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Tropical Cambisol as Affected by Sugarcane (*Sacharum officinarum L.*) Foam and Inorganic Fertilizer

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Authors' contributions

Author BK conceived the protocol of this study and supervised this report which was entirely conducted by author BBF. Authors YK, YKA and SOO have contributed to the writing of the manuscript.

Original Research Article

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ABSTRACT

Aim: For promoting an alternative source of nutrients to restore the fertility (pH, carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg)) of agricultural soils affected by long-term cultivation with inorganic fertilizer, the use of sugarcane foam and inorganic fertilizer on a Cambisol was assessed.
Design: The study was laid out in a randomized complete blocks design with three replications.
Place and Duration: A study was conducted at Zuenoula in the forest/savanna transition agro-ecosystem of Côte d'Ivoire, during 2011 and 2012 cropping seasons.
Methodology: The soil was tilled and the different rates of Foam (0,6,12,18 and 24t/ha) and that (0,150,300,450 and 600kg/ha) NPK+Mg+S (18%-9%-14%-2%-2.5%) were incorporated onto the soil.
Results: Application of sugarcane foam significantly (p< 0.05) enhanced soil contents of C,N,P and slightly of Ca^{++} but not of K^{+} and Mg^{++} with the most increase for 6t/ha (C and P) and 18t/ha (N and Ca^{++}) than that induced by 300kg/ha and 600kg/ha NPK

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according to nutrients.
Conclusion: The use of 18t/ha of sugarcane foam applied once for two cropping seasons was the most suitable for improving the quality of soils deficient in N and P but not for K^+ and Mg^{++} deficient soils, thus this rate was recommended for restoring the fertility of degraded tropical Cambisol.

Keywords: Sugarcane foam; organic matter; inorganic fertilizer; soil-chemical characteristics; tropical soil.

1. INTRODUCTION

Industrial agriculture requires intensification of the production systems consisting essentially of continued monoculture in most cases. However, monoculture cropping systems are well known for their soil degrading effects, inducing declining yields during successive cropping seasons, especially in the humid tropics [1]. Beside soil nutrients depletion often caused by leaching, there are problems of soil acidification and low soil organic matter content.

The soils of western Côte d'Ivoire (West Africa) characterized by Ferralsols and Cambisols are experiencing declining soil fertility due to over three decades of intensification for sugarcane production. Sugarcane yields are declining, thus affecting the economy of sugar manufacture. There is an urgent need to restore the fertility of these soils. The use of inorganic fertilizers to restore the fertility of the soil has not been effective because of high leaching, continued exports of nutrients through crop harvest and unbalanced mineral contents in the soil [2,3,4]. Moreover, the available compound fertilizers (NPK) in the local markets have no micronutrients despite the soils are highly micronutrients deficient.

There is no site-specific nutrient diagnosis to guide the application of fertilizers based on site-specific soil fertility management [5], therefore, there has been haphazard application of mineral fertilizers [6] mostly NPK+(Mg and S) for sugarcane production for a long time. Deficiencies of Fe and Zn and excess of Mn are common as typical of tropical soils experiencing chemical degradation under continuous cropping [1] and structural degradation due to soil erosion and compaction [7,8].

The use of organic amendments can improve soil structure and supply soil nutrients via mineralization [9,10,11,12,13,14]. However, large quantities of up to $12t/ha^{-1}$ are required to optimize the use of organic amendments in agriculture [15]. The limited availability of organic inputs is restricting this practice [16]. The use of animal manure though readily used for agricultural purpose is also declining, while 90% of crop residues are exported from the field for domestic use in Africa [17].

About 19,000 to 20,000 tons of sugarcane foam are annually available at Zuenoula in Côte d'Ivoire as derived product of sugarcane manufacture. This bio-waste can be used for amending agricultural lands, hence, increasing the availability of organic source of nutrients [10]. In fact, a ton of sugarcane foam contains about 7kg of nitrogen, 9kg of phosphorus, 8.5kg of calcium and 20kg of silicon [18]. The high silicon concentration can enhance soil P bioavailability [19] and reduce Mn and Al toxicities in the soil [20].

However, there is limited knowledge on the use of this bio-waste for crop production on tropical Cambisol, especially in the agro-ecosystems of Côte d'Ivoire. This limited knowledge can lead to injudicious use of sugarcane foam for the amendment of agricultural lands.

