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Full Length Research Paper

Morpho-agronomic characteristics of cowpea under different environments and planting densities

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The aim of this study was to evaluate the growth and production components of cowpea 'BRS Nova Era' under different planting densities in two growing conditions. The experiment followed an experimental design of randomised blocks, which comprised two environments (Pesqueira and Lajedos cities, Brazil) and five planting densities (6, 8, 10, 12 and 14 plants m^{-1}). In Pesqueira, all production components were influenced by planting density except for plant height. In Lajedo, all production components were influenced by planting density. Productivity per total area was 74.25 and 58.33% higher at a density of six plants m^{-1} compared to the highest density for both Pesqueira and Lajedos, respectively. The growth of cowpea under edapho-climatic conditions of Lajedos resulted in better development and productivity than in Pesqueira. Therefore, under the conditions of our study, different planting densities of the cowpea promote changes in production components and productivity, with better results obtained at a density of 6 plants m^{-1}.

Key words: *Vigna unguiculata* (L.) Walp, spatial arrangements, growth, production components, productivity.

INTRODUCTION

Cowpea [*Vigna unguiculata* (L.) Walp.] is widely cultivated in tropical and subtropical regions, being characterised as a hot-season crop due to its adaptation to high temperatures (Naim and Jabereldar, 2010). In Brazil, the cowpea is widely grown in northern and northeastern regions, especially in the semi-arid areas of the Northeast, where it is well adapted to climate and soil conditions. However, the crop has been expanding into the cerrado regions of the Midwest; this has helped to foster research into the crop, which has been intensively

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Table 1. Analysis of soil fertility in the experimental areas and chemical analysis of the cattle manure used in the experiment.

Location	pH	MO	P	K	Ca	Mg	Al	H+Al	BS	CEC	V
	($CaCl_2$)	(g Kg^{-1})	(mg dm^{-3})		------------cmolc/dm^3------------					(pH 7)	(%)
Pesqueira	6.2	34.4	100	0.25	28	1.23	0.0	3.31	29.48	32.79	89.90
Lajedo	6.2	16.7	47	0.30	3.75	0.75	0.0	4.26	4.80	9.06	52.98
	N	P	P_2O_5	K	K_2O	Ca	CaO	Mg	MgO	S	-
Manure cattle			-- % --								
	1.97	0.07	0.17	1.97	2.36	0.47	0.66	0.45	0.78	0.29	-

researched in recent decades (Brilhante et al., 2014; Souza et al., 2016; Costa et al., 2017a, 2017b).

Even with the increasing expansion of cowpea to other regions of the country coupled with the physiological quality of the materials being released, there has been no substantial increase in the productivity of this legume. Among the agronomic practices that have a direct relationship with grain production in the cowpea, plant density is one of the most important, especially influencing morphophysiology, production components and productivity (Bezerra et al., 2012). In this respect, Klehm et al. (2013) developed research towards the interaction between plant density and changes in the productive behaviour of the plant, and found that every dense plants undergo modifications to their physiological components, triggering significant changes in production components, and consequently altering productivity.

The choice of spacing used is closely linked to density and cultivar to be introduced; and thinning allows for better crop establishment in the field, optimising plant development and reducing competitiveness, which consequently results in more significant grain production (Klehm et al., 2013).

According to Cardoso and Ribeiro (2006), productivity and grain production per plant in the cowpea are modified by row spacing and plant density. The effects of spacing decrease linearly for the two aforementioned characteristics. As spacing increases over 50 cm, both grain production per plant and productivity per hectare are negatively affected; and with an increase in plant density, there is a decrease in the number of pods per plant, as well as in grain production per plant. For Bezerra et al. (2012), a lack of attention to the plant population when planting cowpea, whether mechanised or not, promotes significant changes in plant morphology, with reductions in the production components.

According to Bezerra et al. (2012), the trend has been to develop cultivars with a high potential for grain production and good plant architecture, thereby adapting denser crops. Further, with the aim of facilitating mechanised harvesting to meet the requirements of technified cultivation, and make large areas in the Midwest, North and Northeast, which have been increasing every year, viable for planting, plant architecture is being worked on and studied in research experiments in an effort to adjust the cowpea to new trends in the marketplace.

With this in mind, the aim of this work was to evaluate the morpho-agronomic characteristics of the cowpea under different planting densities.

MATERIALS AND METHODS

This experiment was conducted in the towns of Pesqueira and Lajedos in the State of Pernambuco, Brazil. The experimental area in Pesqueira is located at latitude 8°34'17" S and longitude 37°1'20" W, in soil classified as Neosol. In Lajedos, the experimental area was located at latitude 8°39'29" S and longitude 36°19'46" W, in soil classified as Regosol (Embrapa, 2006).

The experimental design was of randomised blocks, comprising five treatments - planting densities of 6, 8, 10, 12 and 14 plants m^{-1} and four replications, using the 'BRS Nova Era' cultivar. Each plot was composed of four rows, five metres in length, spaced 0.5 m apart; the working area was taken to be the complete middle four rows. The experiment was kept free of weeds through manual weeding, while other cropping treatments were those normally applied to the crop.

Soil samples were taken at a depth of 20 cm for chemical analysis (Table 1), in order to check soil fertility and nutrient availability to the plants, and for the possible correction of nutrient levels. The soil was prepared mechanically, which consist of ploughing and harrowing to level the ground. Seeding was carried out on May 7, 2014, following the recommendations for climatic risk zoning of the Ministry of Agriculture, Livestock and Supply. Planting was done manually, at four seeds per hole. Thinning was carried out 15 days after planting, leaving one plant per hole to achieve the desired populations.

Fertilisation was manual, distributing the equivalent of 5 t ha^{-1} of cattle manure in the planting furrows (Table 1); chemical fertilisation was unnecessary due to the concentration of the soil nutrients. Evaluations were made of growth (plant height) and production, such as productivity and its primary components (number of pods per plant, number of grains per pod and mean 100-grain weight). When 90% of the pods were physiologically mature and ready for harvest, and the grain displayed 13 to 15% humidity, the following characteristics were evaluated: pod weight, pod length, number of pods, shell weight, mean 100-grain weight and productivity per hectare.

All the characteristics were submitted to analysis of variance, to observe the effect of the different locations on the genotypes. The mean values for the variables were compared by Tukey's test at 5% probability. The data on sowing density were submitted to regression analysis.

Table 2. Summary of the analysis of variance (mean squares) of the data for plant height (PH), stem diameter (SD), shoot dry weight (SDW), height of pod insertion (HPI), number of pods per plant (NPP) and productivity (P) of cowpea grown in Pesqueira, Brazil, due to different planting densities.

S.V.	DF	PH	SDW	SD	HPI	NPP	P
Density	4	64.80ns	12310.67**	0.078*	159.82*	47.93**	32757.51**
Linear	1	72.90ns	44622.40**	0.21**	396.90*	176.40**	123309.92**
Quadratic	1	8.64ns	604.57ns	0.004ns	18.29ns	0.286ns	260.15ns
Regr. Dev.	2	177.66ns	4015.73	0.0982ns	224.11ns	15.01ns	7459.98ns
Block	3	44.85ns	54.98ns	0.006ns	44.13ns	4.40ns	4361.04ns
Residual	12	107.93	1091.11	0.0206	45.26	2.53	5356.17
C.V. (%)	-	14.41	22.01	23.52	11.89	18.06	8.72

**Significant at 1% probability, *Significant at 5% probability, ^{ns}Not significant.

RESULTS AND DISCUSSION

In Table 2, it can be seen that, in the region of Pesqueira, with the exception of plant height, there was a significant effect, ranging from 1 to 5% probability, for all the variables under study, as a function of planting density. It can further be seen that, except for plant height, the linear model fitted the mean values of the variables, also as a function of planting density.

Plant height, stem diameter, shoot dry weight, height of pod insertion, number of pods per plant and productivity displayed maximum values of aproximatelly 78 cm, 8 mm, 213 g, 64 cm, 12.5 and 951 kg ha^{-1}, respectively, under a planting density of 6 to 8 plants m^{-1}, with exception of plant heigh, which showed inversal behaviour (Figure 1). These responses observed for the variable plant height are usually related to the development of undesirable processes, such as etiolation, due to the competition for light and another production factors (Larcher, 2003; Taiz et al., 2015).

The lower values for the morphoagronomic components seen with the increase in planting density, occurred due to the stress imposed by the competition between plants, which results in a decrease in light intensity that directly affects the photosynthetic activity of the plants (Larcher, 2003). In the region of Pesqueira, the increase in cowpea planting density had a negative effect on productivity (Figure 1). Based on the linear behaviour (R^2=0.94), the total productivity per area was 74.25% greater at a density of 6 plants m^{-1} in relation to the density of 14 plants.m^{-1}.

With the aim of evaluating different population densities (10^5, $3×10^5$ and $5×10^5$ plants ha^{-1}) on the morphological and production characteristics of cowpea genotypes, Bezerra et al. (2012) reported a higher productivity (1,836 kg.ha^{-1}) at a planting density of 300,000 plants ha^{-1}. Under such conditions, there was a cooperative interaction when competition occurred at favourable times and levels, which promoted greater grain productivity. According to the same authors, a reduction in productivity with the increase in plant density is a response to the reduction in the number of lateral branches, which is a consequence of the increased competition, and directly affects the productive capacity of the plants.

Photosynthesis is limited by low levels of incident light, causing a decrease in carbon gain, plant growth and consequently, grain productivity (Larcher, 2003). However, the reduction in the number of lateral branches with the increase in population density, favours mechanised harvesting of the cowpea crop. Table 3 shows a significant effect from planting density in the Lajedo region (1 to 5% probability) for all the variables under study. It can also be seen that the linear model fitted the mean values for stem diameter, height of pod insertion and shoot dry weight. The mean values for height, number of pods per plant and productivity were fitted to the quadratic model.

In Lajedo conditions we observed that both growth and production components showed similar behaviour as observed in Pesqueira, with better results under the lowest planting densities (6 to 8 plants m^{-1}), except for plant height values. In this environment, plant height, stem diameter, shoot dry weight, height of pod insertion, number of pods per plant and productivity presented maximum values of aproximatelly 106 cm, 7 mm, 202 g, 61 cm, 14 and 1,240 kg ha^{-1} respectively (Figure 1). The enhanced productivity obtained in this region occurred as a result of better values in production components under this condition, such as height of pod insertion and number of pods per plant. Therefore, under Lajedo environmental conditions, cowpea seems to enhance carbon allocation driven to sink organs, such as pods and grain, improving the source-sink interactions of this crop (Taiz et al., 2015).

The data for plant height differ from Horn et al. (2000), who found an increase in plant height (12%) for an increase in spacing. Taller plants tend to display greater lodging. However, this did not occur, due to the uniformity seen in the field, that is, the plants supported each other, reducing the instances of lodging.

As also seen in the region of Pesqueiro, in Lajedo, the

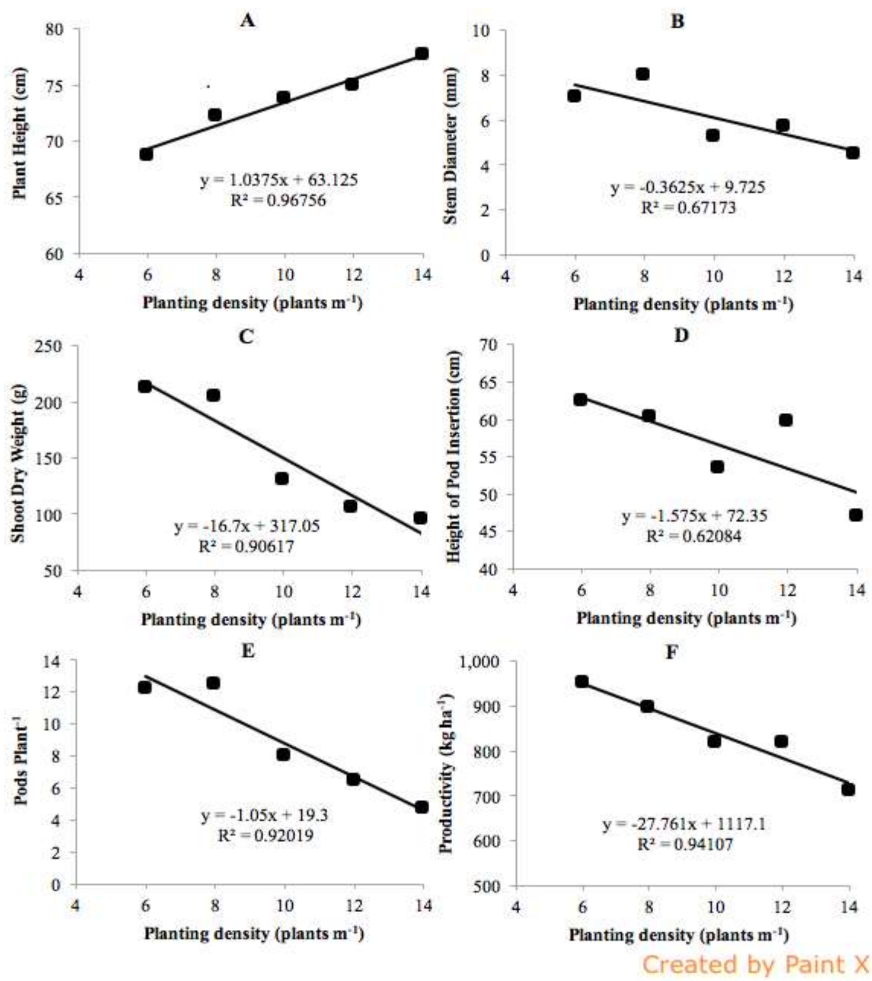

Figure 1. Plant height, cm (A) stem diameter, mm (B), shoot dry weight, g (C), height of pod insertion, cm (D), number of pods per plant (E) and productivity, kg ha^{-1} (F) of cowpea grown in Pesqueira, Brazil, due to different planting densities.

Table 3. Summary of the analysis of variance (mean squares) of the data for plant height, stem diameter (SD), shoot dry weight (SDW), height of pod insertion (HPI), number of pods per plant (NPP) and productivity (P) of cowpea grown in Lajedo, Brazil, due to different planting densities.

S.V.	DF	Height	SD	HPI	NPP	SDW	P
Density	4	1783.67**	0.072**	546.93**	51.825**	3710.69**	216235.18**
Linear	1	3515.63**	0.256**	1428.03**	189.23**	9063.11**	786541.60**
Quadratic	1	3165.02**	0.0257ns	161.16ns	17.16*	0.0016ns	75925.79**
Regr. Dev.	2	454.06ns	0.00623ns	598.51ns	0.914ns	5779.66ns	2773.31ns
Block	3	22.80ns	0.0193ns	75.00ns	3.325ns	738.14ns	2542.45ns
Residual	12	76.67	0.0077	83.13	1.20	638.60	7374.08
C.V. (%)	-	11.64	14.84	18.49	21.20	15.50	9.70

**Significant at 1% probability, *Significant at 5% probability, ^{ns}Not significant.

increase in cowpea planting density reduced productivity (Figure 2). Following a linear behaviour (R^2=0.91), the total productivity per area was 58.33% higher for a density of 6 plants m^{-1} compared to the density of 14 plants m^{-1}.

As seen in Pesqueiro, there was an inverse relationship

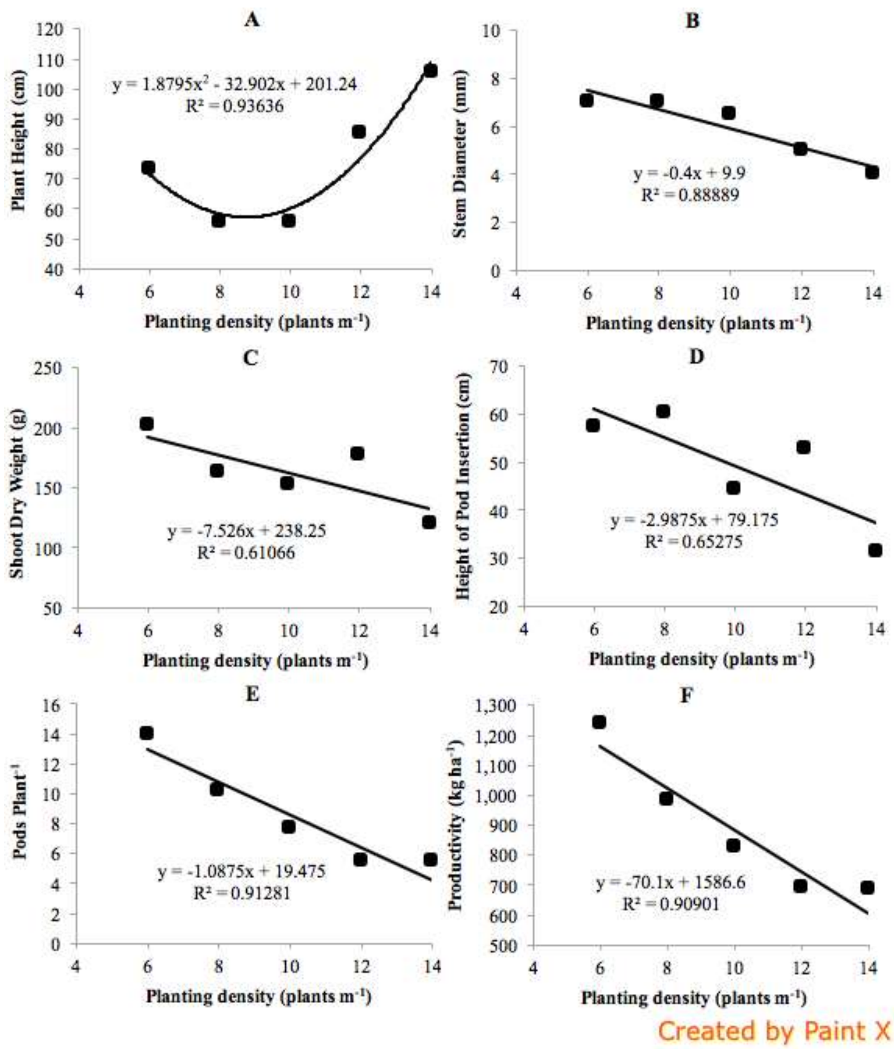

Figure 2. Plant height, cm (A) stem diameter, mm (B), shoot dry weight, g (C), height of pod insertion, cm (D), number of pods per plant (E) and productivity, kg ha^{-1} (F) of cowpea grown in Lajedos, Brazil, due to different planting densities.

between the increase in plant height and productivity, probably due to a reduction in the number of lateral branches. This inverse relationship also suggests a smaller leaf area per plant, which, according to Saidi et al. (2007), affects production and biomass partitioning, as well as grain production per plant and area. According to Taiz et al. (2015), the ability to produce dry matter from a crop under satisfactory conditions of water and nutrients will ultimately depend on solar radiation use efficiency, considering that only 5% of incident radiation is converted into carbohydrates by the leaf.

In our study, the reduction in productivity was due to a reduction in the number of pods per plant. Similarly, a reduction in the mean value for NPP in response to the increase in plant population per hectare was also reported by Cardoso and Ribeiro (2006), Lemma et al. (2009) and Naim and Jabereldar (2010).

Conclusions

Different cowpea planting densities and edapho-climatic conditions promote changes in production components and productivity, in a way that most parameters evaluated are reduced in both regions due to increases in cowpea planting density.

Therefore, the density of 6 plants per linear meter is the most adequated for both regions, being environmental conditions of Lajedo more appropriated to achieve better productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Phosphorus fractionation and P sorption capacities of Fincha Sugar Estate soils, Western Ethiopia

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Soil chemical forms of Phosphorus and P sorption capacities of Fincha Sugar Estate soils were studied using samples collected from luvisols, vertisols and fluvisols of the farm. P forms were sequentially extracted following standard P fractionation procedure. In sorption study, 3 g of soil sample was equilibrated with 30 ml of 0.01 M $CaCl_2$ containing various amounts of KH_2PO_4. Data were fitted into Langmuir and Freundlich equations. Results revealed that organic P (Po) accounted for the larger proportion of total P than total active inorganic P fraction in 66.7% of soils. The ratio of organic carbon to Po was < 200 in all soils indicating net mineralization of Po. Ca-P was dominant in luvisols and vertisols whereas Fe-P was dominant in fluvisols. P sorption data of all soils fitted well with Langmuir equation but the P sorption data of these soils were found not to fit with Freundlich equation. Langmuir adsorption maxima and external P requirement (EPR) of soils ranged from 227.3-344.8 and 63-153.8 $mgkg^{-1}$ respectively. Luvisols and vertisols which account for more than 95% of the farm had EPR values < 150 $mgkg^{-1}$ and hence they were classified as low P sorbing soils. This implies that high P sorption is not P limiting factor in the estate. The result further indicates that current P fertilizer application rate of 30 kg P ha^{-1} being practiced across all soil types of the farm needs to be revised after validating the EPR values estimated in this study for each soil both in greenhouse and in the field at Fincha Sugar Estate.

Key words: P fractions, P sorption, Langmuir equation, Freundlich equation.

INTRODUCTION

Phosphorus (P) is the second most important limiting nutrients for crop production in Ethiopia next to nitrogen. Nutrient mining including P due to continuous cropping, soil erosion, inadequate use of organic and inorganic nutrients are some of the cause of declining soil P content (Wakene and Heluf, 2003).

Deficiency of P in soils may also occur due to conversion of added soluble P fertilizer into unavailable form for plant uptake and this phenomenon is called P sorption/fixation (Ravikovitch, 1986). According to Gichangi (2007) P sorption is defined as a loss of orthophosphate from soils solution due to either adsorption or precipitation reaction. Soil P limitation due to sorption/fixation is a major problem in highly weathered

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tropical acid soils dominated by aluminum and iron oxides (Sanchez et al., 1997). The same authors compared the P requirements of 200 soil samples collected from West, east and Southern Africa based on their P sorption isotherm and they found thatto be in order of Anidsol >Oxisol >Ultisols >Alfisols >Entisols. High P-sorbing soils are characterized by clayey topsoil having red color as indicative of Fe and Al oxides and such soils make the bulk of soils in smallholder farms of Africa. This implies that P sorption is the major factor that limits P bioavailability in most African soils most of which are acidic.

The extent of P sorption greatly varies from soil to soil owing to their differences in physicochemical properties (Brady and Weil, 2002) and management (Moazed et al., 2010). Thus, understanding the P-sorption characteristics of soils are important for designing appropriate management strategies and predicting fertilizer requirements that are need to be applied (Zhang et al., 2005).

