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Change in a ferralsol physico-chemical properties under pineapple cropping system in southern of Benin

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ABSTRACT

Objectives: The study examines the evolution of soil properties under the main pineapple cropping system, in order to evaluate the effectiveness of this system towards maintaining sustainable productivity.

Methodology and Results: The plots of different cropping durations (1.5, 3, 6, 7, 10, 15 and 16 years) were selected from the predominant pineapple cropping system. A fallow plot was identified in a neighbourhood of each selected pineapple plot. Soil profiles were installed in the selected fields and their adjacent fallows to characterize morphological and physico-chemical soil dynamics. The results showed that the values of the morphological and physical characteristics of the soil began to decrease after 10 years of pineapple cropping. The values of chemical characteristics started to decline after 7 years of pineapple cropping.

Conclusions and application of findings: The main pineapple cropping system in the study region improves and maintains the morphological and physical characteristics of the soil up to 10 years of cultivation after which lower values were recorded. In general, the values of the chemical characteristics begin to decline after 7 years of pineapple cropping. It is important to study crop residue management practices that will better manager soil fertility and conservation. For a sustainable use of ferrallitic soils under pineapple, the fertilization system on the plateau of Allada should be strengthened by the addition of organic fertilizers with appropriate crop rotation. This will keep these lateritic soils under pineapple production over a longer period.

Keywords: Cropping systems, soil properties, pineapple, Benin.

INTRODUCTION

Pineapple is one of the most requested tropical fruit on the international market. In West Africa, it is the second most important tropical fruit in terms of production volume, after bananas (FAO, 2009). In Benin, pineapple is the main fruit crop in the south, especially in the Atlantic department. It is grown by about 70% of farmers whose production represents about 95% of total production of the country (Helvetas-Benin, 2008). Some authors have identified in Benin a diversity of pineapple cropping systems with various cultural practices likely to influence soil fertility (Agbangba *et al.,* 2008; Agbangba *et* *al.,* 2010; Sossa *et al.,* 2014). They pointed out the use of varying amounts of mineral fertilizers by pineapple producers, who do not follow the recommended fertilizer rates. Agbangba *et al.* (2008) have mentioned that some Beninese farmers in present conditions of pressure of land use intercrop with pineapple other crops like maize, tomato, cowpea, oil palm, in order to diversify their sources of income. It is recognized by several authors that these practices are likely to affect soil fertility. Moreover, the nearly exclusive use of mineral fertilizers causes soil acidification (Zougmore *et al.,* 2004). The continued use of land causes a decline in soil carbon content, total phosphorus content and in the sum of exchangeable bases; whereas the recycling of crops residues combined with soil tillage techniques and crop rotations improve some soil properties and reduce soil erosion (Wei *et al.,* 2006). The impact of pineapple cropping systems on the changes in soil physical and chemical properties is not well documented. Tossou (2001) found that pineapple monocropping causes soil and biodiversity degradation. Kintohou (2003) studied the different types of mineral fertilization of pineapple in the town of Allada and showed that NPK fertilizer (10-10-20) is no longer effective. Lui *et al.* (2013) observed a decrease in soil bulk density, following the use of composted pineapple crop residues. Due to the importance of pineapple crop in Benin and for its sustainable production this study aimed to assess the influence of pineapple cropping systems on soil properties in order to: i) analyze the evolution of the soil physico-chemical properties, ii) evaluate the effectiveness of the pineapple cropping system in sustainable maintaining soil productivity and iii) offer to the farmers an additional cultural practices that can improve the performance of this system.

MATERIAL AND METHODS

Study area: The study was carried out on the plateau region of Allada located in the Atlantic department in southern Benin (6 ° 40 'N and 2 ° 15'0 E). In this area, average rainfall is 1200 mm. The dominant soil type is a low-desaturated lateritic soil, commonly called "terre de barre." This soil has a favourable textural profile with a sandy texture in surface for easy cultivation and over a clayey horizon well structured from about 40 cm deep, ensuring good water reserve (Azontondé, 1991). The vegetation is a shrubby bush, associated either with more or less dense oil palm plantation that is found on the plateau naturally or by planting (CeRPA, 2005).