Thus, we hypothesize that optimum rate of sugarcane foam lower than 12t/ha can be adequate for agricultural soil amendment.

The objective was to identify the optimum rate of sugarcane foam required to restore fertility on a Cambisol affected by long-term cultivation in Zuenoula area under inorganic fertilizer (NPK) management.

2. MATERIALS AND METHODS

2.1 Site of Experimentation

The study was conducted in 2011 and 2012 in the experimental station of the sugar company SUCRIVOIRE of Zuénoula (7°38' 53"N, 6°9' 46"W, 218m) in Côte d'Ivoire. The station is located in the humid/savanna transition agroecology having a bimodal rainfall pattern with 1115.3mm in 2011 and 1295.1mm in 2012, and with average annual temperatures of 32.9°C and 32.4°C in the respective years.

2.2 Soil of Experimental Site

The soil of the experimental site was a deep (>120m) plinthic Cambisol with hydromorphic features (5YR 2.5/1–2.5YR 3/4) induced by irrigation water and presenting a brown colored (5YR 3/2) matrix. It was a silty-clay (36% silt and 33% clay), stony (75%) with 40–70% of exchangeable cation saturation and 19 cmol/kg of cation exchangeable capacity. The soil was continuously under sugarcane cultivation in the past five years with annual application of 600kg/ha of NPK+Mg+S (18.5%–9%–14%–2%–2.5%). Residual biomass (root, residues of stalk and leaves) of sugarcane was annually incorporated during land preparation for the next cropping.

2.3 Foam of Sugarcane

The foam is an industrial waste from sugarcane manufacture after filtration of sucrose juice constituting a solid residue with more than 20% of moisture content. It has dark-brown color and odorless, composed of sugarcane fragments ranging from 200µm to 1mm in dimension.

2.4 Experiment Layout and Soil Sampling

About 4518m^2 of bush fallow was cleaned manually and the soil was sampled in 0–20cm at the four corners and the centre of the plot using an auger. The five soil samples collected were mixed and a composite soil sample of 500g was taken for initial site characterization before the experiment.

A tractor was used for soil tillage to plough and harrow the soil before setting 9 micro-plots (10m×7.5m) in 3 replications using a randomized complete block design. In 2011 and 2012, five rates (0,6,12,18 and 24t/ha) of the sugarcane foam and four rates (150, 300, 450 and 600kg/ha) of inorganic fertilizer composed of NPK+Mg+S (18.5%–9%–14%–2–2.5) were applied every year by incorporating them to 0–10cm depth. The micro-plots were left under weather and biotic conditions.

Twelve months later, another composite sample was taken from the micro-plot for laboratory analysis.

2.5 Laboratory Analysis

Soil samples were sun dried, ground and sieved (2mm) before the laboratory analyses were carried out. Soil pH (water) was measured using a glass electrode at a soil/solution ratio of 1:2.5. Its contents for organic carbon-C (Walkley-Black) and total nitrogen-N (Kjeldahl) were determined according to the procedure described by Pauwel [21]. Soil P (Olsen), exchangeable K,Ca,Mg (1 N NH_4OAc (pH7.0)) and cation exchangeable capacity-CEC were also determined according to Peech [22]. Standard procedures for laboratory quality control measurements, including the use of blanks, replicates and internal reference samples were followed.

2.6 Statistical Analysis

Analyses of variance (ANOVA) of soil characteristics (N, P, K, Ca, Mg, Ca: Mg, Mg: K and CEC) were performed to compare the mean values for different rates of sugarcane foam and inorganic fertilizer respectively for each year of the experiment and across years. The differences between the mean values of these variables due to different rates of inorganic fertilizer versus sugarcane foam were determined by T-test (Turkey-Kramer) of mixed model analysis. The evolution trend of studied parameters in the soil from the beginning to 2012 was determined by simple regression using Excel while the other analyses were done by SAS (version 8) considering α=0.05.

3. RESULTS

3.1 Chemical Characteristics of the Soil and Sugarcane Foam

Table 1 summarized the chemical composition (N,P, K, Ca and Mg) of the studied sugarcane foam. There were high concentrations of Ca^{++} and Mg^{++} in the order of 2 to 20 times greater than the normal range of these nutrients. Phosphorus (P) concentration (0.25–4g/kg) was also high but, that of N (2.8–5.6g/kg) was normal and the concentration of K(<2.5g/kg) was low.