However, little or no information is available on sorption capacities of Ethiopian with the notable exception of the work of Sahlemedhin and Ahmed (1983), Duffera and Robarage (1999) and Birru et al. (2003). Thus, it is important to determine the P sorption capacities of as many arable soils of Ethiopia as possible and identify properties affecting the sorption characteristics of soilsas such information serve as a basis for improving the P nutrition of crops. Moreover, the P sorption capacities of soils are mostly determined by fitting sorption data of different soils into commonly known Langmuir and Freundlich equations (Sparks, 2003). However, the degree to which the P sorption data of soil fit to these equations vary from soil to soil. Thus, it is necessary to test and identify best fitting equation that describes a sorption characteristic of for a particular soil.

The chemical forms of P in which it exists in soils is another factor that greatly influence bioavailability of P and have environmental consequences (Rubio et al., 1998).The forms of soil P are broadly categorized into organic (Po) and inorganic (Pi) P forms. Organic P can account for 5-95% of total P (TP) content of soils. Soil Po is derived mainly from manures, plant material, and products of microbial decomposition. On the other hand, the Pi originates from the addition of inorganic fertilizers and weathering of primary minerals such as apatite and secondary minerals such as Ca and/or Mg phosphates and Fe and Al phosphates (Hedley et al*.,* 1982). The Po and Pi forms are further categorized into several different forms. However, the types and quantities of different forms of P that occur in a particular soil is the function of parent material, management and climate conditions. For instance, in acidic soils Fe and Al bound P is the predominant forms of soil P whereas Ca bound P is the major forms of Pi in calcareous soil. Knowledge on the different forms of soils is important to know the P supply potential of the soils, the degree of weathering of a particular soil, mineralization rate of Po and the extent of P sorption/fixation capacities of soils (Samadi, 2006).

In this regard, there is limited information on the chemical forms of P in the soils of Fincha Sugar Estate soils, Western Ethiopia. Thus, experiments were conducted to quantify the different P fractions of Fincha Sugar Estate soils, to determine their P sorption capacities and external P requirements; and to evaluate the ability of Langmuir and Freundlich equations in describing the P sorption data of the Fincha Sugar Estate soils.

MATERIALS AND METHODS

Site descriptions

The experimental soils were collected from Finch sugar estates which are under Ethiopian Sugar Corporation. Geographically Fincha Sugar Estate is located in Nile basin of western Ethiopia lying between of 9°30' to 10°00' of North of latitudes, and 37° 15' to 37°30' of East of longitude. It was established in 1995 and situated at a distance of 340 km west-east of Addis Ababa, the capital of Ethiopia. It has an altitude in the range of 1350-1600 masl and average annual precipitation of 1300 mm. The sugar cane farm of Fincha has total area of 8004 ha as of 2007 (Getahun et al., 2013). Based on FAO-UNESCO classification system, the soils of FINCHA are belong to luvisols, vertisols and fluvisol (Getahun et al., 2013) and the former two soils accountfor more than 95 % of the total area of land planted with sugarcane.

Soil sampling and preparation

Random soil samples from each soil type of Fincha Sugar Estate farm were collected following standard procedure described in Brook (1983) in which surface soil (0-20 cm) were taken using augur from thirty replicated pointsby waking in a zigzag manners.Then all the thirty samples collected from each soil type were transferred in to clean plastic bucket and mixed thoroughly to make a composite sample. From the composite sample 1 kg of subsample from each soil were taken and brought to Fincha Sugar Estate soil laboratory. In the laboratory the samples were air dried, grounded to pass 2 mm sized sieve and preserved for analysisof physicochemical properties, P fractionation and P sorption isotherm experiments.

Analytical procedures

The processed soil samples were analysed for selected physicochemical properties following procedures described in Jones (2001) in which texture determined by Bouyoucous hydrometer method, pH was measured in 1:2.5 soil water solution by pH meter, organic carbon (OC) by wet digestion method (Anderson and Ingram, 1996). Soil available P was determined by Olsen method (Olsen et al., 1954). Exchangeable cations were extracted by 1N NH_4OAC and in the extract; Na and K were determined by flame emission spectrophotometer whereas Ca and Mg were determined by atomic absorption spectrophotometer.

Phosphorus fractionation experiment

The total P was extracted with $HClO_4$ digestion technique (Jackson,

1964) whereas the inorganic P fractions were sequentially extracted, soluble P with 1 M NH_4Cl, aluminum bound P (Al-P) with 0.5 M NH_4F, iron bound P (Fe-P) with 0.1 M NaOH and calcium bound P (Ca-P) with 0.25 M H_2SO_4. The organic p was estimated by the difference between P extracted with 1N H_2SO_4 for calcinated and non-calcinated soil. Phosphorus in all extracts was determined spectrophotometrically by ascorbic acid-molybdate method (Olsen et al., 1954).

Phosphorus sorption experiment

Three grams of soil (Duffera and Robarge, 1999) from each sample was transferred in to 50 ml capacity plastic bottles and equilibrated with 30 ml of 0.01 M $CaCl_2$ solution containing 0, 1, 5, 10, 15 and 20 mg P L^{-1} in the form of KH_2PO_4. The bottles were shaken at 25°C on reciprocal shaker for 24 h (Graetz and Nair, 2000). Then, the suspensions were filtered through Whatman filter paper No. 42 and the concentration of P in the clear extract was determined by ascorbic acid-molybdate method (Olsen and Sommers, 1982). The amount of adsorbed P by each soil was calculated using Equation 1.

$$\frac{Co - Cf}{Weight\ of\ soil\ (kg)} x\ V \qquad (1)$$

Where: C_0 = initial concentration of P (mg L^{-1}), Cf = final concentration of P (mg L^{-1}) and V = volume of solution (L).

The P sorption data of the soils were fitted in to linearized forms of Langmuir and Freundlich Equations (Equations 2 and 3).

Langmuir Equations

$$\frac{C}{X} = \frac{1}{bXm} + \frac{C}{Xm} \qquad (2)$$

Where C is = equilibrium concentration P (mg L^{-1}), X = the amount of P adsorbed (mg kg^{-1}), b = constant related to bonding energy of sorption (L kg^{-1}), and X_m=Langmuir's adsorption maxima (mg kg^{-1}). Linear regressions for each soils were obtained by plotting C/X vs C. From the regression equation, the reciprocal of the slope was taken as adsorption maxima and the value of the b was obtained by dividing the slope by intercept.

Freundlich Equation

$$logX = Logkf + 1/nLogC \qquad (3)$$

Where: X (mg kg^{-1}) = Amount of P adsorbed per unit mass of soil, and C (mgL^{-1}) is the equilibrium concentration, Kf (mg kg^{-1}) = Capacity factor (Shayan and Davey, 1978) and 1/n = a constant related to bonding energy (Siradz, 2008). The linear graph and regression equation for each soil was obtained by plotting LogC against LogX. The slope and intercept were taken as 1/n and Kf respectively.

The external P requirements (EPR) of the soils were determined by substituting the desired P concentration (0.2 mg P L^{-1}) in the soil solution into the fitted Langmuir and Freundlich equations (Dodor and Oya, 2000). The soil solution concentration of P at 0.2 mg L^{-1}(SPC) provides P adequately to for many crops if it is maintained throughout the growing period and medium. This concentration P is known as standard soil solution concentration of P (Chaudhary et al., 2003). A soil with EPR < 150 mgkg^{-1} of soil at SPC are classified as low P and those soil with EPR values >150 mgkg^{-1} of soils are classified as high P sorbing soils (Fox, 1981).

Statistical analysis

Data on soil properties, soil P fractions and sorption indices were subjected to Pearson correlation analysis using SAS software (SAS, 2000) to determine the relationship between soil properties, P fractions and P sorption indices.

RESULTS AND DISCUSSION

Some of the physicochemical properties of experimental soils

Some of the physicochemical properties of soil samples of Fincha sugar states are summarized in Table 1. The soil pH was in the range of 6.6 to 7.3 with mean value of 6.9. Thus, the soils of Fincha Sugar Estate are classified as neutral in its reaction. OC content varied between 1.3-1.6% with mean value of 1.5%. According to Jones (2001) soil with OC contents between 1-2% are in low category and hence all soils of Fincha Sugar Estate are classified as low in their OC contents. Available P (Olsen) contents of all samples were in the high range (Tekalign and Haque, 1991).

The exchangeable Ca and Mg contents of all samples were in high ranges (Brook, 1983). But the exchangeable K level of the soils was in medium range for sugar cane production.

Chemical forms of phosphorus in Fincha Sugar Estate soils

The total and different chemical forms of phosphorus in surface soils of Fincha Sugar Estate farms are summarized in Table 2. The total P (TP) contents of these soils were in the ranges of 310.2- 544 mg kg^{-1} soils with mean value of 415.3 mg kg^{-1} and the amounts are in low range as per the rating of Murphy (1968). However, TP contents of the present soils were similar to the TP contents of soils of Bako and Jimma, western Ethiopia (Piccolo and Hulluka, 1986). The test soils have significantly ($P<0.001$) varied among each other in their TP contents. It was highest in luvisols followed by fluvisols and the least in vertisols.This shows that the amount of non-active mineral forms of phosphorus is higher in the luvisols than in the remaining two other soils.

Considering, the various P fractions studied, organic P (Po) fraction was significantly higher in fluvisols, followed by luvisols and lowest in vertisols. The variation among Po values of these soils is related to soil organic matter content and this can be evidenced by the fact that there was a significant and positive correlation ($r = 0.99$, $P < 0.05$) between Po and OC content of the soils (Table 4).

Table 1. Selected physicochemical properties of Fincha Sugar Estate soils.

Soil type	Sand	Clay	Silt	Textural class	pH	OC (%)	avP (mg kg^{-1})	Ca	Mg	K	Na	CEC
	g kg^{-1}							Cmol kg^{-1}				
Luvisol	340	528	132	Clay	6.8	1.5	24.2	15.8	5.8	0.5	0.38	50.4
Vertisol	220	610	170	Clay	6.6	1.3	21.9	17.5	7.4	0.35	0.39	54.0
Fluvisol	260	560	180	Clay	7.3	1.6	31.2	12.7	3.4	0.36	0.33	40.6

Table 2. Total P, organic P and inorganic P fractions (mg kg^{-1}) in the surface soils of Fincha Sugar Estate.

Soil Type	TP	Po	Inorganic P fractions			Total Active P	c:p ratio
			Al-P	Fe-P	Ca-P		
Luvisol	544.0	136.3	3.4	27.9	43.0	74.2	110.3
Vertisol	310.2	106.1	11.2	26.0	71.0	108.1	122.5
Fluvisol	391.7	162.1	1.6	69.9	34.1	105.6	98.7

Similar results have been reported by Tekalign et al. (1988) for vertisols of Ethiopia. Among inorganic P fraction, Al-P and Ca-P were significantly highest in vertisols followed by luvisols and they were least in fluvisols. This is in line with Fisseha et al. (2014) who have found higher amount of Ca-P in vertislos and in fluvisol in Tigray, North Western Ethiopia. However, Fe-P fraction was significantly higher in fluvisols than in vertisols and luvisols (Table 2). Ca-P was dominant P fraction in all soils and this could be related to high temperature of Fincha farm where the incidence of leaching loss of Ca is low (Fisseha et al., 2014). On the other hand, total active inorganic P (Pi) fraction (phosphates associated with Ca, Al and Fe) was highest in vertisols followed by fuvisols and lowest in luvisols. However, Po fraction was higher than mean Pi across all the three soils. This is in line with Tekalign et al. (1987) that in most case the organic P fraction accounts for the largest fraction of soil P pool.

The carbon and Po (C: P) ratio which is an index of mineralization capacity of organic P of soils was in the range of 98.7-110.3 with mean value of 110.5 (Table 2). Accordingly, C: P values of all soils < 200 mg kg^{-1} indicating rapid turnover and net mineralization of organic P (Tekalign et al., 1987). This may be one of the reasons for high amount of available P (Olsen) in all the soils of Fincha (Table 1). This reasoning can further be substantiated by the fact that there was a significant positive correlation ($r = 0.99$, $P < 0.05$) between Po and available P (Table 3).

The proportions (%) of the different P-fractions of the three Fincha Sugar Estate soils relative to the respective total P content of each soil are presented in Figure 1. Even if luvisol had the highest TP, the relative proportions of the different P-fractions were generally lower than those in vertisols and fluvisol. This suggests that the degree of weathering is lower in luvisol than that in the latter two soils. Generally, the proportion of Po fraction of the soils was in the range of 25 -41% of total P (TP) andaccounted for the higher proportion of TP than the proportion of total active inorganic P fraction (Pi) which was in the range of 14– 35% indicating that Po isthe major pool of phosphorus in Fincha Sugar Estate soils. However, the proportion of Po of these soils was relatively lower than the percentage of Po reported for some vertisols of Ethiopia which was in the range of 40 - 50% of TP (Ahmed and Islam, 1986). This difference could probably be due to rapid turnover rate of soil organic matter which in turn is caused by high humidity and high temperature of Fincha area.

The proportion of inorganic P fractions, in luvisols and vertisols were in the order of Ca-P> Fe-P>Al-P. This is in agreement with the report of Desta (1982). But the trend for fluvisol was in order of Fe-P>Ca-P>Al-P. The present finding for fluvisol is in line with Piccolo and Huluka (1986) who found that the inorganic P fractions of seven different soils types of Ethiopia including calcic fluvisol to be in the order of Fe-P >Ca-P > Al-P. In all the three soils, Al-P accounted for the lowest proportions of TP compared to the other inorganic P forms and this is in agreement with Piccolo and Huluka (1986). There is a high degree of weathering in soils where Fe and Al bound P is dominant (Wakene and Heluf, 2003). This implies that Ca-P is dominant in the luvisol and vertisolof Fincha sugar cane farm indicating low degree of weathering in these soils whereas Fe-P makes dominant fraction of inorganic P in fluvisol suggesting that it is advanced stage of weathering (Tekalign et al., 1988).

Phosphorus sorption isotherms

The P sorption isotherms of the three Fincha Sugar Estate soils are represented in the graphs of Figure 2.

Table 3. P sorption indices of Fincha Sugar Estate soils derived from Langmuir and Freundlich equations.

Soil type	P sorption Indices of Langmuir Equation				P sorption Indices of Freundlich Equation			
	X_m (mg kg^{-1})	b (Lmg^{-1})	EPR (mg kg^{-1})	R^2	1/n	Kf (mg kg^{-1})	EPR (mg kg^{-1})	R^2
Luvisols	227.3	1.9	63.0	0.98	0.97	256.0	53.2	0.80
Vertisols	344.8	3.6	145.0	0.96	1.2	1172.0	160.8	0.70
Fluvisols	333.7	4.3	153.8	0.97	1.4	1153.0	134.0	0.80

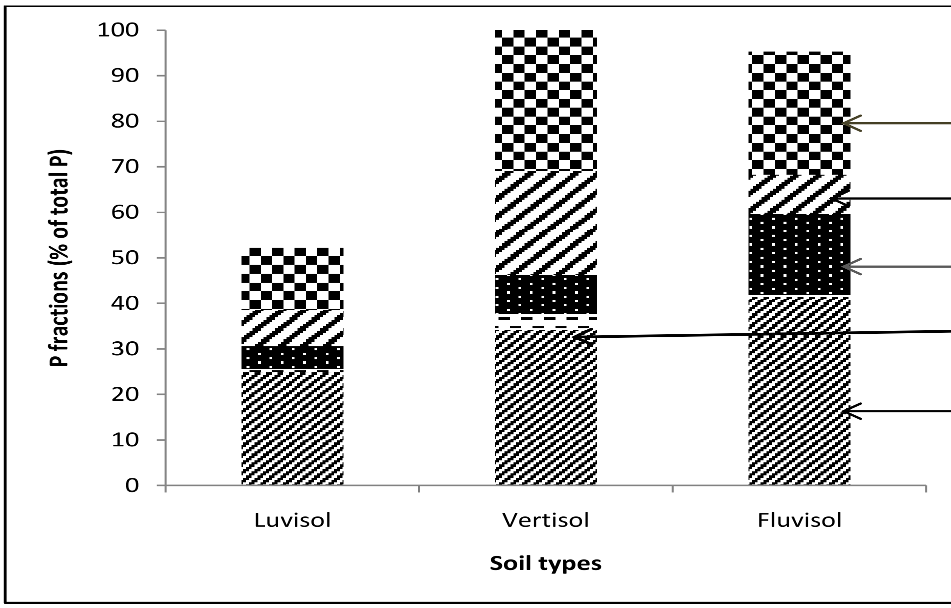

Figure 1. Soil phosphorus fractions expressed as percentage of total P content of the corresponding soil of Fincha Sugar Estate.

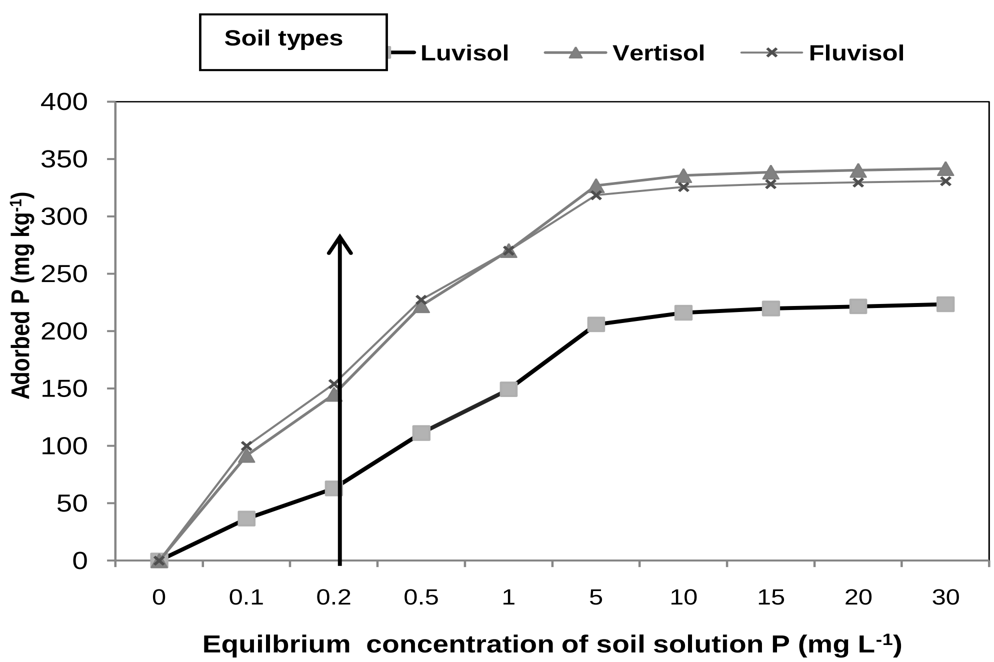

Figure 2. Phosphorus sorption isotherms of three soils of Fincha Sugar Estate, Western Ethiopia.

Table 4. P sorption indices of Fincha Sugar Estate soils derived from Langmuir and Freundlich equations.

Soil type	P sorption Indices of Langmuir Equation				P sorption Indices of Freundlich Equation			
	X_m (mg kg^{-1})	b (Lmg^{-1})	EPR (mg kg^{-1})	R^2	1/n	Kf (mg kg^{-1})	EPR (mg kg^{-1})	R^2
Luvisols	227.3	1.9	63.0	0.98	0.97	256.0	53.2	0.80
Vertisols	344.8	3.6	145.0	0.96	1.2	1172.0	160.8	0.70
Fluvisols	333.7	4.3	153.8	0.97	1.4	1153.0	134.0	0.80

The isotherms of these soils are similar and took more or less L-shaped curve. This indicates that the affinity of P was higher to the soil than to the soil solution at lower equilibrium concentration of P. However, as the soil solution concentration increased, the situation is reversed and the affinity of P towards the soil solution became higher than to the soils (Sparks, 2003). But, the soils greatly varied in the steepness of the curve where by the isotherm of fluvisol was stepper than those of vertisols and fluvisol. This is evidenced by the fact that amount of adsorbed P by fluvisolat standard soil solution concentration of P (0.2 mg L^{-1}) was > 150 $mgkg^{-1}$ (vertical arrow in Figure 2) of soil whereas the amount adsorbed by luvisol and vertisol was <150 mg kg^{-1}.

Phosphorus sorption indices of Fincha Sugar Estate soils

The P sorption data of all the three soils of Fincha Sugar Estate were fitted well with Langmuir equation with mean r^2 value of 0.97. However, the sorption data of these soils failed to obey well with Freundlich equation (Table 4). It is natural that the P sorption data of different soils fit with different equations to different degrees and there are occasions where the P-sorption data of particular soils may not obey with one, two or none of such sorption equations (Chaudhary et al., 2003; Hussain et al., 2003). For instance, Moazed et al. (2010) studied the P sorption characteristics of five soils in Iran and they found that Langmuir equation was best fit than Freundlich equation. But, contrary to these, Khan et al. (2010) reported that Freundlich equation was best in describing the P sorption data of three Pakistan soils. Such variations are related to P sorption mechanisms on the surfaces of different soils. For example, Langmuir equation fits best with soil having homogenous sorption sites throughout their surfaces but for soils with heterogeneous sorption sites, Freundlich equation suits better in describing the P sorption data of such soils (Sparks, 2003). Thus, it seems that the present soils had homogenous P sorption site on their surfaces.

The Langmuir adsorption maxima (X_m) values of the study soils ranged between 227.3-344.8 mg kg^{-1} with mean value of 302 mg kg^{-1}. It was highest for vertisol and lowest for luvisols. However, these values are quit lower than that we have reported for seven highland acidic soils of southern Ethiopia (Sahlemedhin and Ahmed, 1983) and also very much lower than that reported for tropical soils (Hartono et al., 2005). The relatively smaller X_m values of the present soils could be due to better management of these soils including yearly application P fertilizer as Fincha sugar cane farm is state owned sugar producing enterprise, better management is practiced relative to that done in subsistent farmers' field. The other probable reason could be related to soil type where the present soils are belongs to luvisol and vertislols which are relatively low P fixing soils than other soil types (Sanchez et al., 1997). This is also in agreement with Birru et al. (2003) who studied the P sorption isotherms of representative soils of north western Ethiopia and reported that vertisols were in low P fixing categories against nitisols and cambisols which were high P fixing soils due to the fact that they were at their advanced stages of weathering.

