems Intensification in Mixed RTB Systems with Plantain in West and Central Africa. CGIAR, Research Program on Roots, Tubers and Bananas.
Sonwa, D.J., Coulibaly, O., Weise, S.F., Akinwumi Adesina, A., Janssens, M.J.J., 2008. Management of cocoa: Constraints during acquisition and application of pesticides in the humid forest zones of southern Cameroon. Crop Prot. 27, 1159–1164.
Speijer, P.R., Budenberg, W.J., Sikora, R.A., 1993. Relationships between nematodes, weevils, banana and plantain cultivars and damage. Ann. Appl. Biol. 123, 517–525.
Temple, L., Engoya Oyep, J., 1998. Système d'information des marchés et analyse de la sécurité alimentaire. Le cas du plantain dans le centre et le sud du Cameroun. In: Picq, C., Fouré, E., Frison, E.A. (Eds.), Bananas and Food Security. Les productions bananières: un enjeu économique majeur pour la sécurité alimentaire. INIBAP, Douala (Cameroun), pp. 252–536.
Temple, L., Touzard, J.M., Kwa, M., Boyer, J., Requier-Desjardins, D., 2015. Comparaison des trajectoires d'innovation pour la sécurisation alimentaire des pays du sud. Base 19, 53–61.
Tenkouano, A., Hauser, S., Coyne, D., Coulibaly, O., 2006. Clean planting materials and management practices for sustained production of banana and plantain in Africa. Chronica Hortic. 46, 14–18.
Tezenas du Montcel, H., De Langhe, E., Swennen, R., 1983. Essai de classification des bananiers plantains (Musa AAB). Fruits 38, 461–474.
Therneau, T., Atkinson, B., Ripley, B., 2018. RPART: Recursive Partitioning and Regression Trees.
Vargas, A., Araya, M., Rojas, S., Roma, P., 2005. Effect of removing or leaving the suckers at flowering of plantain (Musa AAB, cv. 'False Horn' type) on bunch weight and foliar nutrient content of the parent plant. Sci. Hortic. 107, 70–75.
Yao, N., 1988. Enquête sur les systèmes de culture intégrant le bananier plantain en milieu paysan de Côte d'Ivoire. Fruits 43, 149–159.
Yao, A.K., Koffi, D.M., Irie, Z.B., Niamke, S.L., 2014. Effect of partial substitution of wheat flour with mashed ripe plantain (< i > Musa < /i > AAB) on pastry products quality. [French]. J. Appl. Biosci. 7436–7448.
Zake, J., Pietsch, S.A., Friedel, J.K., Zechmeister-Boltenstern, S., 2015. Can agroforestry improve soil fertility and carbon storage in smallholder banana farming systems? J. Plant Nutr. Soil Sci. 178, 237–249.