Plots selection and soil study: The farmer's plots were selected in the predominant pineapple cropping system identified by Sossa *et al.* (2014) in Allada. This pineapple system practiced by 49% of producers is characterized by the absence of rotation and intercropping, the non-use of organic manure, the recycling of crop residues and by large areas. The plots have been used for a long time by pineapple crop, with a mean of 5.3 ± 2.5 years of cropping (Table 1).

Table 1: Characteristics of the dominant pineapple cropping system on the plateau of Allada (Sossa *et al.,* 2014)

Cropping system characteristics	
Rotation	no
Crops association	no
Organic manure use	no
Recycling of crop residue	yes
Cultivated area (ha)	1.0 ± 0,8
Mean land use duration (years)	5.3 ± 2,5
Maximum land use duration	16 years
Urea (Kg/ha)	281.2 ± 128.0
TSP (Kg/ha)	49.1 ± 78.7
K_2SO_4 (Kg/ha)	1.7 ± 17.7
NPK (Kg/ha)	414.8 ±183.7

The choice of the plots was based on a chronosequence of land use duration under pineapple crop. Seven land use durations were identified: 1.5; 3; 6; 7; 10; 15 and 16 years (Sossa *et al*., 2014). For each period of land use, three plots were selected. A fallow plot (used as control) was identified in a neighbourhood of each selected pineapple plot. Each associate fallow age was equal to the use duration of the soil under pineapple cultivation. A soil profile for one meter depth was installed in each selected plot and in the adjacent fallow. Each profile has been described by the identification of different soil horizons and by soil morphological characterization. A soil sampling was performed in each soil layer with a knife until 60 cm depth (rooting depth of pineapple). The soil samples were air-dried for determination of soil parameters in laboratory. Nitrogen (N) was determined by the Kjeldahl method (Kjeldahl, 1883), available phosphorus (P) by Bray-1 method (Bray and Kurtz, 1945), carbon (C) by Bell method (Bell, 1964), the exchangeable cations (K, Ca, Mg) by Helmke and Sparks's method (Helmke and Sparks, 1996), cationic exchange capacity by the Metson method (Metson, 1956), the pH by the potentiometric method (in a soil / water ratio of 1 / 2.5) (Jackson, 1968) and soil particles size by the international method, modified by the use of pipette Robinson (Robinson, 1949). A soil sampling with the density cylinder of 100-cm3 volume was made three times in each soil layer for the determination of bulk density. The soil properties for each soil layer were used to calculate the mean value of each parameter for the 0-60 cm soil layer.

Statistical analyses: A Student t-test was performed on the soil parameters values in order to compare the pineapple plots and the fallow plots relative to the same duration of land use. A principal component analysis was performed using R software (version 3.2.0, 2015) on the soil physico-chemical parameters, in order to evaluate the influence of land use duration on the soil fertility.

RESULTS

Changes in the soil morphological characteristics over the land use duration: The morphological characteristics of soil profile varied depending on the land use duration. The number of soil horizons varies between 3 and 4 according to the land use duration. Soil profile showed an A0 surface organic horizon between 3 and 10 years of soil using under pineapple cultivation. The thickness of this horizon A0 decreases of 46.7% from 1.5 to 10 years cropping. Similarly, the thickness of all the horizons A declines of 10% from 1.5 to 16 years cropping (Table 2).