The Langmuir boding energy (b) values which show the tenacity with which P isadsorbed by soils was in the ranges of 1.9–4.3 L mg^{-1} with mean value of 3.3 L mg^{-1}. The value of b was highest in fluvisol followed by vertisol and list in luvisol (Table 4). However, the values of b for all the three soils were > 0.07 Lmg^{-1} suggesting that there is no risk of loss of P in to water (Mcdowell et al., 2002).

The external P requirements (EPR) derived from Langmuir equation of experimental soils varied from 63.0–153.8 mg kg^{-1} with mean value of 120.6 mg kg^{-1}. It has significantly and positively correlated with X_m and b indices of the soils (Table 5). This means that as X_m and b values of the soils increase, the corresponding values of EPR increases. In luvisol and vertisol the EPR was < 150 mg kg^{-1} of soil and consequently classified as low P-fixing soils whereas fluvisol had EPR > 150 mg kg^{-1} and hence classified as high P sorbing soil (Fox, 1981). As luvisols and vertisols are low P sorbing soil and at the same time these soils account for more than 95% of the farm, limitation of P due to high P sorption is not a major problem in Fincha Sugar Estate soils.

At present, Fincha Sugar Estate is practicing application of P fertilizer at 30 kg P ha^{-1} across all soil types which is equivalent to 15 mg P kg^{-1} of soil (Damte et al., 2012) and this rate was developed based on the result of crop response study. However, compared to the EPR estimated from the Langmuir equation for each soil in this study, this rate of P being applied currently on the farm is very low.

Table 5. Pearson correlation coefficients between soil properties, P fractions and P sorption indices of Fincha Sugar Estate soils.

Properties	Sand	Clay	Silt	pH	OC	avP	Ca	Mg	K	Na	TP	P0	Al-P	Fe-P	Ca-P	Pi	X_m	b	EPR
Sand	-																		
Clay	-0.95	-																	
Silt	-0.85	0.7	-																
Ph	-0.09	-0	-0.4	-															
OC	0.5	-0.99	-0.01	0.9	-														
avP	0.05	-0	-0.5	0.99*	0.9	-													
Ca	-0.2	0.5	-0.4	-0.95	-0.93	-0.99*	-												
Mg	-0.2	0.5	-0.3	-0.94	-0.95	-0.98	0.99*	-											
K	0.96	-0.99*	-0.96	-0.2	0.2	-0.2	0.1	0.5	-										
Na	0.03	0.3	-0.5	-0.91	-0.85	-0.99*	0.98	0.97	0.3	-									
TP	0.99*	-0.99*	-0.85	0.1	0.5	0.06	-0.2	-0.23	0.95	0.02	-								
Po	0.4	-0.95	0.2	0.95	0.99*	0.99*	-0.99*	-0.99*	0.1	-0.9	0.4	-							
Al-P	-0.6	0.8	0.14	-0.83	-0.96	-0.8	0.9	0.9	-0.4	0.7	-0.6	-0.95	-						
Fe-P	-0.2	-0	0.6	0.97	0.8	0.97	-0.95	-0.93	-0.4	-0.99*	0.1	0.9	-0.7	-					
Ca-P	-0.6	0.8	0.09	-0.8	-0.99*	0.84	0.9	0.9	-0.3	0.8	-0.6	-0.97	0.94	-0.99*	-				
Pi	-0.96	0.8	0.96	0.2	-0.2	0.2	-0.1	0.05	0.99*	-0.3	-0.96	-0.1	0.4	0.4	0.3	-			
X_m	-0.98*	0.98*	0.96	0.2	-0.3	0.2	-0.08	-0.03	-0.99*	-0.3	-0.99*	-0.1	0.4	0.4	0.4	0.94	-		
b	-0.8	0.6	0.99*	0.5	0.1	0.5	-0.4	-0.94	-0.9	-0.6	-0.8	0.3	-0.06	0.7	0.02	0.94	0.93	-	
EPR	-0.91	0.7	0.99*	0.3	-0.1	0.4	-0.3	-0.2	-0.99	-0.4	-0.91	0.04	0.3	0.5	0.2	0.9	0.99*	0.99*	-

* = Significant at 0.05 probability level. All figures in Table 4 without star (*) symbol are statistically non-significant.

Relation between soil properties, P fractions andsorption indices

The Pearson correlation coefficients between some soil properties, P fractions and P sorption indices of Fincha Sugar Estate soils are presented in Table 4. Organic P (Po) fraction has significantly ($P< 0.05$) and positively correlated with OC ($r = 0.99$) but negatively correlated with exchangeable Ca and Mg contents. On the contrary, the Pi fractions of Al-P and Ca-P were found to significantly and negatively correlate with OC content of the soils. Positive and significant correlation between Po and OC is expected because the source of organic P is soil organic matter and thus as the OC content of soil increase there will be an increase in Po content of soils and vice versa. Ca-P and Fe-P have significantly and negatively correlated with each other indicating that in soils where Ca-P is dominant Fe-P is low and vice versa.

The P sorption index of X_m was found to significantly and negatively correlate with sand, K and TP but positively correlated with clay, silt content and Pi. The apparent negative correlation observed between X_m and TP is in agreement with the finding of Bastounopoulou et al. (2011) who found negative correlationsbetween P sorption parameters and soil TP and Pi in Greek inceptisols. On the other hand, the bonding energy (b) has significantly and negatively correlated with sand and K but positively correlated with silt content. Similarly, EPR correlated negatively with sand and K content but positively correlated with silt, Pi, X_m and b (Table 4).

Conclusions

The results of P fractionation study of Fincha Sugar Estate soils showed that the organic P accounted for the largest proportion of total P (TP) in luvisol and fluvisoil. But in vertisols,Po and Pi accounted for 50:50 proportions of TP. The C:P ratio was <200 in all three soil types suggesting that there is net minerlization of soil Po. Among inorganic P fractions, Ca-P accounted for the highest proportion in luvisols and vertisols whereas Fe-P accounted for highest proportion in fluvisols. This implies that the incidence of weathering is relatively high in fluvisol than in the former two soils.

On the other hand, the results of sorption experiment revealed that the P-sorption data of all the three soil fitted best with Langmuir equation but failed to fit with Freundlich equation. The study soils varied in their adsorption maxima (X_m), bonding energy (b) and EPR. Based on these indices the P-sorption capacities of experimental soils were in increasing order of luvisols < vertisols < fluvisols. Sand, clay, TP and Pi were found to be major soil properties responsible for variations in P sorption capacities of Fincha Sugar Estate soils. Luvisols and verisols which account for more than 95 % of the ESTATE had EPR < 150 mg kg^{-1} suggesting that P limitation due to high P sorption is not a problem in the farm. This could be due to low P sorbing nature of luvisol and vertisol; and the prevailing good management practices in the farm are the two most likely reasons for this to happen. However, the current P fertilizer rate of 30 kg ha^{-1}which is roughly equivalent to 15 mg kg^{-1} being practiced across all soil types in the farm is far less than that estimated for the three soils using Langmuir equation in this study. Thus, it is recommended that this dose of P fertilizer should be revised after validation of the EPR values estimated for each soil through real time field or greenhouse experiment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Environmental and genetic concerns on genetic gains via selection in Pequi mother tree for seeds emergence

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Genetic (populations and progenies) and environmental (planting date, germination stimulator, insecticide and fungicide) effects were evaluated on Pequi (*Caryocar brasiliense* Camb.) seeds emergence. Two Completely Randomized Block Design (E_1 and E_2, on 2005 and 2009 years, respectively) experiments were set up on field. Seeds for E_2 were harvested in mother trees whose seeds showed higher germination rate in E_1. The effects, in E_1, of planting date, insecticide, fungicide and gibberellic acid were not significant. The mother tree effects were significant for both trials. The seeds emergence rates for all and selected mother trees in E_1, and in E_2 were 17.2% (P_0), 24.2% (P_s) and 28.2% (P_m), respectively. The environment effects supposedly responded for the actual (P_m-P_0) gain being higher than the greatest expected (P_s-P_0) since the estimated correlation of common progenies between E_1 and E_2 was 36.4%. In direct sowing in the field, the emergence rate of Pequi seeds is strongly influenced by mother trees from where they were collected. Phytosanitary control and the use of germination stimulator did not change the emergence rate in Pequi seeds.

Key words: *Caryocar brasiliense*, mother tree, populations, genetic gain, correlation.

INTRODUCTION

Naturally occurring in all the Brazilian Savannah (Vera et al., 2005; Kerr et al., 2007; Correa et al., 2008), Pequi (*Caryocar brasiliense* Camb.) is considered one of the most characteristic species of this biome, mainly because of its use as a natural or processed food (Almeida and Silva, 1994; Lopes et al., 2003). Extractivism is still the main form of exploitation of this species being an important economic activity of the communities living in this biome (Almeida and Silva, 1994; Guedes et al., 2004; Fernandes et al., 2004; Silva and Medeiros Filho, 2006; Nogueira et al., 2009). In some regions, according to these authors, the harvest and commercialization of

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Pequi involves half the population, representing 55% of their incomes. It is known that extractive activity is not sustainable at levels where demand is greater than the potential supply of the product. Considering that the products derived from Pequi constitute a potential market it will be necessary, it has happened with several other species, the development of research to generate technologies and policies that aim at its domestication, contributing to its conservation and rational exploitation (Guedes et al., 2004).

The genetic improvement of a species is nothing more than its domestication in record time. Success in a breeding program depends, among other factors, on the reproductive system of the species associated with its cycle. This is a problematic aspect in Pequi, given its long cycle and the low germination rate of its seeds (Fernandes et al., 2005; Rocha et al., 2009a, b).

Several factors are indicated as determinants of the expression of this characteristic (Dombroski et al., 1998; Bilir et al., 2004; Fernandes et al., 2005; Rodrigues et al., 2007; Carvalho and Martins, 2009; Rocha et al., 2009a, b; Dombroski et al., 2010; Yazici and Bilir, 2017) in different tree species. The germination of Pequi seeds can be influenced by both the endocarp and the almond itself (Dombroski et al., 1998). Although the opening or removing of the endocarp can improve it, this practice causes damage to the seeds and makes them more susceptible to fungal attack (Lopes et al., 2003).

The effect of gibberellic acid has been widely tested by several authors both in putamens and directly on almonds (Piña Rodrigues, 1988; Souza et al., 2007; Bernardes et al., 2008; Dombroski et al., 2010).

From the information found in the literature on germination in Pequi seeds, it can be concluded that they are far from meeting two fundamental requirements: rate and speed of germination. Pequi seeds usually take more than a month to germinate and the germination rate hardly exceeds 40% (Carvalho et al., 1994; Fernandes et al., 2005; Rocha et al., 2009a, b; Moura et al., 2013).

Another aspect that can be observed in most of the studies on germination in Pequi seeds is that the factors considered has been on environmental factors only. Studies involving genetic factors such as mother trees and populations effects, as well as the interaction between these and those of environmental nature are more recent (Fernandes et al., 2005; Rodrigues et al., 2007; Souza et al., 2007; Rocha et al., 2009a, b). It was also reported that many genetically (that is, population) and environmental effects (that is, growth practices, year) in reproductive characteristics included seed quality and their growth performances in different tree species (Yazici, 2010; Dilaver et al., 2015; Yilmazer and Bilir, 2016; Yazici and Bilir, 2017).

Studies on the germination of Pequi seeds planted directly in the field are another major gap. It was not found in the literature any study involving environmental and genetic factors, as well as interactions among them, in the germination of seeds of the species, planted under these conditions. Knowledge of this nature is important because they can subsidize breeding programs for the species. Thus, the aim of this paper was to evaluate the genetic and environmental effects on the emergence of Pequi seeds planted directly in the field.

MATERIALS AND METHODS

This work composed of two experiments. For the first, seeds were collected from 133 mother trees originating from seven populations (geographically isolated populations), all from the state of Minas Gerais: Caetanópolis; Curvelo; Diamantina (district of Mendanha); São Gonçalo do Rio Preto; Carbonita; Bocaiúva (district of Terra Branca); and Montes Claros.

These seeds, harvested in the months of January and February 2005, were sown directly in the field in a farm near Carbonita, MG. The area, logistical support and financial expenses were sponsored by SADA Bio-energy Agricultura Ltda, a private company, in a cooperation agreement with Universidade Federal dos Vales do Jequitinhonha e Mucuri.

The experimental design was a randomized complete block design (DBC) with 133 treatments (mother trees), ten replications, five hills and five seeds per hill. Five blocks were planted in September 2005 and, due to some technical concerns, the other five were planted at the end of December 2005.

As some mother trees did not produce enough fruits, some blocks were incomplete (with less than 133 progenies). Considering this restriction and to assure a balanced and complete block design, evaluations were assessed in 108 progenies in six blocks (blocks 1 and 2, sown in September 2005 and blocks 6, 7, 8 and 10, sown in December 2005). The seeds of block 1 were treated with fungicide (Tecto®) and insecticide (Tuity®) and those of block 6 with these two products plus 500 mg L^{-1} gibberellic acid.

The second experiment was installed in February of 2009, with 20 mother trees, 11 from Curvelo, MG, and nine from São Gonçalo do Rio Preto, MG. Among these 20 mother trees, 18 (ten from Curvelo and eight from Rio Preto) were selected from mother trees that presented the highest emergence rates in the Carbonita experiment, installed in 2005.

Seeds were also sown directly in the field in an area of Plantar Reflorestamentos SA (PLANTAR), in Curvelo, MG, in a complete block design with 20 treatments (mother trees) with 50 replications, one hill per plot (Single Tree Plot) and five seeds per hill. The emergence rate was assessed eleven months after planting.

The data were analyzed considering the model: $Y_{ij} = m + t_i + b_j + e_{ij}$, where Y_{ij} is the record of the i^{th} treatment in the j^{th} block; t_i is the effect of the i^{th} treatment (mother tree, including the effect of populations); b_j is the effect of the j^{th} block; e_{ij} is the experimental error; and m is the overall mean. The ANOVA with the sources of variation, degrees of freedom, and expected values of the mean squares, is shown in Table 1. The effects of the model, except the overall mean, were considered random.

Data were transformed to the scale $(x+0.5)^{0.5}$ following recommendations for variables evaluated by counting and expressed in percentage.

RESULTS AND DISCUSSION

The coefficients of variation of the ANOVA's for the original data were 60.48 and 16.65% (data not shown) whereas for the transformed data they were 7.45 and 14.52% (Table 2), for E1 and E2, respectively. The

Table 1. Appropriated analysis of variance for two experiments carried out in Carbonita, MG, in the year of 2005 and Curvelo, MG, in the year of 2009, both in a complete block design.

SV	DF	MS	Expected value of MS
Carbonita, 2005			
Blocks	5	MS_b	$V_e + 108V_b$
Pop. and Mother Trees (Treatments)	107	MS_t	$V_e + 6V_t$
Populations	6	MS_p	$V_e + 6V_{m/p} + 47V_p$
Mother Trees/Pop.	101	$MS_{m/p}$	$V_e + 6V_{m/p}$
Mother Trees/Curvelo	20	$MS_{m/p1}$	$V_e + 6V_{m/p1}$
MotherTrees/Caetanópolis	3	$MS_{m/p2}$	$V_e + 6V_{m/p2}$
MotherTrees/Diamantina	28	$MS_{m/p3}$	$V_e + 6V_{m/p3}$
MotherTrees/Rio Preto	21	$MS_{m/p4}$	$V_e + 6V_{m/p4}$
MotherTrees/Carbonita	2	$MS_{m/p5}$	$V_e + 6V_{m/p5}$
MotherTrees/Bocaiúva	6	$MS_{m/p6}$	$V_e + 6V_{m/p6}$
MotherTrees/M. Claros	21	$MS_{m/p7}$	$V_e + 6V_{m/p7}$
Error	535	MS_e	V_e
Total	647	-	-
Curvelo, 2009			
Blocks	49	MS_b	$V_e + 20V_b$
Pop. and Mother Trees (Treatments)	19	MS_t	$V_e + 50V_t$
Populations	1	MS_p	$V_e + 50V_{m/p} + 495V_p$
Mother Trees/Pop.	18	$MS_{m/p}$	$V_e + 50V_{m/p}$
Mother Trees/Curvelo	10	$MS_{m/p1}$	$V_e + 50V_{m/p1}$
MotherTrees/Rio Preto	8	$MS_{m/p4}$	$V_e + 50V_{m/p4}$
Error	931	MS_e	V_e
Total	999	-	-

efficiency of the transformation was greater, therefore, in E_2. On the other hand, the F test estimates and their respective levels of significance for the various sources of variation considered almost did not change with the transformation of the data. This finding implies a greater confidence in the conclusions obtained from the ANOVA's for the transformed data.

The non-significance (p>0.05) of the block effects for the Carbonita experiment (Table 2) demands further discussion. The seeds of block 1 (sown in September 2005) were treated with fungicide (Tecto®) and insecticide (Tuity®) and those of block 6 (sown in December 2005) with these two products plus Giberelic Acid (GA_3) 500 mg L^{-1}. Therefore, not only the effects of blocks themselves were not significant, nor were the effects of planting season and GA_3, fungicide and insecticide treatments.

The treatment in Pequi seeds by fungicides is recommended by Lopes et al. (2003), besides the effect of GA_3 being reported by several authors (Piña Rodrigues, 1988; Souza et al., 2007; Bernardes et al., 2008; Dombroski et al., 2010), both in putamen and directly on almonds. However, the effect of these factors was not observed in this work, that is, the treatment with GA_3 and fungicide did not influence the emergence of Pequi seeds in the field. The absence of effects of GA_3 may be due to the fact that the tests were conducted directly in the field and not in shaded sand beds as done by these authors. Another possibility is that both environmental and genetic factors that influence the endogenous level of hormones and their antagonistic substances (Agusti and Almela, 1991) may have reduced or nullified the effect of GA_3. It is also likely that the time at which the seeds were treated (seven and 11 months post-harvest for blocks 1 and 6, respectively) is the main factor responsible for the lack of response to treatment with the insecticide and fungicide.

The effects of populations were not significant for Curvelo (2009) (Table 2). Essentially, under satisfactory sampling, population's effects are not significant for many other traits (Melo Júnior et al., 2004; Souza et al., 2007; Rocha, 2009a). The significant effect for Carbonita population for 2005 (Table 2) is probably due to the small number of mother trees for some populations. In such cases, the effects of populations can be confounded with those of mother trees (Rocha et al., 2009a). This is likely the main reason for the great difference between the 29.5% observed for three mother trees from Carbonita and the 12.1% observed for 29 mother trees of Diamantina (Table 3). The difference observed between

Table 2. Analysis of variance for seed emergence rate in two experiments carried out in Carbonita, MG, in the year of 2005 and Curvelo, MG, in the year of 2009, both in a complete block design.

SV	DF	MS	F	P(F)
Carbonita, 2005				
Blocks	5	0.0031	0.82	52.95
Pop. and Mother Trees (Treatments)	107	0.0347	9.41	0.00
Populations	6	0.0704	2.17	5.20
Mother Trees/Pop.	101	0.0325	8.83	0.00
Mother Trees/Curvelo	20	0.0233	6.32	0.00
MotherTrees/Caetanópolis	3	0.0332	9.01	0.00
MotherTrees/Diamantina	28	0.0372	10.10	0.00
MotherTrees/Rio Preto	21	0.0215	5.83	0.00
MotherTrees/Carbonita	2	0.1216	33.01	0.00
MotherTrees/Bocaiúva	6	0.0552	14.98	0.00
MotherTrees/M. Claros	21	0.0312	8.46	0.00
Error	535	0.0037	-	-
Total	647	-	-	-
CV	7.45%	-	-	-
Curvelo, 2009				
Blocks	49	0.0142	0.89	68.31
Pop. and Mother Trees (Treatments)	19	0.1003	6.31	0.00
Populations	1	0.1516	1.55	22.91
Mother Trees/Pop.	18	0.0975	6.13	0.00
Mother Trees/Curvelo	10	0.0930	5.85	0.00
MotherTrees/Rio Preto	8	0.1031	6.49	0.00
Error	931	0.0159	-	-
Total	999	-	-	-
CV	14.52%	-	-	-

Rio Preto and Diamantina can be attributed to a higher rate of emergence of the first one (Table 3). However, even under satisfactory sampling conditions, the effect of populations is not always significant (Melo Júnior et al., 2004, Souza et al., 2007; Rocha, 2009a).

The effects of mother trees, on the other hand, were highly significant in both experiments (Table 2). It is observed that in the experiment conducted in Carbonita, there were significant differences between mother trees for all the populations, reinforcing the conclusions reported by Fernandes et al. (2005), Rodrigues et al. (2007) and Rocha et al. (2009a, b).

Table 4 shows that in most of the mother trees, emergence rates are below 30% for the Carbonita experiment, 2005 and below 40% for Curvelo, 2009. At least one mother tree in Carbonita, 2005 had an emergence rate above 60%. These results are probably related to the genetic factors of the matrices (maternal effect) or the seed itself (xenia effect) (Fernandes et al., 2005).

Other environmental factors may also be involved. Rocha et al. (2009b) observed the presence of an insect (Coleoptera Bruchidae of the genus *Amblycerus*, a species not yet identified) that has not been reported in Pequi seeds, which apparently remains for a long time within the seed without being possible to be detected only through direct observation. As the frequency of attack of this pest varies greatly among mother trees, some of which may reach 60% of its fruits attacked, the low germination rate of its seeds will of course reduce greatly (Rocha et al., 2009b). Another pest that causes serious damage to Pequi seeds is *Carmenta* species, Lepidoptera: Sesiidae (Lopes et al., 2003), making them inappropriate for consumption as well as seriously compromising the germination of its seeds. Although apparently healthy seeds have been used, these pest attacks may have occurred, altering the emergence of seeds.

A relevant comparison is that referring to the average seed emergence rates of the 18 mother trees common to the experiments of Carbonita in 2005 and Curvelo in 2009, which were 24.2 and 28.2%, respectively (for Curvelo experiment (2009) the mother trees with the highest emergence rate of Carbonita experiment (2005) were selected). The expectation, considering the correlation between the emergence rates for these two

Table 3. Seed emergence rate, by populations, in two experiments carried out in Carbonita, MG, in the year of 2005 and Curvelo, MG, in the year of 2009.

Populations	Carbonita, 2005[1] All populations and mother trees		Carbonita, 2005[2] Mother trees selected from two populations		Curvelo, 2009 Mother trees selected from two populations	
	Emergence (%)	No. of mother trees	Emergence (%)	No. of mother trees	Emergence (%)	No. of mother trees
Curvelo	17.3	21	21.5	10	30.4	10
Caetanópolis	15.1	4	-	-	-	-
Diamantina	12.1	29	-	-	-	-
Rio Preto	22.5	22	27.6	8	25.6	8
Carbonita	29.5	3	-	-	-	-
Bocaiúva	14.1	7	-	-	-	-
Montes Claros	18.2	22	-	-	-	-
Average/Total	17.2	108	24.2	18	28.2	18

[1]Seeds were harvested in 108 mother trees came from seven geographically isolated populations. [2]Ten, out of 21, and eight, out of 22, mother trees from Curvelo and Rio Preto, respectively, that showed the highest emergence rate in Carbonita, 2005[1] were selected, their seeds harvested again in 2008 and their emergence rate evaluated in Curvelo, 2009.

Table 4. Distribution of mother trees with in some intervals for emergence rate. Data came from two experiments carried out in Carbonita, MG, in the year of 2005 and Curvelo, MG, in the year of 2009.

Emergence rate interval (%)	No. of mother trees in the interval		
	Carbonita, 2005	Curvelo, 2009	Total
<10	42 (38.9)	0 (0.0)	42 (32.8)
10 - 20	27 (25.0)	3 (15.0)	30 (23.4)
20 - 30	21 (19.4)	10 (50.0)	31 (24.2)
30 - 40	13 (12.0)	6 (30.0)	19 (14.8)
40 - 50	4 (3.7)	1 (5.0)	5 (3.9)
50 - 60	0 (0.0)	0 (0.0)	0 (0.0)
>60	1 (0.9)	0 (0.0)	1 (0.8)
Total	108	20	128

Data inside parenthesis are in %.

experiments (r = 36.4%) was that in 2009 the emergence rate was above 17.2% (Table 5) but below 24.2% (Tables 3 and 5). A possible explanation for the fact that the gain was above expected is that the seeds, planted in March 2009, were collected in January of the same year, therefore, much newer than those of the 2005 experiment that were collected in January and planted in September and December, which was observed by (Rocha et al., 2009a) who observed a great influence of the age of the seed on the rate of emergence in Pequi seeds.

Based on the estimate of the correlation between the emergence rates for these two experiments (r = 36.4%, Table 5), a plausible inference is that a mother tree whose seeds has a high rate of emergence in a given year may not repeat it in another year. That is, the expectation of genetic gains from the selection of mother trees whose seeds have the highest emergence rate should not be high.

Conclusion

In direct sowing in the field, the emergence rate of Pequi seeds is strongly influenced by mother trees from where they were collected. The genetic gains in emergence rates via selection of mother trees with high emergence rate seeds is not expected to be large.

Phytosanitary control (insecticide and fungicide) and the use of germination stimulator (gibberellic acid) did not change the emergence rate in Pequi seeds.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

Table 5. Seed emergence rate, by mother tree, in two experiments carried out in Carbonita, MG, in the year of 2005 and Curvelo, MG, in the year of 2009.

Population	Mother tree	Carbonita 2005	Curvelo 2009
Curvelo	2	26.67	28.00
	4	22.30	45.60
	8	16.22	24.40
	9	27.93	33.60
	18	4.19	30.40
	22	48.15	30.00
	33	13.12	21.60
	40	18.67	27.60
	42	16.16	26.40
	48	21.77	36.00
Rio Preto	160	26.22	31.20
	167	32.67	30.40
	168	17.33	20.80
	169	37.33	29.60
	170	40.67	38.00
	171	32.00	21.60
	172	8.67	12.00
	175	26.00	21.20
-	Average	24.23	28.24
-	-	r = 36.4%	P(t) = 6.9%

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Full Length Research Paper

Effect of plant density on oil yield of safflower

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The definition of the ideal plant population is important for good safflower agricultural management in Brazil, as they are gaining importance as oleaginous plant. Two experiments were conducted in an Rhodic Acrudox in 2014 in Cascavel, PR, Brazil, to evaluate the effect of plant density on growth, yield components and grain yield in safflower oil during autumn and winter seasons. The experimental design was a randomized complete block design with three replications and four plant densities per meter (5, 10, 15 and 20 m). Densities of 14 and 16 plants per meter gave greater heights of plants during autumn and winter, accordingly. Increasing densities reduce the number of branches and chapters in autumn, but increase in the productivity of grains and oil. The oil content was improved by cultivating plants in winter, since the population of safflower in winter is higher as compared to fall. In safflower sown in autumn, between 15 and 16 plants per meter was sufficient for maximum grain yield and oil. The oil yield was 15% higher in autumn (992 kg ha^{-1}) as compared to winter (858 kg ha^{-1}).

Key words: *Carthamus tinctorius* L., oil content, oilseed.

INTRODUCTION

Due to the growing concern of power generation without damaging the environment, bio-energy species that have favorable characteristics in this regard are under study; thus, highlighting the safflower crop (*Carthamus tinctorius* L.), though little is still known in Brazil (Santos and Silva, 2015). The culture has productive potential, easy adaptability and good resourcefulness in clayey and sandy soils (Santos et al., 2015).

Strategies and cultural managements should be studied in order to determine and increase the productive potential of this new culture so that the safflower can become a culture for production systems in Brazil. According to Mertz et al. (2009), numerous factors determine the development and productivity of cultivation;

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however, the ideal population of plants or the stand is important in achieving sustainability.

Due to the plant characteristics, safflower can compensate for the spatial variation by producing secondary and tertiary heads by plants with more branches formation in the plant (Elfadl et al., 2009), since the plant morphology depends on the degree of intraspecific competition (Gimplinger et al., 2008). Studies indicate the desired density of 40-50 plants per m^2 and up to 70 plants per m^2 in light soils (Espig and Rehm, 1991). However, increased oil content (Emami et al., 2011), grain yield (Ozel et al., 2004) and oil yield (Alessi et al., 1981) were found with increase in the plant density.

Important factors of production should be taken into consideration, in order to achieve greater productivity, highlighting the spatial arrangement of plants. In search of the optimum population for production, given the scarcity of information and with the hypothesis that the population density affects safflower production, the study aimed to evaluate the growth, yield components and grain production of safflower oil with regards to population densities in two growing seasons.

MATERIALS AND METHODS

Location and climatic conditions

Two experiments were conducted in 2014 in Cascavel-PR, Brazil, with geographic coordinates of 24°56'40 "S and 53°30'31" W and an average altitude of 715 m. The behavior of the meteorological variables of the experiment is shown in Figure 1.

The soil of the experimental area was classified as Rhodic Acrudox (Soil Survey Staff, 2010). The experimental area was under no-tillage system for over 20 years, with crops such as corn or soybeans in the summer crops and oats or wheat in the fall/winter seasons. The chemical characteristics are presented in Table 1.

Experimental set-up

The first growing season was characterized by sowing on April 30, 2014 (autumn), and the second growing season on July 30, 2014 (winter). Sowing IAPAR genotype was performed manually. There was no need to apply pesticides and cultivation was carried out manually.

Treatments and experimental design

A randomized-blocks design with three replications was used. Four seed densities (5, 10, 15 and 20 seeds m^{-1}) were sown. Each plot consisted of four rows measuring 4 m long.

Traits evaluated

When the plants showed 50% of flowering in 80 and 60 days after emergence during the autumn and winter seasons respectively, the plant height and the distance between the soil level and the plant apex, six plants at random within each plot, was determined, by measuring with graduated tape. The number of branches per plant and capitula was determined by counting. When the crop had 50% of flowering was also determined, by collecting six plants at random in each plot, measuring the stem diameter with the aid of a digital caliper and the basal region of the stem.

At harvest, 160 and 140 days after emergence during autumn and winter seasons, respectively, the grain yield was determined, after manual threshing and cleaning of the grains, each portion was harvested from plants collected from a linear meter, and the values expressed in kg ha^{-1}, making the moisture content to be 12%. The 1000-seed weight was performed by counting sub-samples of 100 grain per plot. The samples were weighed on a precision scale to two decimal places, making the moisture content to be 12%. The 1000-seed weight was determined in accordance with the Rules for Seed Analysis (Brasil, 2009).

Oil content was determined from a TD-NMR in a SLK-SG-200 spectrometer (Spin Lock Magnetic Resonance Solutions, Malagueño, Córdoba, ARG) at 25°C, equipped with a permanent magnet of 0.23 T (9 MHz for 1H) and a probe with 13 × 30 mm of useful area. The Condor IDE software with CPMG pulse sequence and Qdamper (Colnago et al., 2011), expressed on a dry basis (% DB) was used. Oil yield (kg ha^{-1}) was calculated as the product of oil content and seed yield.

Statistical analysis

Satisfactory adjustment that provided higher coefficient of determination higher than 70% and present minimal significance level of 5% of probability in the coefficients was considered. To perform regression analysis, the program Sigma Plot 11.0 (Jandel Scientific, Sausalito, CA, USA) we used.

RESULTS AND DISCUSSION

The height of safflower plants (Figure 2A) was affected by plant densities, with densities of 14 and 16 plants per m (311 and 355 thousand plants per ha, accordingly) resulting in maximum heights for fall and winter, accordingly. In early sowing of autumn, the plants received more solar interception which favored growth, requiring fewer plants per meter for maximum growth, since the plant morphology is reflected by the degree of intraspecific competition (Gimplinger et al., 2008). In winter, due to the lower growth, the density of plants is necessary, but the plant height observed in this study is substantially lower (67%) in the late seeding (0.74 m) in relation to the early one (1.24 m). These results are aligned to those observed by Omidi and Sharifmogadas (2010) in Iran, since both the delayed sowing as well as the lowest density negatively affected the safflower plant growth, although the maximum height has been achieved with a greater population than the present study. Tarighi et al. (2012) also in Iran found that the lower density of plants per hectare resulted in lower plant height. Bellé et al. (2012) in Brazil did not observe greater growth of plants when the density increased from 48 to 128 plants per m^2 in sowing autumn/winter and spring/summer. There are also reports that indicate that the increased density has limited the height of the plant (Gonzalez et al., 1994; Elfadl et al., 2009). Plant densities effect of safflower growth is likely to occur, since the greater or lesser light interception by plants reflect the plasticity of

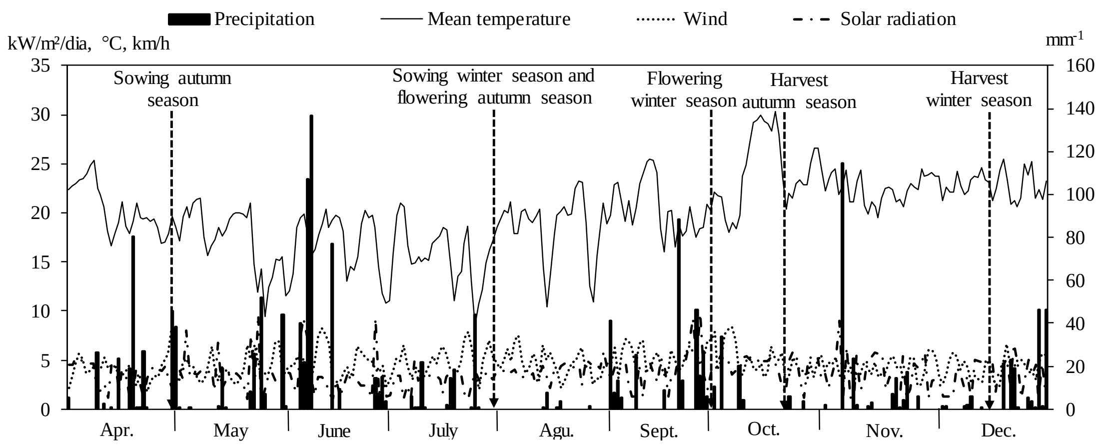

Figure 1. Behavior of meteorological variables of precipitation, mean temperature, wind and solar radiation in safflower cultivation during autumn and winter seasons in Cascavel, PR, Brazil, in 2014.

Table 1. Soil chemical attributes in the depth of 0 to 0.20 m in the experimental areas.

Soil characteristics	Soil	
	Autumn season	Winter season
Soil pH	5.20	5.48
Organic matter (g kg^{-1})	38.28	46.48
Available P (mg kg^{-1})	12.85	5.48
H + Al ($cmol_c$ kg^{-1})	5.7	5.2
Exchangeable K ($cmol_c$ kg^{-1})	1.3	0.8
Calcium ($cmol_c$ kg^{-1})	4.6	4.5
Magnesium ($cmol_c$ kg^{-1})	2.2	2.8
CEC ($cmol_c$ kg^{-1})	14.3	13.3
Soil base saturation (%)	59	61

growth, as observed by authors (Zarei et al., 2011; Necdet et al., 2007; Omidi and Sharifmogadas, 2010; Amoughin et al., 2012).

The decrease in stem diameter (Figure 2B) with the increase in the population during fall can be related to the bigger internode lengthening due to competition for solar radiation, as suggested by Bellé et al. (2012). Nevertheless, the greatest increase in autumn contributed to the greater diameter, because the plant has a longer cycle. In winter cultivation, the lowest growth of the plants in relation to fall may not affect internode lengthening, making the stem diameter to have 8.3 mm on average. Nevertheless, Bellé et al. (2012) reported reduction in stem diameter during autumn/winter and spring/summer with increased densities for 128 plants per m^2.

The reduction of the number of branches per plant (Figure 2C) and the consequent decrease in the number of chapters per plant (Figure 2D) in autumn cultivation, clearly demonstrates that increasing the competitiveness among plants affect these variables, as reported by other authors and common in the literature (Azari and Khajehpour, 2003; Elfadl et al., 2009; Bellé et al., 2012; Emami et al., 2011; Amoughin et al., 2012; Santos et al., 2016). In the second crop, in winter season, the lowest growth of the plant was also reflected in the average values of 6.4 and 9.3, branches and chapters per plant, accordingly. The plant growth components are most affected by densities in early cultivation, since high temperatures and increased water availability result in a greater cycle and the effect is more noticeable, since growth is also the result of interactive phenomena between genetic characteristics, physiological, ecological and morphological of the plant (Farooq et al., 2009).

In the present study, the plant densities did not affect the weight of 1000 grains in both seasons (Figure 3A), which is in line with the results of experiments with population densities of Malvi et al. (1988) with winter safflower India in (Azari and Khajehpour, 2005) with

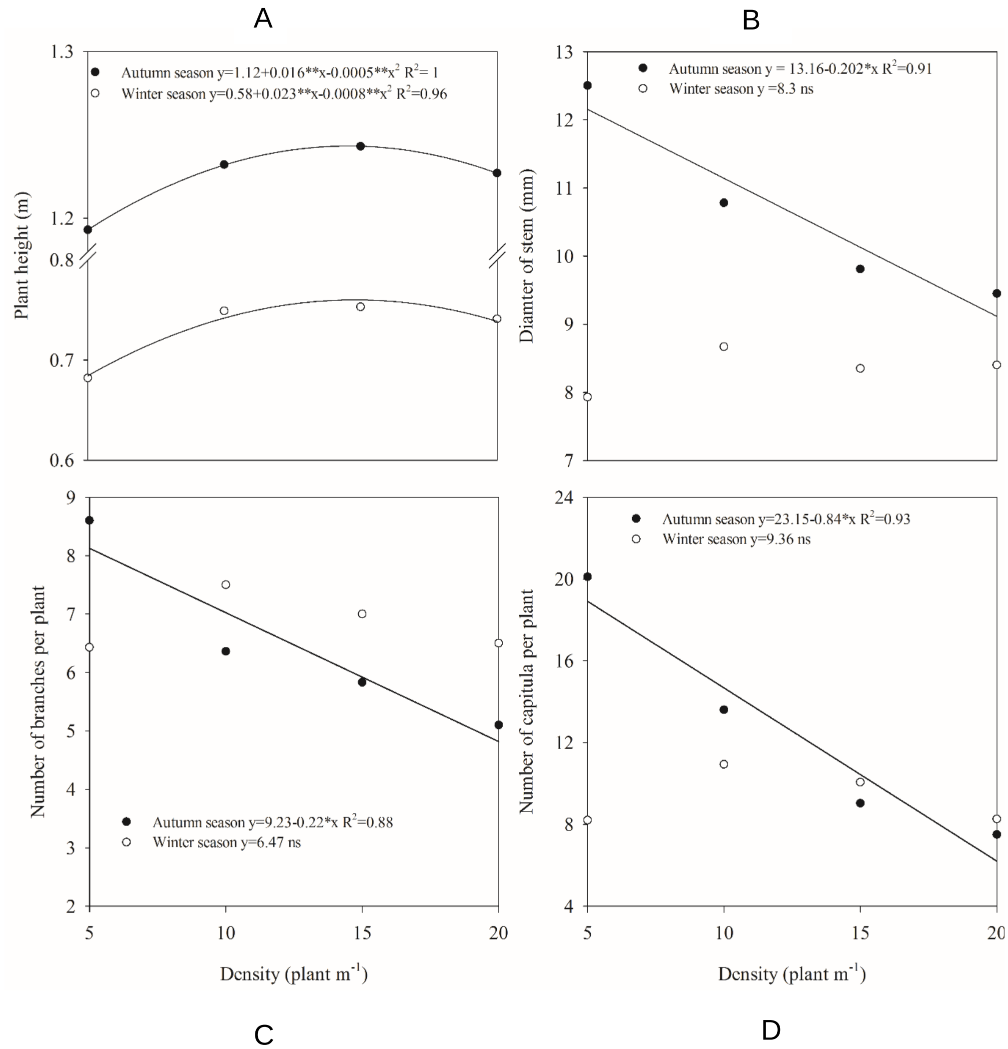

Figure 2. Plant height (A), diameter of stem (B), number of branches per plant (C) and number of chapter per plant (D) in autumn and winter seasons according to plant dens

summer safflower in Iran and Elfadl et al. (2009) with safflower in Germany summer. It is noted that despite reducing the number of chapters per plant and the possibility of having reduced number of seeds per plant, population densities do not compromise the grain weight, showing safflower capacity to react to the plant density, which is due to an undetermined cycle of culture according to Elfadl et al. (2009).

The grain yield (Figure 3B) benefited by the maximum density of plants in winter (20 plants per m) and up to 16 plants per meter (355,000 plants per ha) in fall. This result can be attributed to an increased number of chapters per area as the number of chapters per plant was reduced. The increase in the number of plants has led to increased productivity, according to the results found by Alessi et al. (1981), Ozel et al. (2004) and Kakhaki et al. (2007), in a study of the same nature with safflower plants. These results are also similar to the findings of Mane and Jadhav (1994), where seed production increased as plant density increased from 7.5 to 22.5 m^2 plants. Nevertheless, different results were observed by Elfadl et al. (2009), who found no significant impact on the production of seeds, which according to the authors is due to safflower capacity to compensate for the variation in plant density. The greatest need of plants per meter in cultivation in winter season (444,000 plants per hectare) to approach the early crop yield of autumn, is due to the slower growth of plants in winter, causing a reduction of the cycle, which afforded lower compensation rate.

The oil content (Figure 3C) averaged 23.3% in autumn, below the ideal range of 35 to 45% (Kaya et al., 2003; Mahasi et al., 2009), although similar values to that of Elfadl et al. (2009) (19.0 to 26.1%). The low oil content is due to the characteristics of the studied genotype. Elfadl et al. (2009) did not observe plants densities effect in summer safflower oil content in Germany, although Beech

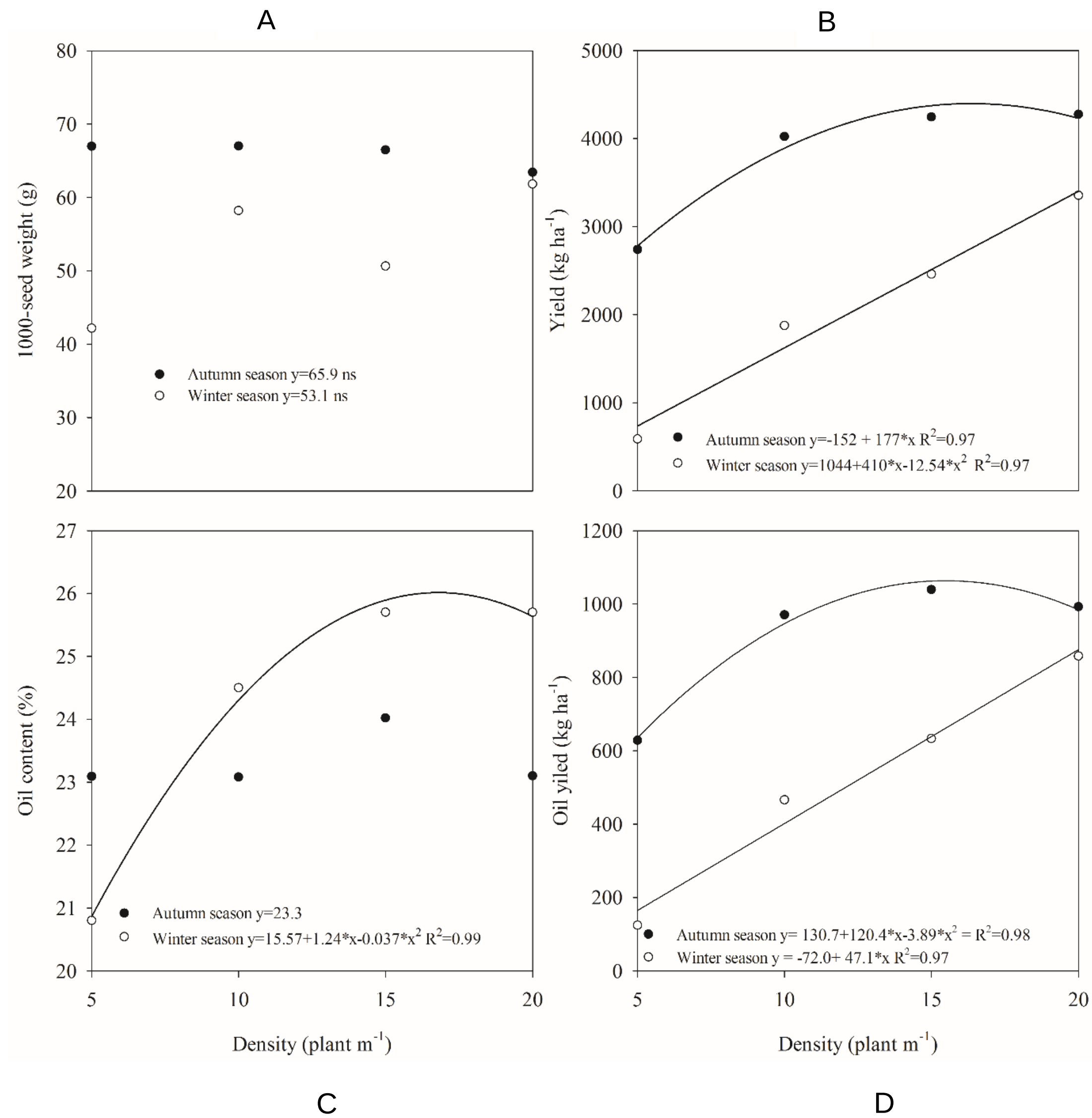

Figure 3. 1000-seed weight (A), yield (B), oil content (C) oil yield (D) in autumn and winter seasons according to plant density.

and Norman (1966) reported a slight effect. In winter, low density damaged plants safflower oil content, whereas 16.7 plants per meter resulted in 26% oil. A likely explanation for the increased oil content with increasing planting density, can be correlated to a substantial grain yield increase (583 to 3335 kg ha^{-1}) in winter cultivation with the increase of plants per meter, that is, the oil content was more sensitive in winter due to contrasting grain yield situation. Sounda et al. (1983) also reported that the low plant density (5 plants m^{2}) significantly reduced the oil content in safflower sown in winter. According to Rathke et al. (2006), optimizing the content of oil involves balancing the protein synthesis and crude oil in the grains as well as energy and carbon dioxide (CO_2), so, the winter crops afforded conditions for this variable.