Dynamics of soil physico-chemical characteristics: The comparison test of means performed on the bulk density data and total porosity of the soil in fallow and cultivated plots indicated that the soil bulk density of the cultivated plots is higher (3.2 to 23%) than the bulk density of the fallow land at each land use duration. A significant difference was observed at 3 years of land use duration. The soil porosity took evidently the opposite trend and is higher on the fallow (1.8 to 11.8%) than the cultivated plots (Table 3)

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Tableau 2: Soil morphological characteristics

Duration (years)	Profile characteristics		
	Horizons numbers	Horizons types	Average thickness (cm)
1.5	3	A	20
		AB	22
		B	≥ 42
3	4	A0	15
		A1	23
		AB	22
		B	≥ 60
6	3	A0	10
		A1	20
		B	≥ 30
7	4	A0	12
		A1	15
		AB	26
		B	≥ 53
10	3	A0	8
		A1	24
		B	≥ 32
15	3	A	27
		AB	18
		B	≥ 45
16	3	A	18
		AB	18
		B	≥ 36

Table 3: Variation of physico-chemical characteristics of soil following land use duration

Land use duration (years)	Land use	Bulk density	Total porosity (%)	pH	C (g/kg)	N (%)	C/N	P (ppm)	K (meq/100g)	CEC (cmol.kg-1)
1.5	Field	1.57±0.09 a	36.91±1.28 b	4,92± 0,05 a	3.1±0.01 b	0.1±0.01 a	2.773±0.1 b	23.18±0.12 b	0.61±0.02 a	35,99±1,39 a
	Fallow	1.47±0.1a	40.96±0.06 a	5,1±0,04 a	6.8±0.04 a	0.12±0.005 a	7.697±0.43 a	26.2±015 a	0.67±0.03 a	36.03±1.38 a
3	Field	1.61±0.01 a	37.47±0.66 b	4.9±0.75 a	5.2±0.03 a	0.13±0.005 a	4.20±0.14 a	27.37±0.09 a	0.55±0.63a	20.65±0.92 a
	Fallow	1.52±0.01 b	41.9±0.13 a	5.87±0.14 a	4.5±0.002 a	0.1±0.004 b	5.5±0.69 a	25.92±0.02 b	0.76±0.003 a	21.5±0.7 a
6	Field	1.48±0.11a	38.98±0.03b	5.28±0.01 b	13.7±0.04 a	0.06±0.002 a	19.59±0.84 a	19.76±0.34 b	0.57±0.002 b	33.56±0.79 b
	Fallow	1.39±0.12 a	42.97±0.04a	5.65±0.05 a	9.8±0.03 b	0.09±0.01 a	17.5±0.71 a	35.64±0.19 a	1.12±0.004 a	38.5±0.71 a
7	Field	1.51±0.13 a	44.41±0.58 a	5.68±0.26 a	11.9±0.02 a	0.1±0.006 b	12.97±0.04 b	23.46±0.09 a	0.66±0.006 b	25.61±0.86 b
	Fallow	1.45±0.07 a	42.74±0.37 a	5.76±0.18 a	5.1±0.02 b	0.14±0.005 a	16.5±0.71 a	12.13±0.05 b	1.07±0.04 a	29.83±0.24 a
10	Field	1.61±0.12 a	40.93±0.1 a	5.48±0.41a	15±0.71 a	0.14±0.0005 a	7.77±0.32 a	22±0.002 a	1.75±0.001 a	31.19±1.69 b
	Fallow	1.56±0.05 a	41.68±0.44 a	5.94±0.08 a	6.2±0.005 a	0.13±0.0001 a	16.5±3.54 a	13.14±0.06 b	1.6±0.003 b	39.5±0.71 a
15	Field	1.71±0.13 a	37.78±0.31 b	5.47±0.12 a	7.5±0.01 a	0.122±0.004 a	5.63±0.89 a	9.59±0.019 b	1.02±0.004 b	31.07±0.1 a
	Fallow	1.39±0.26 a	39.85±0.21 a	5.81±0.26 a	5.3±0.004 b	0.121±0.001 a	8.5±0.71 a	19.33±0.18 a	1.1±0.001 a	31±2.83 a
16	Field	1.6±0.14 a	42.569±0.61 b	5.44 ±0.46 a	8.9±0.01 a	0.13±0.0001 a	5.5±0.71 b	20.57±0.1 b	1.3±0.01 b	30.71±1.0 b
	Fallow	1.35±0.1 a	46.47±0.75 a	6.353±0.63a	6.1±0.004 b	0.13±0.001 a	19.5±0.71 a	33.29±0.006 a	1.5±0.02	36.5±0.71 a