The oil yield (Figure 3D) is a combination of grain yield and grain oil content, thus follows a grain yield similar results, since the effects on oil content is limited to compensation. Despite this, the oil yield in fall (992 kg ha^{-1}) is only 15% higher than in winter (858 kg ha^{-1}), a difference that was 27% for grain yield between seasons. In this regard, it was observed that increasing densities favored the winter safflower. In summer, 15 plants per meter were sufficient for maximum productivity of oil.

Conclusion

The oil content improved with increase in plant densities in winter, so, the population of safflower in winter was higher than in fall. In safflower sown in autumn, between 15 and 16 plants per meter are sufficient for maximum grain yield and oil.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

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Full Length Research Paper

Comparison of spatial interpolators for variability analysis of soil chemical properties in Cuamba (Mozambique)

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The knowledge of spatial distribution of soil attributes, particularly chemical ones, which is very relevant for agricultural planning. Several studies have focused on spatial interpolation of soil properties, but only a few of them have been undertaken in sub-Saharan Africa. This study aims to analyse the spatial variability of hydrogen potential (pH) and electric conductivity (EC) within an agricultural region in Cuamba district of Mozambique. Efficiency of a deterministic and a stochastic interpolator were compared, namely Inverse Distance Weighting (IDW) and Ordinary kriging, respectively. Soil samples were collected at random locations scattered through the study region, and were later analyzed in water and soil laboratory. These point data were then used to produce interpolated surfaces of soil chemical properties. Efficiency of spatial interpolation methods was assessed based on prediction errors' statistics derived from cross-validation. Results show that ordinary kriging was less biased and more accurate than IDW at samples' locations. Hence, maps produced using the former method are a valuable contribution for the spatial characterization of soil quality, according to its chemical properties. Considering the spatial patterns of pH, southeast area is characterized by clayey soils, which has a high fertility potential for food crops.

Key words: Geostatistics, inverse distance weighting , kriging, electric conductivity, pH.

INTRODUCTION

Obtaining a correct spatial distribution, various soil attributes is very relevant in agricultural planning (Kravchenko, 2003; Mueller et al., 2001), particularly for planting and maintenance of crops. Spatial distribution of soil attributes may affect various elements such as hydrologic responses and yield potential. Moreover, if there is detailed knowledge about spatial variability of different attributes, local application of nutrients and fertilizers, or even lime, can be optimized and more effective, thereby improving production system (Behera

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and Shukla, 2015; Souza et al., 2010).

High cost and amount of time required for soil samples collection has motivated researchers to develop methods for creating soil maps from sparse soil data (Bishop and McBratney, 2001). Geostatistics techniques have been increasingly applied in the assessment of spatial variability of parameters of interest for agrarian sciences, thus allowing for mapping, quantification and modeling of continuous phenomena through interpolation of sampled points in space (Goovaerts, 1999). However, challenges still exist in determining the best method of interpolation for that purpose (de Moura Guerreiro et al., 2017; Piccini et al., 2014; Reza et al., 2010).

There are only a few studies characterizing the spatial variability of soil characteristics in Mozambique, particularly in northern provinces which are among the most fertile country areas (e.g., Nankani et al., 2006). Some of available studies are reported by Maria and Yost (2006) and Maria (2004) regarding the study of soil nutrient status, spatial variability of soil chemical properties and fertilization requirements in Cabo Delgado, Nampula and Manica provinces of Mozambique, and a survey of soil fertility status of four agroecological zones of Mozambique, respectively. Moreover, to best of our knowledge, little or no documentation exists on the comparison of spatial interpolators for soil properties in Mozambique.

The main objective of this study was to characterize the spatial variability of hydrogen potential (pH) and electric conductivity (EC) in Administrative Post of Cuamba in Mozambique. In order to obtain suitable interpolated surfaces of these soil properties, we assessed the efficiency of Inverse Distance Weighting (IDW) and Ordinary Kriging (OK). Spatial patterns of pH and electric conductivity may provide valuable information for assessing soil condition for plant growth.

Study region

Republic of Mozambique lies on the eastern coast of Southern Africa. Country region was grouped into ten agroecological zones and four zonal research centers (Walker et al., 2006), but it can be broadly divided into three geographical regions (Batidzirai et al., 2006; Nankani et al., 2006): North (Niassa, Cabo Delgado, and Nampula), Center (Zambézia, Tete, Manica, and Sofala) and South (Inhambane, Gaza, and Maputo province). Agroecological zones differ from each other in terms of physiographic, climatic and soil characteristics. The northern region covers approximately 50% of the total land area, corresponding to agroecological zones R7, R8, R9, and R10, and supports about 33% of the country's population.

This region is characterized by high population growth and land use pressure. Low natural forest productivity associated with wide unproductive land abandoned by farmers have encouraged Mozambique's government to promote exotic forest plantation for companies, that plant large-scale monoculture (Mbanze et al., 2013). This study was carried out at Administrative Post of Cuamba (Figure 1), which is situated in District of Cuamba, south of Niassa Province, and classified as agroecological zone R7. Administrative Post of Cuamba shares borders with Administrative Post of Lúrio in the east, Administrative Post of Etarara in the southeast, and with Administrative Posts of Mitande and Metarica in the north. The study region has an area of 216 215 ha, where altitudes vary from 200 to 500 m above sea level. It has a wavy relief that is sometimes interrupted by rocky formations. This region is physiographically characterized by a low plateau area that gradually passes to a more dissected relief with steeper slopes, starting from sub-planaltic zone of transition to lateral zone.

In Cuamba region, as in most of northern country part, arid and dry weather and sub-humid dry, where average annual rainfall can vary from 800 to 1500 mm. As for mean temperature during plants growing period, there are some areas that exceed 25°C, although this may vary annually between 20 and 25°C on average (Marques et al., 2001).

Physiography of region is dominated by alternation of inter-rivers valleys that may alternate with dambos (complex shallow wetlands) due to their width, depth and position in relation to rivers. River's valleys are dominated by alluvial dark soils that are characterized by a dense to moderate texture, which are moderately or poorly drained and subject to regular flooding (MAE, 2005). Hydrogeomorphic soils of varying texture can be found in dambos. On slopes of intermediate interfluves, soils are moderately well drained, varying in color from brown to yellowish, and have a clayey texture (Marques et al., 2001). In Cuamba district, total cultivated area is approximately 49 000 ha and number of agricultural explorations is almost 31 000 (INE, 2012), thus average land size under cultivation is about 1.58 ha per farmer. According to Lukanu et al. (2004), besides cropping, farmers also obtain their food and income through livestock such as goats, chickens, ducks, pigs, sheep and doves.

MATERIALS AND METHODS

Data

In order to know the geographic location where soil samples should be collected, 40 random points were generated within Administrative Post of Cuamba (Figure 2). During the collection of soil samples, a GPS (Global Positioning System) locator was used to determine the direction and data of geographic location, of each point that was previously defined. However, it was impossible to obtain samples at all points due to inaccessibility of certain locations.

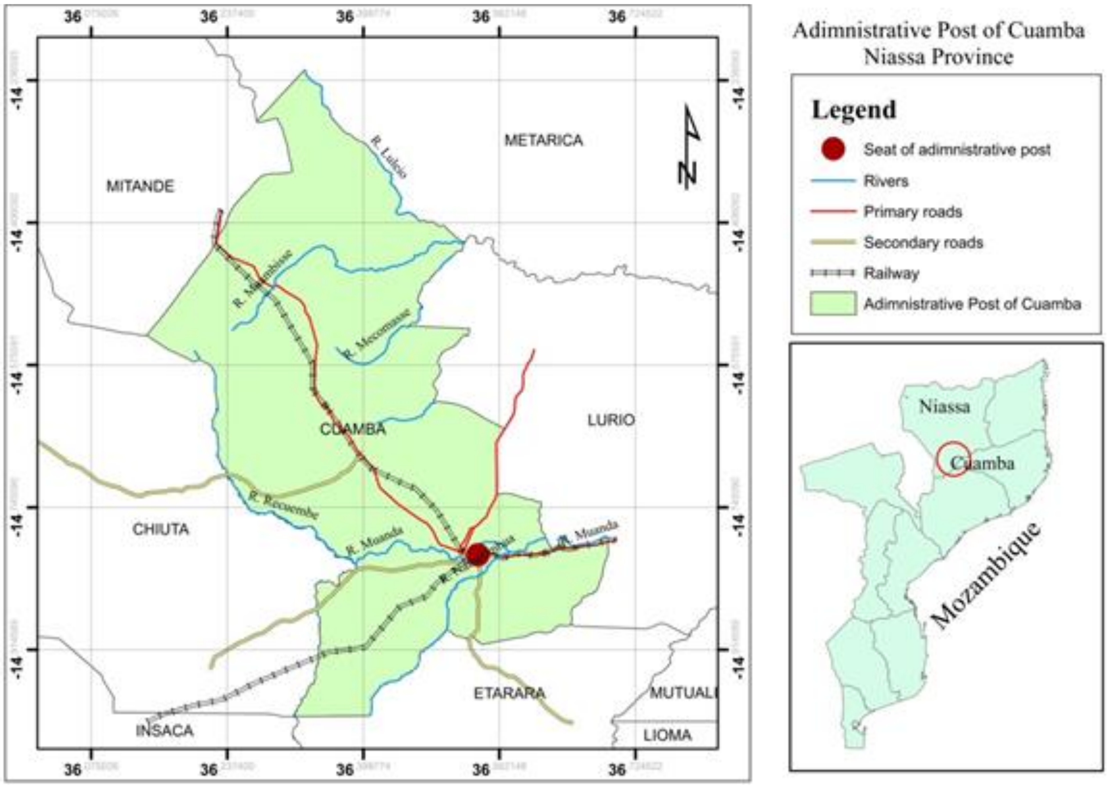

Figure 1. Map of Administrative Post of Cuamba, District of Cuamba, Niassa Province in Mozambique.

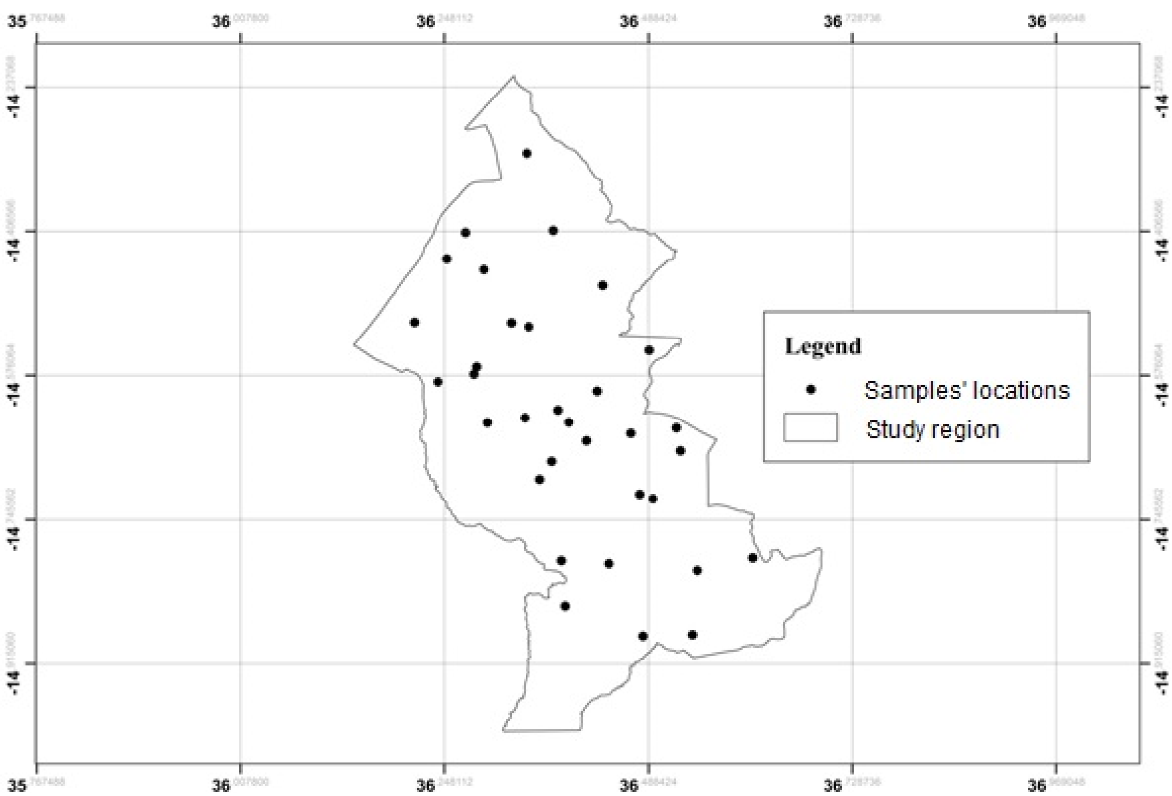

Figure 2. Map of samples' locations in Administrative Post of Cuamba.

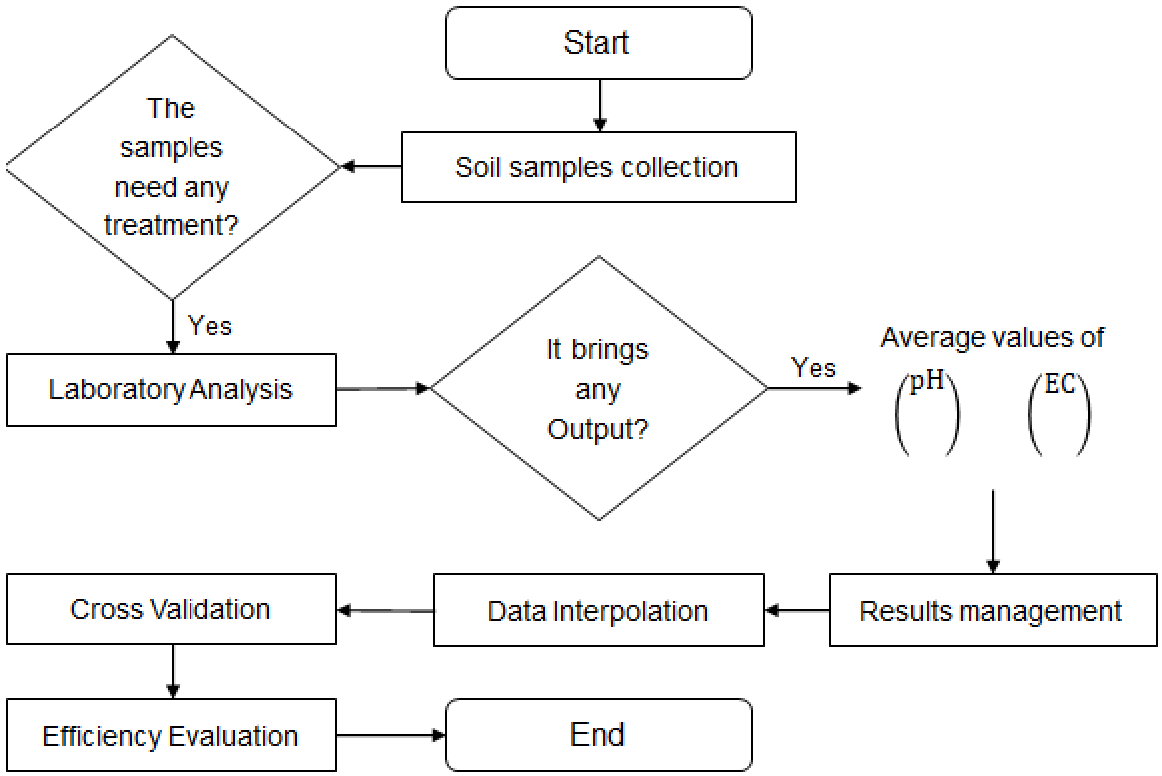

Figure 3. Flow chart of methodological framework.

Hence, only 33 soil samples were collected. Soil samples were collected using a hand probe of 18 cm. Values of pH and EC, were obtained through laboratory analyses of those soil samples using a pHmeter and a Conductometer, respectively.

Spatial interpolators

A flow chart summary of all procedures undertaken is shown in Figure 3. Data of pH and EC were organized and processed in order to evaluate interpolation efficiency of two methods. Values of IDW and OK were obtained using the geostatistical analyst extension of ArcGIS© 10.2. Before implementing spatial interpolation, an exploratory data analysis was undertaken aiming to uncover underlying patterns of soil attributes, as well as to detect possible outliers and anomalies, that could influence spatial analysis efficiency.

IDW is a deterministic spatial interpolator that accounts for distance relationships only. A predicted value of the attribute is computed as a weighted sum of data points located within a given search neighborhood, centered at the location of the point being predicted. Weight values are computed based on the inverse of distance (raised to some power) between data points and location being predicted.

Smoothness of the predicted surface increases as the power parameter value increases. Hence, we considered a power of two, which is the most common value of this parameter. In this case, the method is sometimes named Inverse Square Distance (ISD). Kriging methods are a family of stochastic spatial interpolators used to predict values of a random field at an unobserved location, using a set of samples from neighboring locations. Kriging estimators vary depending on the adopted model for trend, given by the expression $m(x_\alpha)$ in the general linear regression estimator $Z^*(x_0)$ of Z attribute, defined as (Goovaerts, 1999):

$$Z^*(x_0) - m(x_0) = \sum_{\alpha=1}^{N(x_0)} \lambda_\alpha(x_0)[z(x_\alpha) - m(x_\alpha)] \tag{1}$$

where x_0 is the predicted location and x_α are samples' locations; $\lambda_\alpha(x_0)$ is the weight assigned to datum $z(x_\alpha)$; $m(x_0)$ and $m(x_\alpha)$ are expected values of the random variables $Z(x_0)$ and $Z(x_\alpha)$; $N(x_0)$ is the number of samples closest to location x_0 being predicted. OK accounts for local variations of mean $m(x)$ by limiting its domain of stationarity to a local neighborhood.

Unlike deterministic interpolators, kriging assigns optimal weights to each sample point considering not only the distance between the samples and the unknown point, but also the spatial autocorrelation of the attribute. Kriging weights are obtained by solving the kriging system. When developing the system's equations, the semivariogram model is assumed known. The semivariogram evaluates the dispersion of values as a function of distance and, under stationarity hypotheses, it is the inverse function of spatial covariances.

Considering Tobler's first law of geography, nearby points in space tend to have values more similar than points farther away, thus it is expected that the variability (dispersion) of values increases with increasing distance between points' locations. While spatial autocorrelation decreases with increasing distance between

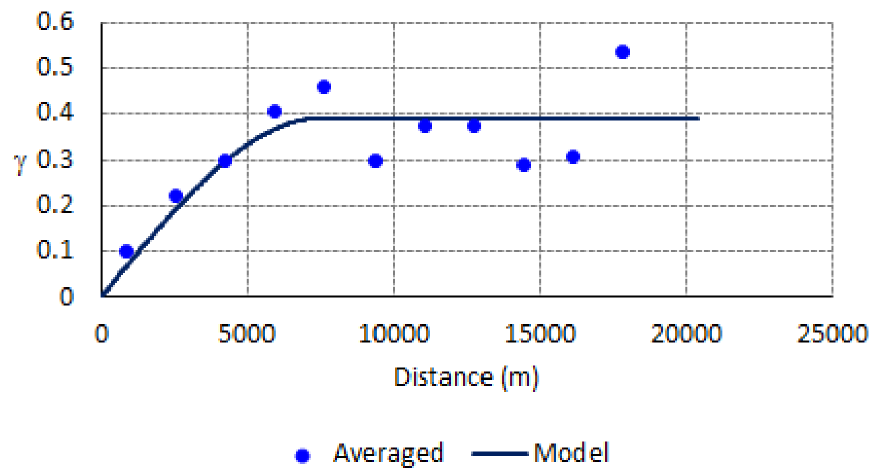

Figure 4. Semivariogram of pH.

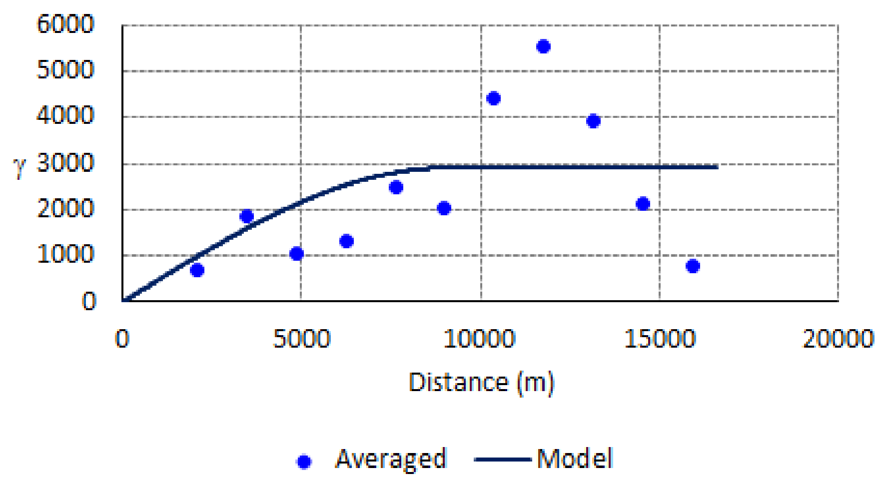

Figure 5. Semivariogram of electric conductivity (EC).

points, semivariogram increases with increasing distance between points. The semivariogram model used in the kriging process must guarantee that kriging equations are solvable (non-singular). Therefore, a mathematical semivariogram model is usually selected from a set of authorized ones and it is fitted to experimental semivariogram values calculated from data for given angular and distance classes.

Most common models are spherical, exponential and gaussian (da Silva Gualberto et al., 2016; de Moura Guerreiro et al., 2017; Hooshm et al., 2011; Robinson and Metternicht, 2006). A nugget effect model, which is a constant structure (C_0), can also be added to create a linear model of regionalization. The nugget effect model, represents a discontinuity at origin due to small-scale variation. On its own it would represent a purely random variable, with no spatial correlation. Data posting maps did not show evidence of anisotropy in attributes, thus omnidirectional experimental semivariograms were modeled. This means that spatial autocorrelation of both attributes was assumed identical in all directions (i.e isotropic). Theoretical semivariograms adjusted for pH (Figure 4) and EC (Figure 5) were spherical models:

$$\hat{\gamma}(h) = \begin{cases} C_1\left(\frac{3h}{2a} - \frac{1}{2}\left[\frac{h}{a}\right]^3\right) & ,0 < h \leq a \\ C_1 & h > a \end{cases} \quad (2)$$

where $\hat{\gamma}(h)$ is the estimated semivariance for h distance between observations; a is the range parameter that takes values 7 and 9 km for pH and EC, respectively; C_1 is the sill parameter that takes values 0.390 and 2900 for pH and EC, respectively. The spherical model shows a progressive decrease of spatial dependence of the attribute until a distance (a) at which there is no spatial dependence. In both cases, we chose not to include a nugget effect model (C_0), because there was no reason to believe that there is a high variability of attributes over short distances.

Prediction errors' statistics

IDW and OK are local interpolators, which means that these

Table 1. Modelling parameters of the local neighborhoods used in the spatial interpolation of pH and electric conductivity (EC).

Interpolation method	Soil attribute	Minimum number of samples in each sector	Maximum number of samples in each sector	Neighborhood type
Inverse Distance Weighting (IDW)	pH	3	17	Circle with four sectors and 45°offset
	EC	2	20	Circle with one sector
Ordinary kriging (OK)	pH	1	3	Circle with four sectors and 45° offset
	EC	2	3	Circle with one sector

methods only use samples' values surrounding prediction location. Therefore, during modelling stage, it is necessary to set a local neighborhood of the point being predicted. The search neighborhood was defined as a circle covering the whole study domain. Then, a fixed number of minimum and maximum sample points were established.

This strategy guaranteed that the circle's radius was small in areas where there was a high density of sample points, but larger where there was a lower density of points. Different combinations of minimum and maximum number of samples were evaluated considering prediction errors' statistics obtained through cross-validation (Falivene et al., 2010), namely the Mean Error (ME) and the Root Mean Square Error (RMSE):

$$ME = \frac{1}{N}\sum_{\alpha=1}^{N}[z^*(x_\alpha) - z(x_\alpha)] \quad (3)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{\alpha=1}^{N}[z^*(x_\alpha) - z(x_\alpha)]^2} \quad (4)$$

where $z^*(x_\alpha)$ and $z(x_\alpha)$ are predicted and measured values at samples' locations x_α, respectively.

To reduce data clusters' influence, the circle was also divided into equal angle sectors and different combinations of minimum and maximum number of samples were then evaluated. Best modelling parameters of local neighborhoods (Table 1) were those that provided a ME value closest to zero and a smallest RMSE value.

Those prediction errors' statistics were also used to compare the performance of the interpolation methods considered (e.g Hooshm et al., 2011; Robinson and Metternicht, 2006). ME allows checking if prediction is biased, while RMSE assesses prediction accuracy.

RESULTS AND DISCUSSION

Exploratory data analysis

A statistical summary of pH and EC properties is presented in Table 2. Considering the classification used by Maria and Yost (2006), soil samples of Administrative Post of Cuamba vary between acid and slightly alkaline, since pH values range from 5.40 to 7.89. Only 14.7% of samples have pH values smaller than six (acid), while approximately 20% have pH values greater than 7.4 (slightly alkaline). Electric conductivity has an average value of 295.55 µS/cm.

The coefficient of variation of both soil attributes was smaller than 20%, thus their measurements have moderate variability in the study domain. However, since EC is more heterogeneous than pH, its interpolated surface might be less precise. Exploratory data analysis did not suggest the existence of potential outliers, which could mislead the spatial analysis. Although normality is neither an hypothesis nor an assumption of interpolation methods considered (e.g Goovaerts, 1997), normality of attributes' data was investigated using the Shapiro-Wilk test (Shapiro and Wilk, 1965). Considering its results (Table 2), there is evidence that both attributes are normally distributed at 5% significance level, since p-values of the test statistic are greater than 0.05.

Strongly acidic soils are likely to have high conductivity, because soils with low pH might have high soluble salt content and therefore high electrical conductivity. Even though pH measurements did not reveal strongly acidic soils in the study region, we investigated the possible existence of a linear relationship between pH and EC using the t-test of Pearson's correlation coefficient, which was equal to 0.24. As expected, results show that there is no evidence to reject the null hypothesis of independence between the two soil properties at 5% significance level (p-value = 0.1874). This indicates that pH and EC have distinct spatial patterns.

Efficiency of interpolation methods

Interpolated surfaces of pH and EC were produced using IDW and OK (Figure 6 and 7, respectively). IDW maps exhibit more homogeneous surfaces than those of OK, thus they are less informative. This result is caused by a greater smoothing effect of the IDW method.

In areas where there is little or no data, the interpolator moves towards the overall mean, thus smoothing the prediction surface. This is not only controlled by the number of averaged neighbors, but also by the method

Table 2. Summary statistics of soil attributes measured at 33 sampling locations.

Statistic	pH	Electric conductivity (EC) in mS/m
Minimum	5.40	137
Maximum	7.89	435
Mean	6.77	295.55
Median	6.80	289
Standard deviation	0.69	55.37
Coefficient of variation (%)	10.19	18.73
Kurtosis	–0.95	2.27
Asymmetry	–0.31	0.16
Shapiro-Wilk	0.96 (p-value: 0.218)	0.94 (p-value: 0.051)

Table 3. Prediction errors' statistics of methods used in spatial interpolation of pH and EC.

Soil attribute	Interpolation method	Mean error	Root mean square error
pH	IDW	0.0526	0.7709
	OK	0.0442	0.7218
EC	IDW	5.9650	66.8086
	OK	–0.3373	65.3358

itself and other method parameters (e.g. semivariogram in kriging) (Falivene et al., 2010). Results of prediction errors' statistics obtained by cross-validation show that OK was more efficient than IDW in the interpolation of both soil properties (Table 3), particularly in the case of EC. Both methods have a ME close to zero in pH interpolation, thus providing evidence of unbiased predictions at samples' locations. However, IDW was much more biased than kriging in the interpolation of EC, most likely because the OK estimator is the Best Linear Unbiased Estimator (BLUE) if its assumptions hold, and EC has more heterogeneous sample values than pH.

Furthermore, RMSE values of OK predictions were smaller than those of IDW for both soil properties. Hence, kriging produced more accurate predictions at samples' locations than IDW. Similar conclusions were reported by Reza et al. (2010) when comparing the efficiency of those two methods in the interpolation of soil properties in Dhalai district of Tripma, India. OK also performed better than IDW for pH and EC in topsoil of a dry land sheep and cropping farm, located in Shire of Wickepin, in southwest of Western Australia (Robinson and Metternicht, 2006).

Spatial variability of soil properties

Considering the interpolation methods' efficiency results, the analysis of spatial patterns of soil properties will be based on OK maps of pH (Figure 6b), EC (Figure 7b) and Land cover (Figure 8).

As expected from exploratory data analysis, most of Administrative Post of Cuamba has slightly acidic (6.1<pH<6.5) and neutral (6.6<pH<7.3) soils, where the former are mainly located in the northwest and southwest (Figure 6b). These areas are covered by closed broadleaved deciduous forests and closed to open shrub land, respectively.

Additionally, patterns of acidic soils (pH < 6) are mainly located in the southwest of the study region. This area is mainly characterized by closed to open shrub land and crop lands (Figure 8). However, cropland area is very small compared to other classes of land cover, implying that a large area with favorable pH conditions for agricultural production was unexplored. Five slightly alkaline areas (pH > 7.4) were scattered in the center of the study region, with open broadleaved deciduous forest as major land cover.

Soil pH helps decision makers and farmers to identify different kinds of chemical reactions that can occur in a specific soil. Toxic elements such as aluminum and manganese are a major cause for crop failure in acidic soil. This is because these elements are more soluble at soils with low pH. Several plants grow best when pH is between 7 and 9 (neutral and alkaline soils). Lower and higher pH levels, particularly lower than three and higher than 11, dramatically reduce plant growth. All plants are affected by extremes of pH, but each plant has its own

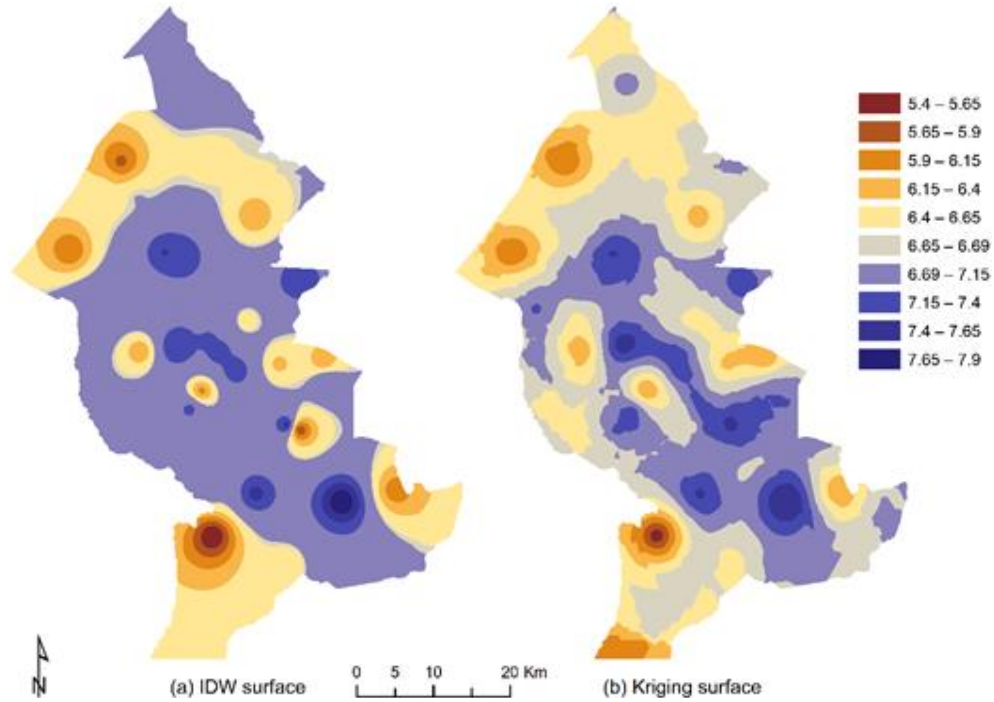

Figure 6. Surfaces of pH interpolated by (a) IDW and (b) OK.

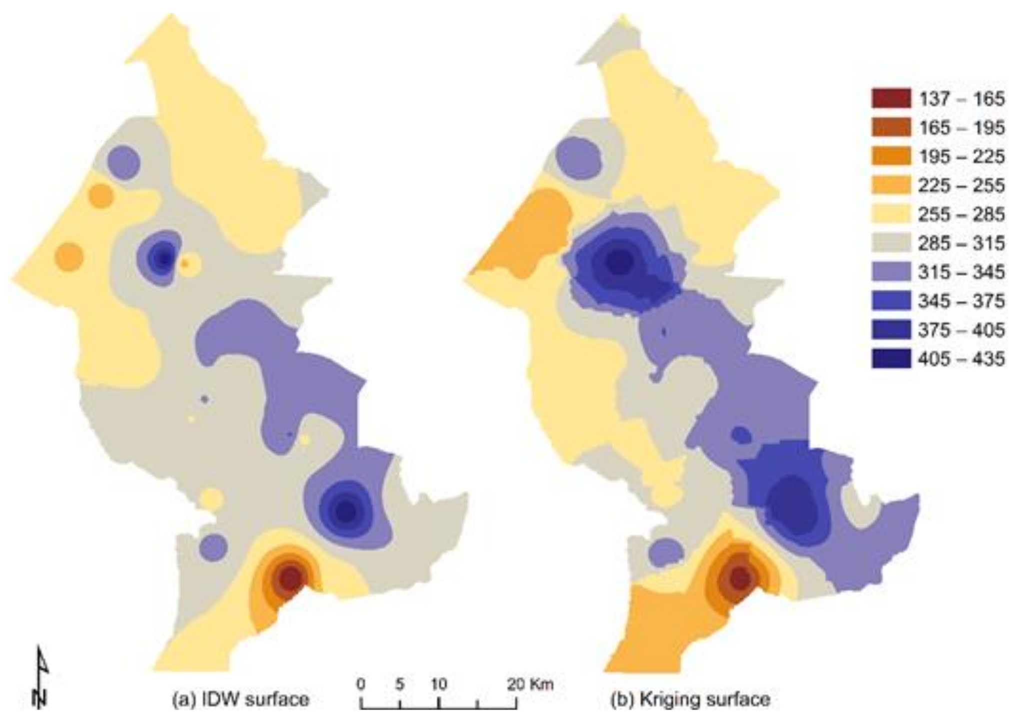

Figure 7. Surfaces of EC (mS/m) interpolated by (a) IDW and (b) OK.

level of tolerance to acidity and alkalinity. However, 5.8 to 7.2 pH levels contributes for normal yield for most vegetables such as lettuce, tomato, cucumber, cabbage, strawberry, carrot, pea and pepper (Lake, 2000). On other hand, to get maximum yields for legumes and cereals, a pH ranging from 6.0 to 7.0 is desirable as it

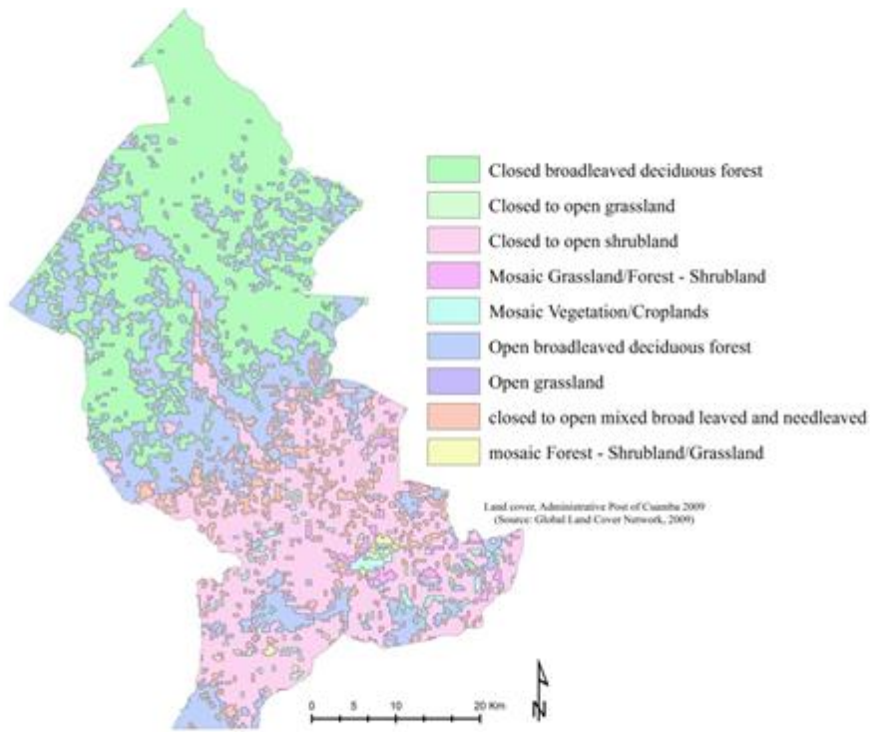

Figure 8. Map of land cover of Administrative Post of Cuamba (GLCN, 2009).

permits optimum availability of nutrients in soil. Lake (2000) mentioned that, in general, a soil pH of 5.2 to 8.0 provides optimum conditions for most agricultural plants.

EC of soils varies depending on moisture amount held by soil particles, and it can be measured in a scale of 0 to 1000 ms/ m. It has been used at field scales to evaluate different anthropogenic properties (Corwin and Lesch, 2005). For example, Corwin et al. (2003) reported that crop yield inconsistently correlates to EC because of influence of soil properties (salinity, water, texture, among others). Wiatrack et al. (2009) mentioned that EC is an important characteristic used for mapping spatial variability of soils within a production field, and that showed a correlation with other soil properties such as organic carbon, cation exchange capacity (CEC) and depth of topsoil.

High values of EC of soils are commonly found in clayey soils. Highest values (Figure 7b) were found in northcentral and southeast regions. According to the land cover map (Figure 8), these areas are characterized by closed broadleaved deciduous forest, closed to open shrub land and mosaic vegetation (croplands). Type of soil (clay), which is representative at Administrative Post of Cuamba (Marques et al., 2001), has the advantage of nutrient retention by using slow–realize mineral fertilizers and this type of soil is good for growing vegetables like beans, potato, cabbage, pea.

In summary, the southeast region of the study area has favorable pH, which is good for growing most food crops. Moreover, this area is characterized by clayey soils and high EC, which are favorable for nutrient retention. Therefore, the southeast region has a high fertility potential for food crops.

Conclusions

This study aimed at analyzing the spatial variability of pH and EC in Administrative Post of Cuamba, Mozambique. Interpolated surfaces of these soil properties were produced using IDW and OK. The latter was less biased and more accurate at samples' locations, thus exhibiting a better performance than IDW. Therefore, the spatial variability analysis of soil properties was based on OK maps.

Results show that soil has favorable pH in most of the study domain, but a large area in the south is still unexplored for agricultural production. Moreover, areas identified with acidic soils can become more productive by artificial liming (i.e by the application of calcium-rich materials). Alternatively, crops that are more tolerant to acidity can be grown in such areas. For example, the pigeon pea (*Cajanus cajan*, L., Millsp.) crop is increasingly being used in Mozambique, because it is moderately tolerant to acidic conditions which is drought resistant due to deep rooting (Rocha et al., 2017).

Administrative Post of Cuamba is characterized by clayey soils, and high values of EC throughout most region. Clay soils are relatively fertile because of their capacity to retain nutrients, thus indicating a favorable production of different types of food crops. There are only a few studies on the variability of soil attributes in Mozambique. Therefore, further studies providing maps of different soil attributes in Mozambique are required, particularly in the north.

Further research on this topic is extremely important, because this will provide scientific information to support precise recommendations and decision making on which of the better crops to grow at specific locations in order to increase area's production and productivity, thus contributing to nation's food security.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

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Full Length Research Paper

Diversity of cultural practices used in banana plantations and possibilities for fine-tuning: Case of North Kivu and Ituri provinces, eastern Democratic Republic of Congo

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Diverse cultural practices have been communicated to and/or applied by resource-poor households over the past two decades to improve the overall farm health and crop tolerance to biotic/abiotic factors. This study assessed the current diversity and use of cultural practices on banana fields in Ituri and North Kivu provinces, eastern Democratic Republic of Congo (DR Congo). Interview schedules coupled with farm diagnosis were used to take stock of cultural practices. Farmers' choice of banana cultivars was mainly influenced by bunch size, demand/price, pulp flavor/taste, and juice quality. Availability of planting materials and the lifespan of mats were also important. In contrast, drought tolerance, soil fertility conditions, length of production cycle, and pest and disease resistance were not highly considered. Suckers were the predominant type of planting material used. Banana-bean (in 15 to 39% of farms) and banana-taro-bean (18 to 30%) were the dominant intercrops. Staking of banana plants with bunches was applied by 94 to 95% of the respondents, possibly due to the perceived immediate benefits from bunches. Cutting of green leaves to among other things improve sunlight penetration for legume intercrops which was practiced by 74 to 85% of the farmers. This practice has greatly contributed to the perpetuation of banana Xanthomonas wilt disease (XW) in the region. Male bud removal was applied in 55 to 66% of farms to control XW and improve bunch size. However, 38 to 51% of these farmers de-budded after the recommended time. Other common cultural practices included de-suckering, pseudostem use for mulch and weeding. Strategies for safe application of some of the practices such as weeding, leaf cutting, de-trashing and in light of diseases such as XW are recommended. In addition, some practices such as mulching and male bud removal are knowledge intensive, while others such de-suckering have no immediate perceived benefits to farmers, thus the need to strengthen knowledge extension to enhance their adoption.

Key words: Cropping, cultivars, cultural practices, de-budding, de-leafing, de-suckering.

INTRODUCTION

Musa species (banana and plantain, here after referred to as banana) constitute the staple food available all year round for the population of eastern Democratic Republic of Congo (DR Congo) with consumption per inhabitant of about 200 kg/year (Ndungo et al., 2004). The eastern provinces of DR Congo produce a staggering 70% of the banana and plantain crop, with 24% produced in North Kivu province (Bakelana and Ndungo, 2004). However, the area planted to banana and plantain, and yield per unit area have declined over the past decades by 20 to 60% (Mobambo et al., 2010) even though demand remains high, leading to high market prices that are beyond the reach of poor urban households (Bakelana and Ndungo, 2004).