The principal component analysis performed on the soil physical characteristics of the soil-cultivated plots for the different duration, reveals that the first two axes alone account for 92.7% of the total variance, which is sufficient to ensure proper interpretation. The total porosity and clay content are positively correlated with axis 1; while sand content, bulk density and available water are negatively correlated to it (Figure 1). The silt content is positively correlated to axis 2. Unlike the sand content, the bulk density and the available water soil, the total porosity and the clay content increase with duration of land use to 10 years of cropping, and fall beyond this land use duration. The clay content of the soil continuously increases with land use duration (Figure 1). Soil parameters values in the fallow and cultivated plots are presented in the table 3. The values of pH, C/N ratio, K and CEC are lower on the cultivated plots than on the fallow land at each land use duration. We note significant differences at 6 years of land use for pH; at 1.5, 7 and 16 years land use for C/N; at 6 and 16 years land use for K; at 6, 7, 10 and 16 years of land use for CEC. The soil phosphorus content is significantly higher on the plots under fallows than on the cultivated fields for the land use durations 1.5, 15 and 16 years. On the other hand, it is higher in cultivated fields for others durations of land use. The carbon content is globally lower on plots under fallows than on the cultivated fields, excepted for the 1.5-years land use. This decline varied with time; it is of 13.5%, 28.5%, 57.1%, 58.7%, 29.3% and 31.5% respectively for land use durations 3, 7, 10, 15 and16 years (table3).

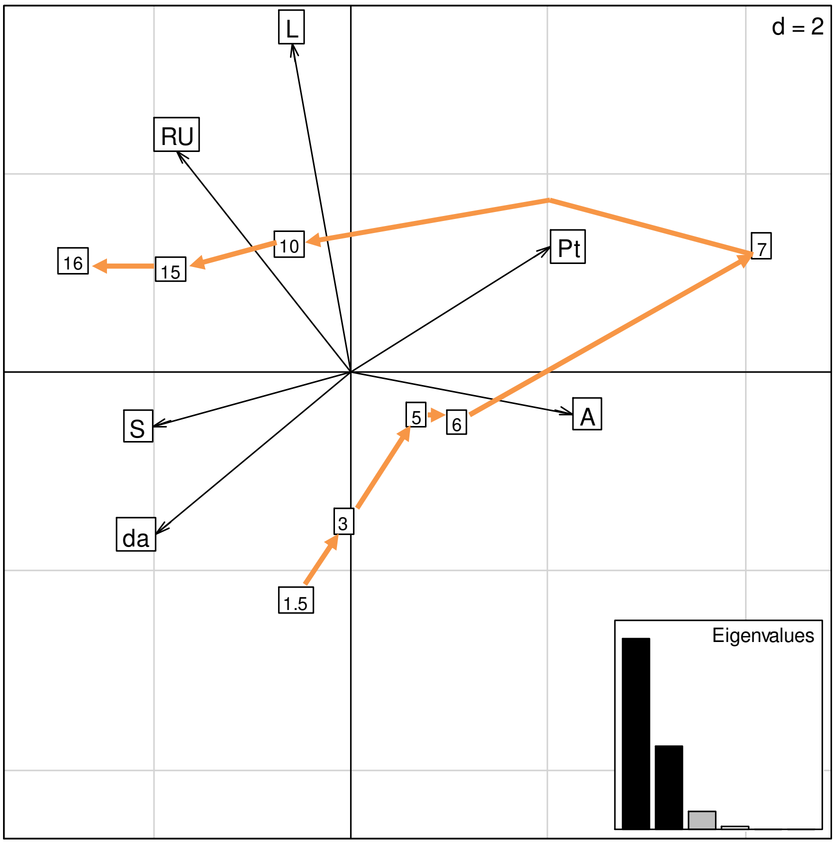

Figure 1: Projection of soil physical properties in the factorial plan (Axis2, Axis1) of the PCA showing the dynamic following land use duration
Pt =Total porosity, A=Clay, L= Silt, S = sand, da = Bulk density, RU = available soil water

The positioning of chemical properties of cultivated soil in plane axes of the principal components analysis (figure 2) showed that the first two components explain 71.44% of the total variance. Potassium levels and pH are negatively correlated to axis 1; while phosphorus, magnesium and CEC are positively correlated to that axis. On the axis 2, carbon and calcium, and C/N ratio are negatively correlated, while the nitrogen is positively correlated.

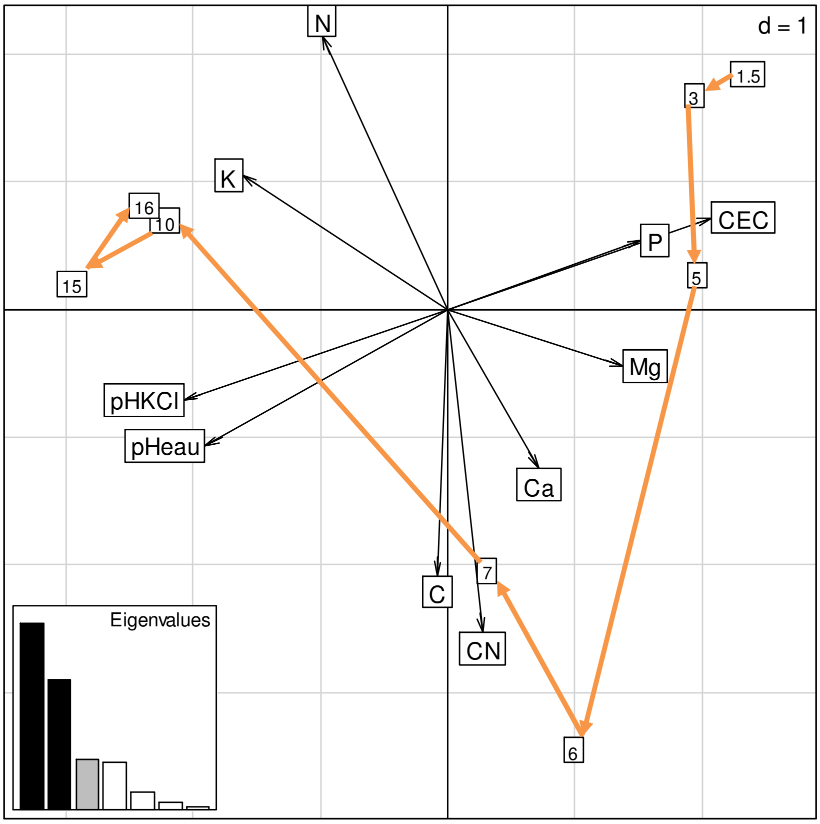

Figure 2: Projection of soil chemical properties in the factorial plan (Axis2, Axis1) of the PCA showing the dynamic following land use duration

The cultivated soil during periods of less than or equal to 7 years, have higher CEC, phosphorus and magnesium levels but lower pH and lower potassium levels. Land use beyond 7 years leads to a decrease in CEC, phosphorus and magnesium contents; but an increase in potassium and pH. In contrast to nitrogen content, C/N, carbon and calcium in the soil increase with the duration of land use up to 7 years under the prevailing system. After this period, a decrease of C/N, carbon and calcium soil associated with an increase in soil nitrogen content was observed.