The decline in banana production and productivity is attributed mainly to the increased burden of pests and diseases (Vuylsteke, 1993). Xanthomonas wilt of banana (XW) and Banana Bunchy Top Disease (BBTD) are the two most important banana diseases threatening food security in DR Congo. There are no known resistant cultivars to these diseases in the east and central African region (Smith et al., 1998; Tripathi et al., 2008). Cultural practices improve the overall farm health and are the main affordable options available to the resource poor households for mitigating crop losses due to pests and diseases and for maintaining soil fertility. Nicholls and Altieri (2005) reported that agroecosystem health can be optimized through habitat manipulation and soil fertility enhancement. Several cultural practices on the banana farms focus at manipulating the crop or crop environment, thus improving its ability to withstand stresses in its environment. For example, cultural practices, including early de-budding, disinfection of garden tools, removal of infected mats, cutting of single diseased plants in mats and banana free fallows are some of the recommended control measures for the control of XW (Turyagyenda et al., 2008; Sivirihauma et al., 2013; Blomme et al., 2014). Similarly, cultural practices such as identifying and destroying virus-infected plants/mats as early as possible, replanting with virus-free plants are recommended strategies for controlling BBTV (Robson et al., 2007; Niyongere et al., 2012).

Practices that replenish and maintain high soil organic matter and enhance the level and diversity of soil macro and microbiota create an environment that enhances plant health, reducing crop losses due to insect pests and diseases (McGuiness et al., 1993; Altieri and Nicholls, 2003). In contrast, farming practices that cause plant nutrition imbalances can lower crop resistance to pests and diseases (Magdoff and van Es, 2000). Cultural practices that improve soil fertility include, but not limited to, crop rotation, mulching, use of organic manure and crop diversification for example through intercropping (Lampkin, 1990; Magdoff and van Es, 2000).

Despite the potential of agronomic practices to reduce pest and disease pressures, improve soil conditions and crop tolerance, their application especially among resource poor farmers in east and central Africa is limited. Ocimati et al. (2013) emphasized the need to strengthen knowledge extension to farmers in banana growing zones of Burundi, Rwanda and eastern DR Congo. For example, Ocimati et al. (2013) observed that the use of clean planting materials was not highly adopted, with most farmers using suckers from their own or neighboring farms. They also noted that, some of the recommended agronomic practices, such as de-trashing (that is, removal of old leaves), de-suckering (that is, removal of excess suckers), de-budding (that is, removal of the male inflorescence part) and weeding, need to be revised/adapted in the face of new and emerging challenges, especially those from diseases such as XW. Agroforestry and fallowing were not widely applied due to an increased pressure on the land arising from a high human population density in this region and the perennial nature of the banana crop. Table 1 gives a summary of examples of different cultural practices and how they impact on banana yields, soil fertility/erosion, pest and disease incidence level. The assumption is that if widely and properly applied, the cultural practices can improve banana productivity in these regions. This study built on Ocimati et al. (2013). It assessed the adoption and use of different recommended agronomic practices for optimizing banana yield and production in Ituri province and parts of the North Kivu province, as a basis for further improvement efforts.

MATERIALS AND METHODS

Farm surveys and focus group discussions (FGD) were conducted in 2011/2012 in North Kivu and Ituri provinces in the eastern DR Congo. This study covered 8 territories, 5 from Ituri province (Aru, Djugu, Irumu, Mahagi, and Mambasa) and 3 from North Kivu province (Beni, Lubero, Rutshuru). A total of three villages in which bananas play an important income and food security role were purposively sampled per territory with the help of local agronomists, resulting in a total of 24 villages across the eight territories. In each village, two focus group discussions consisting of 20 men and 20 women were separately conducted to obtain a quick impression of the cultural practices applied on the banana farms. Women and men were separated to encourage greater participation

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Table 1. The links between cultural practices with soil factors, pests and diseases and banana crop management. Stars ('*') denote the ease with which the cultural practice can be applied. The more the stars, the easier it is for the practice to be applied.

Cultural practice	Importance in disease, pest, soil and crop management	Possible negative effect/ limitations	Ease of applicability under small-scale farmer conditions
De-budding using a forked stick	Increases bunch size (Tushemereirwe et al., 2001), reduces sites for insect vector transfer of bacterial and fungal infections such as XW, Bugtok and Moko disease caused by *Ralstonia solanacearum,* blood disease caused by *Pseudomonas celebensis*; and cigar end rot caused by either *Verticillium theobromae, Trachsphaera fructigena* and/or *Gloeosporium musarum* (Tushemereirwe et al., 2001; Blomme et al., 2005; Molina, 2006)	De-budding using metal farm tools can increase XW infections if tools are not sterilized between plants/successive cuts.	*****
Mulching	Improves moisture retention, reduces weed growth and enhances soil fertility and microbial activity thus improving plant growth and yield	Access to mulch often limiting	*
Staking/ propping	Prevents snapping/doubling/toppling of plants under the weight of the bunches (Tushemereirwe et al., 2001)	Staking material may be limiting	***
De-trashing	Minimizes black leaf streak/black sigatoka spread to young leaves and plants from old diseased or dry leaves. Improves light penetration for intercrops, air flow reducing risk of fungal infections (Tushemereirwe et al., 2001)	Cutting leaves that are still fresh/green possess the risk of spreading XW within the farm (Addis et al., 2010; Ocimati et al., 2013)	****
Weeding	Reduces competition for water and nutrients, improves soil drainage and aeration, helps to incorporate manure	Weeding with tools in the presence of XW could lead to within field spread of the disease	***
De-suckering	Reduces competition for light, water and nutrients – leading to more vigorous plant growth and bigger bunches (Tushemereirwe et al., 2001)	Failure to sterilize tools between mats could lead to the spread of XW if present in the field	**
Leaf cutting	To increase level of sun light penetration for annual intercrops	Poses the risk of spread of bacterial diseases (XW, Moko, Bugtok, Blood disease). If done extensively could affect the photosynthetic capacity of the plant.	****
Manure application	Improves organic matter content, soil fertility and properties	Access to livestock is limiting	*
Selection of planting material	Clean, disease/pest-free and vigorous planting materials improve yields	Use of suckers increases the risk of spread of banana pests and diseases. Build-up of pest and diseases occurs with repeated use of suckers from own or neighboring fields.	**
Inter-cropping	If well managed improves resilience of the soils/cropping system and improves plot yields	Inter-cropping with annual crops increases risk of XW spread. Could increase competition for nutrients water and light if not well managed	***

Table 1. Contd.

Banana agroforestry practices	Increases total farm productivity. While intercropped with some tree species e.g. with Arabica coffee higher coffee and banana yields were reported (van Asten et al., 2011).	Could increase competition for nutrients water and light if not well managed e.g. intercropping banana with Robusta coffee negatively impacts on banana yield (van Asten et al., 2011).	*
Fallowing	Recommended for breaking the disease cycle especially for XW and BBTD. Can also help in the control of banana pests, e.g. the banana weevil and nematodes. Not practiced with the objective of improving soil conditions due to the perennial nature of the crop	Care should be taken to remove all corm bits and alternative hosts while fallowing to control pests and diseases. Has been limited due to high population density and land shortage	*
Planting spacing	Varies with mono and intercrops. 3 m by 3 m is the most widely recommended	Where intercropping is inevitable, this spacing often leads to shading of annual crops and leaf cutting	*****
Leaf bending	Recommended in fields were XW is present. Recommended in intercropped fields instead of leaf cutting. The bent leaves can still continue to some degree with photosynthesis (Blomme et al., 2017).	Could possibly increase black leaf streak incidence/severity on younger leaves.	*****

in each group.

The FGD were followed by field diagnostic surveys. A total of 10 farms/households having at least 20 mats per plot/farm of banana/plantain were selected per village, totaling 240 farms for this household survey using a questionnaire (Figure 1). The questionnaire determined the typologies of the banana cropping systems and the key cultural practices on the banana farms. The questionnaire for example ranked nine criteria that could be used by farmers to select banana cultivar types to grow. The nine criteria included: (i) the availability of planting materials, (ii) bunch size, (iii) tolerance to infertile soils, (iv) drought tolerance, (v) good pulp flavor, taste and juice quality, (vi) long mat lifespan, (vii) high market demand and prices, (viii) short production cycle and (ix) resistance to pest and diseases. Other cultural practices such as de-suckering, de-leafing, de-budding, mulching and manuring were also assessed.

Geographical positions of the sampled farms were recorded using a GPS (Etrex) device at a precision of ±3 m and used to generate a map (Figure 1). Data were cleaned, coded and the SPSS software used to generate descriptive statistics for different cultural practices obtained across the study sites. Chi-square tests were used to compare means for the different cultural practices between the North Kivu and Ituri province sites at $P < 0.05$.

RESULTS

Farmer selection criteria for banana cultivars, type and origin of planting material

Similar trends in farmer's criteria for selection of cultivars to grow were observed in both North Kivu and Ituri provinces (Figures 2 and 3). Across the study sites, farmers ranked bunch size, pulp/juice flavor/taste/quality and the market price of bunches highest out of nine possible banana cultivar selection criteria presented to them. Other important criteria included the availability of planting materials and the lifespan of the mats for a cultivar. Soil fertility and drought tolerance and resistance to diseases were not highly ranked in both study sites (Figures 2 and 3).

No significant differences ($P>0.05$) were observed between the two provinces for the period of selecting banana planting materials, the responsibility of selecting planting materials within the household, type, and source of planting materials. Planting materials were selected by most farmers at the beginning of the rainy season in September in both North Kivu (58%) and Ituri provinces (62%) while the other farmers were not conscious of the timing. This task was, in over 83% of cases undertaken by the heads of the households (predominantly male) in both sites (Table 2).

All of the farmers across the study sites used suckers as planting material (Table 2). These planting materials come mainly from neighboring farmers' fields. A small proportion (1 to 3%) of the farmers obtain planting materials from either their own farms or from Uganda, the neighboring country.

Banana cropping systems

Most farmers across North Kivu (61%) and Ituri provinces

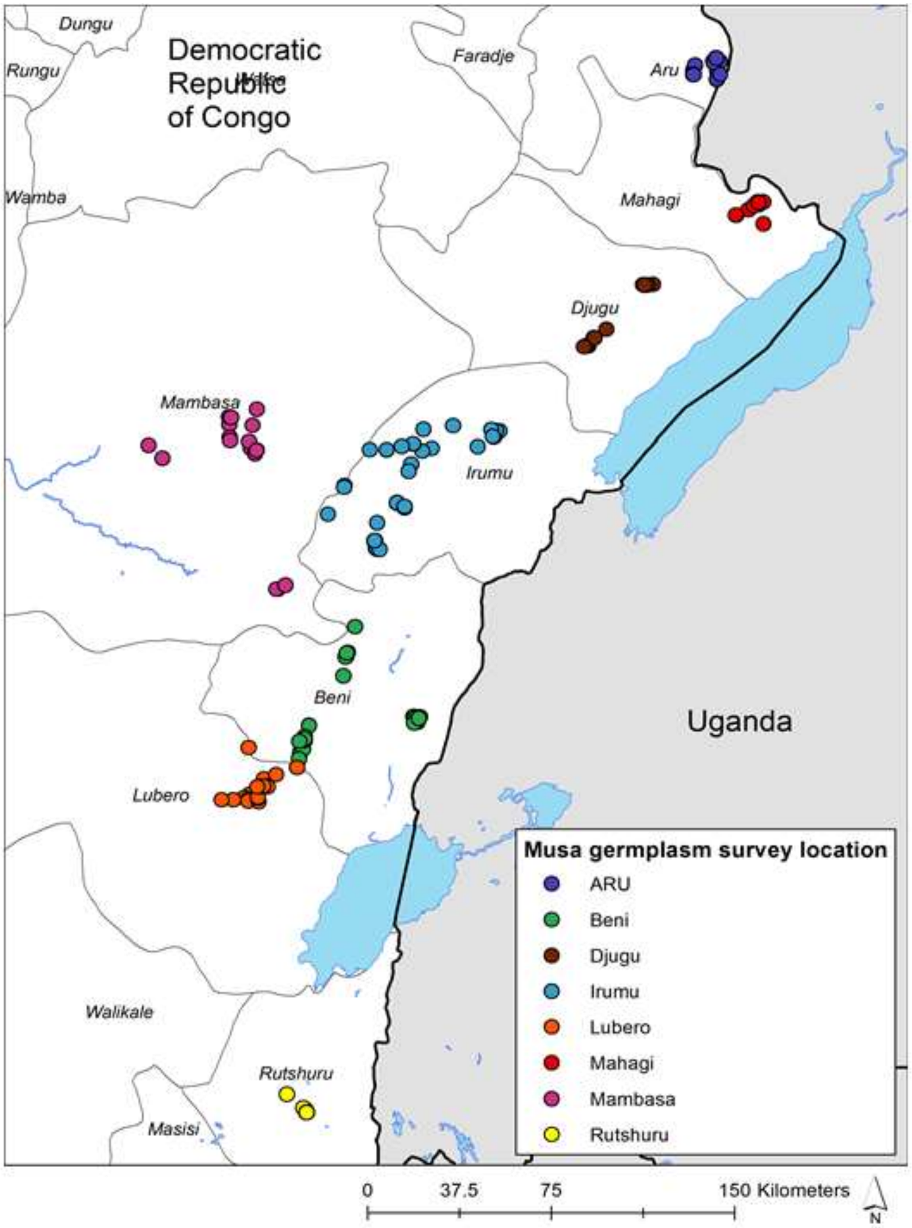

Figure 1. Survey locations across Ituri and North Kivu Provinces in eastern DR Congo.

(52%) practiced intercropping compared to 39 and 48%, respectively, who planted banana as a mono-crop. More farmers in North Kivu province intercropped banana compared to Ituri province (Table 3). However, no significant differences (P>0.05) were observed between the two sites in the proportions of farmers who either intercropped or mono-cropped banana.

Only between 14 and 18%, respectively, in North Kivu and Ituri provinces practiced agroforestry on their farms. In most of the cases (89 to 92%), farmers had scattered trees within their banana farms. No significant differences (P>0.05) in agroforestry practices were observed between the two sites (Table 3).

Eighteen and 14 different banana-other crop (annual and perennial) or banana-tree associations were found in Ituri and North Kivu provinces respectively. Among the different types of inter-cropping systems, the most commonly practiced in both Ituri and North-Kivu provinces included banana-bean (15 and 39%), banana-bean-taro (18 and 30%), banana-maize-bean (2 and 14%) and banana-coffee (7 and 5%) intercrops (Table 3). Significant differences (P<0.05) in the combinations of cropping mixtures were visible between the two provinces.

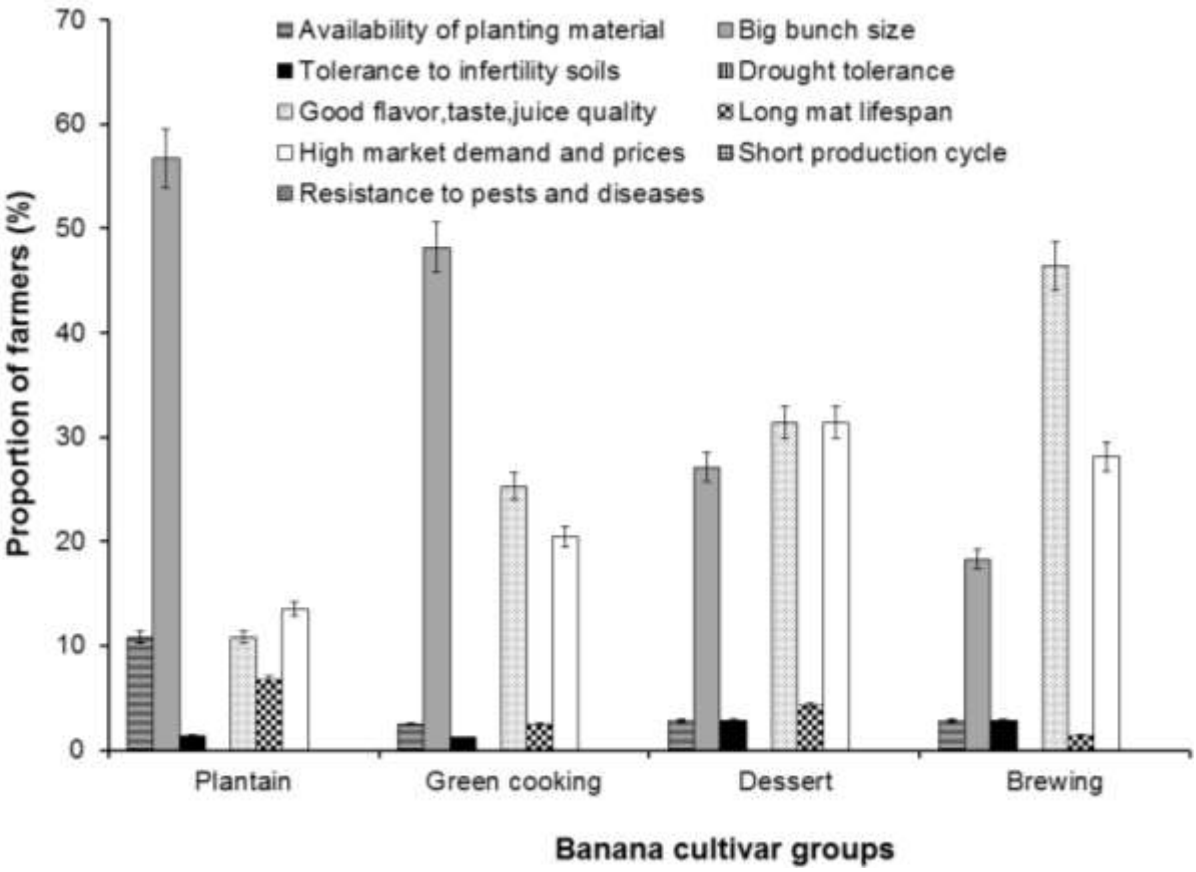

Figure 2. Farmer rankings for different criteria they consider for when selecting/ chosing cultivars in different use groups to grow in North Kivu, eastern DR Congo. Error bars denote 95% Co-efficient Interval.

De-suckering of banana mats

Sixty nine percent of the farmers in both Ituri and North Kivu provinces applied the technique of de-suckering, mainly to (i) decrease interplant competition and hence increase bunch sizes, (ii) obtain suckers for establishing new banana plots/fields and (iii) to maintain their fields tidy. The majority of farmers (between 53 and 57%) de-suckered when it was necessary, while 42 to 41% at the onset of the rainy season at the beginning of September/ October (Table 4). The number of suckers maintained varied between 3 and 5 per banana mat. No significant differences occurred in the de-suckering practices between North Kivu and Ituri provinces.

A minority of farmers (31%) did not apply de-suckering on their farms. In North Kivu this was mainly because the plantations were old and less productive (45% of farmers) to warrant further investment, while it was due to lack of time (that is, competed with other farm activities) in Ituri province (61%). Between 26 and 28% did not de-sucker because it was cumbersome (Table 4). Significant differences ($P<0.05$) were observed between the two sites for the reasons cited by the farmers not de-suckering their farms.

De-leafing and de-budding

Eighty five percent of the farmers in North Kivu and 74% in Ituri province cut off fresh green banana leaves (de-leafing) in their plantations. The green leaves were mainly cut to maintain banana plantations clean, to obtain mulch material and to decrease shade and allow in sunlight for the intercrops, especially beans (Table 5). Most farmers (62 to 65%) cut leaves when they found it necessary, while a good proportion (34 to 38%) cut leaves at the onset of the rainy season, corresponding with the time of planting annual crops. Significantly, more farmers ($P<0.001$) cut leaves as a field maintenance practice in Ituri province, while more cut leaves to allow light for intercropped annual crops in North Kivu. For the purpose of reducing shading, most farmers maintained between 4 and 6 leaves on each banana plant (Table 5). Those that did not de-leaf and de-trash attributed it to lack of time for this practice.

De-budding (removal of the male buds) is a more

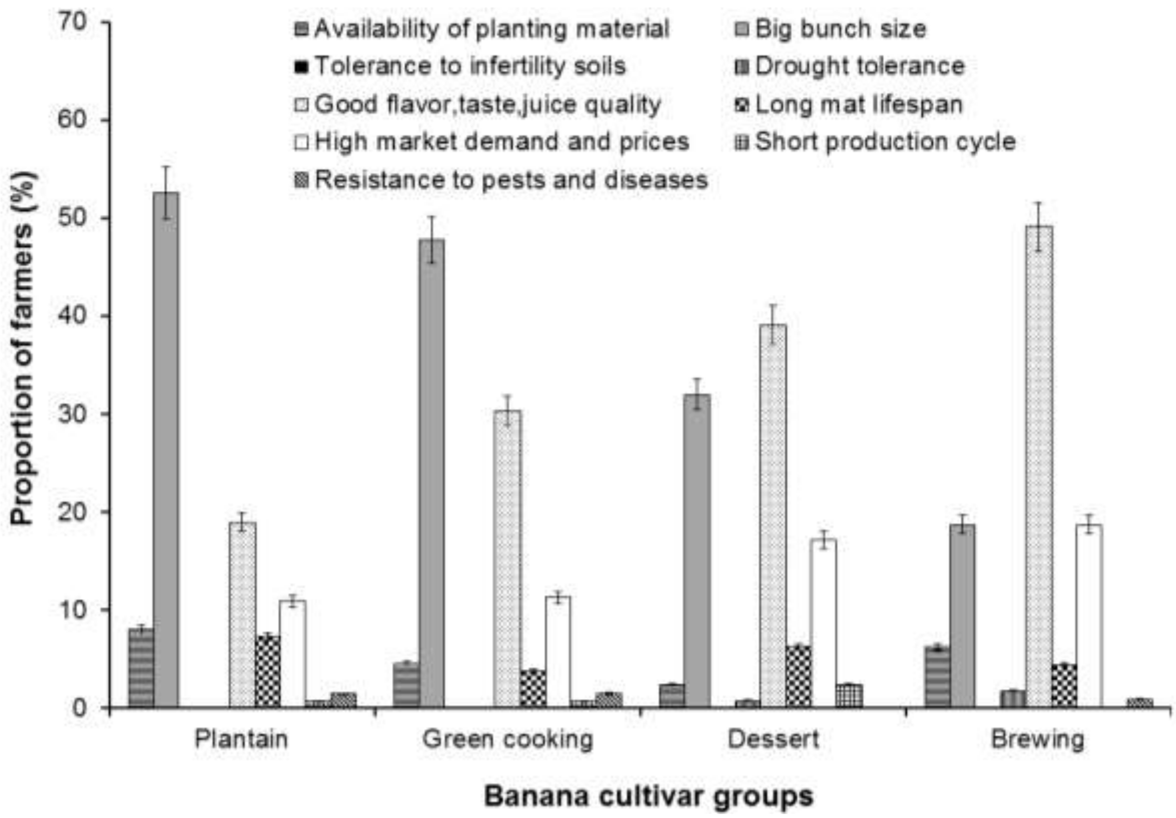

Figure 3. Farmer rankings for different criteria they consider when selecting/ chosing cultivars in different use groups to grow in Ituri Province, eastern DR Congo. Error bars denote the 95% Co-efficient Interval.

common practice in North Kivu (66% of farms) than Ituri province (56%) (Table 5) despite no significant difference (P<0.05) was observed between the two sites. The major reason behind de-budding was to prevent spread of diseases, especially XW disease that is prevalent in the study sites (Table 5). A smaller proportion (12 to 33%) of farmers de-budded to increase the bunch size. Significant differences (P<0.01) in the objectives of de-budding were recorded between the two sites, with more farmers (88%) de-budding to manage diseases in North Kivu compared to 67% in Ituri province. In contrast, more farmers (33%) in Ituri province compared to 12% in North Kivu de-budded to increase bunch size. Farmers who did not de-bud solely attributed it to the lack of time for the practice. Timely de-budding with a forked stick to minimize access to the male inflorescence by insect vectors of *Xanthomonas campestris* pv. *musacearum* is one of the control options for banana bacterial wilt (Brandt et al., 1997). However, a good proportion of farmers, 51% in North Kivu and 38% in Ituri did not timely de-bud their plants (Table 5).