DISCUSSION

The study of the characteristics of lateritic soils under the prevailing pineapple cropping system on the plateau of Allada revealed that soil morphological and physico-chemical properties varied according to land use duration. This system is characterized by the absence of rotation, intercropping and non-application of organic manure and by the recycling of crop residues and large areas (Sossa *et al*., 2015). It modifies the soil morphological and physico-chemical characteristic according to the land use duration up to 16 years. The recycling of crop residues is certainly the practice that justifies the effectiveness of this system. Indeed, Lui *et al*. (2013) noted a decrease in soil bulk density, following the use of composted pineapple crop residues. The decline in soil bulk density, due to the use of crop residues has also been demonstrated by several authors (Edwards *et al*. 2000; Abdelhamid *et al*., 2004; Evanylo *et al*., 2008). The decomposition of crop residues while increasing the carbon content and the total porosity of the soil, causing the decline in soil bulk density (Shaver *et al*., 2003), making soil looser, with consistent aggregates and well individualized (Yemefack *et al*., 2004). According to Hien *et al*. (2002), inputs of organic compounds in the form of aerial and root litter participate in rebuilding of the soil organic matter. This justifies the presence of the organic surface horizon A0 in the soil profile of our study plots. The increase of silt and clay contents, and the decrease of sand contents between 1.5 and 10 years cropping would be linked to the use of crop residues. Indeed, soil macrofauna is enriched by the incorporation of crop residues (Mamoudou *et al.*, 2012). The activity of soil organisms including termites and soil-ingesting worms is likely to go up from the subsurface horizons, the fine soil surface particles (clay and silt) reducing the proportion of sand in the first horizons (Yemefack, 2004; Alongo, 2013). The practice of continued pineapple monoculture and exclusive incorporation of crop residues in the dominant system of pineapple cultivation could justify the revival of the proportion of sand in the upper soil horizons beyond 10 years, made of the gradual decline of the richness and the diversity of soil macrofauna. According to Parmelee *et al.* (1990) and Decaëns *et al.* (1994), soil macrofauna should be maintained particularly through the association or rotation with legumes and the reduction of tillage frequency. The incorporation of the crop residues into the soil, also increases soil content in N, P, K and enhances its exchangeable cations (Kowaljow and Mazzarino, 2007; Courtney and Mullen, 2008; Sommer *et al.*, 2011;. Lui *et al.*, 2013). This practice also allows reducing the need for mineral fertilizers (Chikae *et al.*, 2006; Gabhane *et al.*, 2012.). In the studied system, the mean levels of carbon, calcium, phosphorus, magnesium and soil CEC began to decline, for land durations beyond 7 years. Even after 10 years of cultivation, bulk density and sand rates rose. This shows that the decline of soil fertility under this system starts after 7 years of use. However, the decrease in the phosphorus content in the soil could not affect significantly the production of pineapple because Godfrey *et al.* (1971) reported that phosphorus requirements of pineapple are limited. In addition, the optimum pH for the cultivation of pineapple is between 4.5 and 5.5 (Py *et al.*, 1965). On all land use studied durations, a change in pH from 4.9 to 5.5 is suitable for pineapple cropping. The optimum pH appears linked to the availability of trace elements in the soil (Py *et al.*, 1965). Mineralization of nitrogen from organic inputs is often limited to short and its accumulation becomes noticeable after 5 years of cropping (Blackshaw *et al.*, 2005; Barbarick and Ippolito, 2007; Leroy *et al*, 2007). The regular input of organic matter in the soil, through compost or manure, improves its contents of C and N and led to over 10 years in the accumulation of nitrogen in the soil, indicating physical protection of this nutrient in macroaggregates (Whalen and Chang, 2002; Meng *et al*, 2005; Mallory and Griffin, 2007; Sodhi *et al.*, 2009). This organic matter is well degraded as underline globally the C/N values of the cultivated plots.

CONCLUSION

This study revealed that the soil properties varied according to the land use duration. The dominant pineapple crop system, mainly characterized by the return of crop residues, contributes to the maintenance of morphological and physico-chemical characteristics of soil, up to 10 years. Beyond this period, soil fertility decrease. It is important to study crop residue management practices that will better manage soil fertility and conservation. For a sustainable use of ferrallitic soils under pineapple, the fertilization system on the plateau of Allada should be strengthened by the addition of organic fertilizers with appropriate crop rotation. This will keep these lateritic soils under pineapple production over a longer period.

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