Staking, use of harvested pseudostems and weeding

The technique of staking (supporting of banana plants) is applied by the majority of farmers surveyed (at least 94% of farmers in Ituri and North Kivu). Staking is mainly practiced in order to prevent lodging/toppling/snapping/ doubling of banana plants caused by either the heavy weight of bunches or wind. A total of 58 and 59% of the farmers in North Kivu and Ituri, respectively staked their plants whenever they found it necessary, while 36 to 39% and 3 to 4% across sites staked plants during bunch filling and at flowering (that is, at specific plant growth stages), respectively (Table 6).

Regarding the use of pseudostems after harvesting, 85 and 91% of farmers in Ituri and North Kivu provinces, respectively, cut them into small pieces for use as mulch material. A minority of farmers (2 to 4%) use it for feeding livestock, while others left them standing (7 to 11%).

Weeding was mainly (96 and 94% in North Kivu and Ituri, respectively) performed using a hand hoe. 12 and 21% of farmers in North Kivu and Ituri, respectively, cut down weeds using machetes (Table 6). Herbicide use to kill weeds was not practiced across the sites.

DISCUSSION

This study assessed the diversity and use of cultural practices in banana plantations in Ituri and North Kivu

Table 2. Planting material attributes, across the study sites in Ituri and North Kivu provinces in eastern DR Congo.

Attributes		North Kivu (n=90)	Ituri (n=150)	χ^2-test
Period of selection of planting material	Beginning of the rainy season	58	62	0.369^{ns}
	Any time	42	38	
	Total (%)	100	100	
Who selects the planting material?	Head of household	90	83	2.491^{ns}
	All household members	10	17	
	Total (%)	100	100	
Type of planting material used	Suckers	100	100.0	ns
	In-vitro plantlets	0.0	0.0	
	Corm/corm piece	0.0	0.0	
	Macro-propagation plantlets	1.1	0.0	
Source of planting materials	Neighbor	96	98	1.193^{ns}
	Own field	1	1	
	Neighboring country, that is, Uganda	3	1	
	Research institution	0.0	0.0	
	Total (%)	100	100	

'ns' denote no significant difference at P<0.05) for a given practice between the two study sites.

provinces, eastern DR Congo. Agronomic practices are often knowledge intensive and yet influence the severity of biotic and abiotic stresses and the production of banana plantations. The study showed a low variability in agronomic practices used and their application within and between sites. Agronomic practices with perceived immediate benefits tended to be widely applied. The study suggests that slight changes are needed to a few practices to achieve good management of XW disease.

The choice of cultivars grown was mainly influenced by their food attributes (taste, flavour and quality) and ability to fetch higher incomes (influenced by bunch size, market demand and prices, and food attributes). Banana and plantains in these regions are important for food and income. The market price for the bunch of a cultivar is based on its size and taste. Availability of planting materials and the lifespan of banana mats were also important. This could be a reflection of farmers need for cultivars with inexhaustible ability to produce suckers. For example, a poor suckering ability has been reported in plantains at the low altitude sites (Sikyolo et al., 2013) despite being conducive for plantain production. Demand for planting materials has also been increased by disease outbreaks, more recently the banana XW disease that has affected swathes of areas. Clean planting materials are currently needed for re-establishment of destroyed fields. Soil fertility and drought tolerance were not perceived important by farmers in the study area. The eastern DR Congo highlands are characterized by fertile soils and a good level of rainfall; as such these criteria may not be listed as priority concerns for farmers. In earlier studies in eastern DR Congo (Ocimati et al., 2013) observed that farmers maintained more suckers than recommended due to the relatively good soil fertility conditions that could support larger number of plants per mat without compromising bunch yield.

Pest and disease resistance was also not perceived as important in the study regions. It was expected that farmers would rank resistance to pest and diseases highly in this region, especially due to the presence of XW which is currently the most important constraint to banana production (Ndungo et al., 2008). Ocimati et al. (2016) reported that diseases had greatly contributed to *Musa* genetic erosion and the diversity trends in eastern DR Congo with Fusarium wilt decimating the AAB dessert and ABB beer bananas, while XW affecting all banana types, with ABB beer type 'Pisang Awak' the most affected cultivar. The observed response could be attributed to the fact that all cultivars in region are susceptible to XW and most farmers are resigned to the disease. For example, several farmers attribute the disease to a curse from God and others to a soil infection as such with no ultimate control (Ocimati W. personal communication). To address such misconceptions, knowledge extension on the epidemiology of the disease is needed.

Cultivar selection was mostly the responsibility of the male household heads. This could be linked to the fact that there is distribution of agricultural work between genders with men mostly occupied with land preparation,

Table 3. Frequency (%) of farms practicing different intercropping and agro-forestry practices in the banana-based systems across the study sites in Ituri and North Kivu provinces in eastern DR Congo. Dash (-) denotes that the cropping system is missing.

Farming system applied	**North Kivu (n=90)**	**Ituri (n=149)**	**X^2-test**
Monoculture	39	48	1.745^{ns}
Intercropping	61	52	
Agro-forestry	14	18	0.494^{ns}
Agro-forestry systems applied	**North Kivu (n=14)**	**Ituri (n=27)**	**χ^2-test**
Alley cropping	7	0	
Leaving hedge (grasses)	0	7	3.5^{ns}
Scattered trees within the plantation	92	89	
Hedge of multipurpose trees	-	4	
Crop/Tree combinations	**North Kivu (n=57)**	**Ituri (n=78)**	**χ^2-test**
Banana-beans	39	15	
Banana-beans-taro	30	18	
Banana-taro	4	-	
Banana-coffee	7	5	
Banana-maize-beans	2	14	
Banana-cassava-beans	2	-	
Banana-cocoa	2	-	
Banana-cocoa-oil palm trees	4	3	
Banana-beans-taro-cassava	2	4	
Banana-eucalyptus-avocado	-	4	
Banana-coffee-beans	4	6	
Banana-taro-maize	2	4	37.833*
Banana-sweet potatoes-taro-maize	-	4	
Banana-beans-maize-cassava	-	1	
Banana-cassava-sugarcane-oil palm trees	-	3	
Banana-sugarcane-taro- -cassava	2	4	
Banana-taro-oil palm trees	2	3	
Banana-leek-chives	-	1	
Banana-citrus trees-mango tree-coffee	2	-	
Banana-soybean-maize	-	4	
Banana-pineapple-beans-soybean	-	1	
Banana-bean-groundnuts	-	5	
Total	100	100	

'ns' and '*' respectively denote no significant and a significant difference at P<0.05) for a given practice between the two study sites.

material, while women are mostly involved in secondary activities such as weeding, harvesting, transportation and processing of banana. Ochieng et al. (2014) observed that despite the existence of gender neutrality for both banana cultivation and harvesting in parts of eastern DR Congo, banana cultivation was mainly male dominated while women mainly dominated in the production of annual crops such as sweet potato, cassava, beans, groundnuts, peas and soybeans. Ochieng et al. (2014) also reported male dominance in farm decision making in this region despite the dominance of women in agricultural activities. Similarly, Enete and Amusa (2010) reported male dominance in farm decision making functions in Nigeria even where women are the largest providers of farm labor.

Planting materials were mainly selected at the onset of the rainy season. This can be attributed to the absolute reliance on suckers picked from own or neighboring fields

Table 4. Frequency (%) of farmers de-suckering or not de-suckering, de-suckering at different times and the number of suckers they maintain on a banana mat across the study sites in Ituri(I) and North Kivu (NK) provinces in eastern DR Congo.

Parameter		NK	I	χ^2-test
De-suckering (n=90 in NK; n=150 in I)	Yes	69	69	0.005^{ns}
	No	31	31	
	Total	100	100	
Reasons for de-suckering (n=62 in NK; n=104 in I)	To increase bunch size	54	37	5.413^{ns}
	To obtain suckers for establishing new mats/fields	36	52	
	For routine field maintenance	10	12	
	Total	100	100	
Reasons for not de-suckering (n=31 in NK; n=46 in I)	Time constraint	29	61	13.476**
	De-suckering is cumbersome	26	28	
	The plantation is old	45	11	
	Total	100	100	
Number of suckers maintained on a mat (n=65 in NK: n=105 in I)	3	34	30	0.410^{ns}
	3-4	33	34	
	4	23	25	
	4-5	10	10	
	Total	100	100	
Time of de-suckering (n=52 in NK; n=101 in I)	Beginning of the rainy season	42	44	1.244^{ns}
	Middle of the rainy season	2	3	
	Any time	57	53	
	Total	100	100	

'ns' and '**' respectively denote no significant at P<0.05 and a significant difference at P<0.01 for the given practice between the two study sites.

that does not require prior preparation. In addition, banana production is entirely rain fed. Reliance on suckers from farmers' own and neighbors' farms in eastern DR Congo has been attributed to the lack of capacity for the production of clean planting material through field sucker multiplication plots, macro-propagation and micro-propagation (Ocimati et al., 2013). Dependency on suckers results in a high risk of pest (e.g. banana weevil and nematodes) and disease (e.g. Xanthomonas wilt of banana, Fusarium wilt, banana bunchy top disease and the banana streak virus) transmission, especially when recommended cultural practices (such as the selection of healthy suckers from clean mother gardens, corm paring and/or boiling water treatment to remove weevil larvae and parasitic nematodes) are not applied (FAO, 2010). For example, the dependency on suckers from own or neighboring farms have been reported to have greatly contributed to the spread of XW in eastern DR Congo (Ndungo et al., 2008). It is often difficult to distinguish between healthy suckers and those apparently healthy especially for XW, BBTD and nematodes which are living inside roots. A minority of farmers (1%) in the province of North Kivu use macro-propagated plantlets, a technology that was disseminated by the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA) in this part of the country. In addition to the lack of capacities to produce clean planting material, the cost of macro-propagated and tissue culture-derived plantlets (~$1) compared to $0 to 0.25 for suckers are high and out of reach for most farmers. Building capacities for clean seed production (e.g., clean mother gardens, macro-propagation) coupled to promotional activities in these study regions is urgently recommended. This is postulated to improve the management of biotic constraints, aid in timely planting and ultimately the improvement of banana production.

In 39 to 48% of farms, banana was grown as a sole crop while in 52 to 61% was intercropped with a total of 14 to 18 different crop/crop and crop/tree combinations. It is important to note that the East Africa highlands have a high population density (Voortman et al., 2003) that has increased pressure on the land (Fermont et al., 2008). The associations of cultivated plants are designed to take

Table 5. Frequency (%) of farmers for different de-leafing and de-budding practices in North Kivu and Ituri provinces, eastern Democratic Republic of Congo. NK and I respectively, denote North Kivu and Ituri Provinces.

Parameter		North Kivu	Ituri	χ^2-test
Deleafing (n=90 in NK; n=150 in I)	Yes	85	74	3.823*
	No	15	26	
	Total	100	100	
Reasons for de-leafing (n=77 in NK; n=110 in I)	Maintenance of banana plantation	43	70	22.337***
	To provide mulch under banana	26	23	
	Cover banana bunches to enhance ripening	12	1	
	Provide light to beans	19	6	
	Total	100	100	
Timing of de-leafing (n=77 in NK; n=110 in I)	Beginning of the rainy season	38	34	0.977^{ns}
	Middle of the rainy season	0	1	
	Any time	62	65	
De-budding (n=90 in NK; n=150 in I)	Proportion who de-bud	66	56	2.455^{ns}
Reasons for de-budding (n=59 in NK; n=83 in I)	De-bud to manage disease	88	67	8.364**
	De-bud to increase bunch size	12	33	
Time of de-budding (n=63 in NK; n=84 in I)	After emergence of the last hand	49	62	2.015^{ns}
	After bunch filling	48	34	
	Any time	3	4	

'ns', '*', '**' and '***' respectively denote no significant at P<0.05, a significant difference at P<0.05, P<0.01 and P<0.001 for the given practice between the two study sites.

Table 6. Frequency (%) for staking banana plants, pseudostem uses and weeding practices by farmers in North Kivu and Ituri provinces, eastern Democratic Republic of Congo. NK and I respectively, denote North Kivu and Ituri Provinces.

Parameter		North Kivu	Ituri	χ^2-test
Staking (n=90 in NK; n=150 in I)	Proportion who stake plants	94	95	0.783^{ns}
Timing of staking (n=85 in NK; n=143 in I)	At flowering stage	3	4	1.53^{ns}
	During bunch filling	39	36	
	Just before harvest	0	1	
	Whenever it is vital	58	59	
Pseudostem use (n=90 in NK; n=150 in I)	Cut into small pieces for use as mulch	91	85	1.73^{ns}
	Leave them standing	7	11	
	Feeding livestock	2	4	
Weeding (n=90 in NK; n=150 in I)	Hand weeding	0	1	4.291^{ns}
	Weeding with the hoe	88	78	
	Weeding with a machete	4	5	
	Weeding with the hoe and machete	8	16	

'ns'- denotes no significant at P<0.05 for the given practice between the two study sites.

best advantage of the available small area of land per household (Sileshi et al., 2007; Ouma, 2009). Diversified cropping systems, such as those based on intercropping and agroforestry or cover crops, have also gained interest largely due to the emerging evidence that these systems are more stable and more resource conserving

(Vandermeer, 1995). Opportunities for coexistence and beneficial interference between species that can enhance agroecosystem sustainability have been reported with increased diversity on farm (Vandermeer, 1995). Banana-bean, banana-bean-taro and banana-coffee were the commonest intercrops in the study regions. Annual intercrops were often planted at the beginning of the raining season. The legume banana associations benefit the banana crop through nitrogen fixation and by controlling erosion. However, this practice involves tilling within the banana plantations which damages the superficial roots of banana plants and could potentially promote the spread of Xanthomonas wilt of banana, Fusarium wilt and nematodes. The practice of mulching of banana plots in combination with zero tillage and the use of a piece of wood for planting e.g. beans could be explored to prevent root damage and limit the risk of infections. The currently most widely recommended banana mat spacing in East and Central Africa is 3 × 3 m (Tushemereirwe et al., 2001). Studies to determine the optimum spacing for banana-annual crop intercropping with minimal interference from the banana crop or the intercrop are thus necessary.

De-suckering helps to maintain the chosen plant density thus reducing competition for available resources (Tushemereirwe et al., 2001). Most farmers (69%) practiced de-suckering across North Kivu and Ituri provinces. A slightly lower number of farmers (65%) were observed to de-sucker in North Kivu in an earlier study by Ocimati et al. (2013), however, North Kivu ranked behind Rwanda, Burundi and the South Kivu province in eastern DR Congo. Ndungo et al. (2008) also reported that farmers in North Kivu put low effort into the management of their banana plantations. However, in the current study, and unlike in Ocimati et al. (2013) where most (over 90%) farmers de-suckered at the onset of the rains, most farmers de-suckered when necessary (that is, not linked to a specific time period). This could be a reflection of the chosen application of the practice. Similarly, most farmers maintained between 3 and 4 plants compared with 4 to 7 plants as reported by Ocimati et al. (2013). This could be attributed to intensive extension efforts spearheaded by the CIALCA project during 2007 to 2011. Nonetheless, a large number of farmers' still maintained more than the three recommended (at various growth stages-parent, child and grandchild) plants per mat (Tushemereirwe et al., 2001). Ocimati et al. (2013) reported that the maintenance of more suckers than recommended is sustained by the high soil fertility conditions in the study region that can still support a large number of plants per mat without compromising the yield per unit area.

Cutting of green leaves (de-leafing) was common in 74 to 85% of farms. Apart from their use for domestic purposes, leaves were mainly cut to maintain the field and reduce shading at the onset of the rains when intercrops especially, legumes were planted. Intercropping bananas is a common practice mainly resulting from the high population density and the limited access to land (Ocimati et al., 2013; Fermont et al., 2008). Despite the potential benefits of intercropping (such as nitrogen fixation, pest suppression, soil erosion control) leaf cutting exposes the banana plants to XW infection through tool use. Indeed, tools are one of the most common means of XW spread in this region. Ocimati et al. (2013) recommends the removal of only the fully dried out leaves to prevent tool transmission of XW through de-leafing. In addition, cutting of leaves at bunch emergence could severely impact on bunch yields. Blomme et al. (2017) recommends leaf-bending in fields where XW is present in order to prevent disease spread because the bended leaves can potentially still carry out photosynthesis.

De-budding, practiced in 66 (North Kivu) to 56% (Ituri) of the farms was aimed at XW management (preventing insect vector transmission) and increasing bunch size. The current figure in North Kivu (66%) is slightly higher than the 62% earlier reported for North Kivu by Ocimati et al. (2013). Male bud removal as soon as the last hand in a bunch is formed has been reported to prevent the spread of XW (Blomme et al., 2005). However, most of the farmers who de-budded, either were not concerned about the time of de-budding or de-budded too late to be able to prevent a possible XW infection. Similar observations were reported by Ocimati et al. (2013). This could partially explain the continuous perpetuation of the XW problem in the study region. De-budding is also one of the measures for preventing fungal infections such as cigar end rot disease caused by *Verticillium theobromae, Trachsphaera fructigena* and/or *Gloeosporium musarum* (Mwangi, 2007). Removal of the male bud has been reported to increase the bunch weight due to an increase in finger size (Daniells et al., 1994). Daniells et al. (1994) reported that the male bud represented a significant competing photosynthetic sink. Thus, there is need to highlight the numerous benefits that accrue from the timely male bud removal so as to promote its application among the farming communities.

The technique of staking was highly applied. Staking was mainly practiced to prevent lodging/toppling/snapping/doubling of banana plants caused by the weight of bunches. Across the sites, the harvested pseudostem was mainly used as mulch material. This practice is important for nutrients recycling, reducing water runoff and loss through evaporation and in suppressing weeds, functions that are important for the sustainable productivity of the banana farms in these regions (Ocimati et al., 2013). The importance of mulching using pseudostems in the study regions is important as the resource poor households are not able to apply other sources of mulch (e.g. grass and other crop residues) due to associated costs and limited availability.

Weeds were mainly controlled using hand hoes, while a minority used machetes to cut or slash the weeds. Hand

Table 7. Recommendations for improving the efficacy of selected cultural practices in the face of Xanthomonas wilt disease and high population densities.

Cultural practice	Recommendation
De-trashing	Only cut the dry leaves to avoid BXW spread
Weeding	Mulching suppresses weed growth, keeps the ground soft, conserves soil moisture and in combination with zero tillage could reduce the risk of BXW spread in fields
De-leafing (cutting green leaves)	Increase spacing of banana to >3 m × 3 m where inter-cropping is inevitable to minimize the need for leaf cutting to increase level of sun light penetration for annual intercrops
	Bend leaves (at the petiole level) using forked sticks instead of cutting. Such leaves could potentially continue to partition assimilates
Selection of planting material	Build capacities for clean seed production using simple techniques e.g. macro-propagation
	Increase promotional activities for the use of clean seed.
Inter-cropping	Increase spacing of banana to >3 m × 3 m to minimize shading of intercrops
	Identify shade tolerant crop species to plant under the banana crops
Banana-agroforestry practices	Test/Fine-tune good practices for integrating trees in banana e.g. use of tree at borders and as hedges
Planting spacing/ density	In densely populated communities and where farmers inter-crop (the case in eastern DR Congo), wider banana spacing (>3 m × 3 m) is recommended
Leaf bending	Recommended in inter-cropped or XW infected fields instead of leaf cutting. The bent leaves could still continue with photosynthesis.

hoe weeding is attributed to the need to intercrop with legumes and other annual crops. Hand weeding and herbicides were not at all used across the sites. Similar observations were reported in North Kivu by Ocimati et al. (2013).

CONCLUSION AND RECOMMENDATION

Cultural/Agronomic practices are crucial agro-ecological intensification practices for enhancing food productivity and soil/field health. However, some of the practices such as de-budding and mulching are knowledge intensive and do not have immediate perceived benefits to the farmers and thus the need to strengthen knowledge extension to farmers to enhance their adoption. Ease of applicability of the various cultural practices and their contribution to pest and disease management and productivity are listed in Table 1. In the face of severe diseases such as XW, cultural practices such as de-trashing, de-leafing and banana spacing need to be modified. Some slight modifications were suggested to the current cultural practices in Table 7 to minimize XW disease spread. For example, cutting of green banana leaves to allow for intercropping was prevalent, potentially affecting banana yields and exacerbating the XW problem. In such communities where intercropping of banana with annual crops is in-evitable, we recommend studies to revise banana spacing to enable both the intercrop and banana to co-exist with minimum interferences. The recommended changes are not cumbersome and with clear benefits, thus have a high probability of success within the communities. Capacities for clean seed production need to be urgently built. In addition, promotional activities are needed to foster clean seed use and other practices for management of biotic constraints. Regular feedbacks from extension workers could possibly contribute to timely fine-tuning of recommended cultural practices and enhance their adoption.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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