Table 1. Sugarcane foam concentration of N,P,K,Mg and Ca as well as soil chemical characteristics in 0–20cm depth before the experiment.

Soil chemical properties		Nutrient concentration in sugarcane foam	
pH $_{H2O}$	6.6	Nitrogen (g/kg)	5.6
pH $_{KCl}$	5.5	Phosphorus (g/kg)	3.6
C-organic (g/kg)	14.9	Potassium (g/kg)	1.3
N-total (g/kg)	1.3	Magnesium(g/kg)	0.8
C:N	11.5	Calcium g/kg)	28.6
P-Olsen (mg/kg)	19.3		
Ca^{2+} (cmol/kg)	5.3		
Mg^{2+} (cmol/kg)	2.5		
K^+ (cmol/kg)	0.3		
CEC (cmol/kg)	19.5		

The soil nutrients content of the experimental site (K^+,Ca^{++} and Mg^{++}) and the CEC were at high levels with a value of +1.2 for ΔpH Table 1. In spite of moderate soil acidity, unbalanced cation ratios were observed: 2:1 for Ca:Mg and 8:1 for Mg:K out of the optimum ranges and coupled with a low (<3%) K:CEC. However, higher soil contents of organic-C (>10g/kg) and total N (>1g/kg) were observed, with acceptable C/N ratio of 11.5.

3.2 Influence of Sugarcane Foam and NPK on Soil pH, C, N, P and C/N

Tables 2 and 3 showed the mean values of soil (0–20cm) pH, C, N, P and C:N ratio as influenced by different rates of sugarcane foam and NPK fertilizer in 2011 and 2012 respectively. No significant change was induced by sugarcane foam for soil pH and C, while the rate of 18t/ha gave the highest total N content of 1.8g/kg in 2011 contrasting with the result observed in 2012 Table 2. Increasing rates of sugarcane foam significantly increased soil P content up to the highest rate which gave 55–90mg/kg in both years. The C:N ratio was significant and highest (13.3) with application of 6 t/ha sugarcane foam in 2011, but no significant effect was observed for this parameter in 2012 Table 2.

NPK treatment had no significant effect on all the studied soil parameters in both years Table 3.

Significant difference between the overall effects of the rates of sugarcane foam and NPK are summarized in Table 4 for soil C, N and P contents. There were significant and positive differences in the contents of soil organic C and total N with application of sugarcane foam at rates above 6t/ha compared with 300 and 600kg/ha of NPK. Differences in soil P content were always significant with sugarcane foam at rates above 6t/ha compared with all NPK rates except 150kg/ha NPK versus 12t/ha sugarcane foam that had a similar soil P content, suggesting that these rates of sugarcane foam enhanced soil P than the NPK rates evaluated in this study Table 4.

Fig.1 highlighted quadratic trends for the studied soil parameters from the initial stage to the end of the experiment in 2012 under the effect of the sugarcane foam treatment. Most decreasing trends were observed for soil pH and organic C from 2011 to 2012 Fig.1a compared with the trends observed for soil P and total N contents Fig. 1b.

3.3 Influence of Sugarcane Foam and NPK on Soil Exchangeable Cations

Exceptionally, soil exchangeable Ca^{2+} content was significantly influenced by application of sugarcane foam only in 2011 Table 5. Application of 18t/ha of sugarcane foam treatment enhanced the exchangeable Ca^{2+} by 32% compared with plots without sugarcane foam application Table 5. No significant effect of NPK treatment was observed for soil exchangeable cations in both years Table 6.

There were significant and positive differences observed in mean values of soil exchangeable Ca^{++} with application of 18t/ha of sugarcane foam compared with all the rates of NPK studied Table 7. Significant negative differences were however observed for soil exchangeable K^{+} content with application of 24t/ha sugarcane foam treatment compared with application of 150 and 450kg/ha NPK treatments. No significant differences were observed for soil exchangeable Mg^{++} content between both treatments Table 7. A decreasing trend for soil K^{+} content, curve-linear trend for Ca^{++} and a stable level of Mg^{++} in the soil under the effect of sugarcane foam treatment during the experiment was apparent Fig. 2.

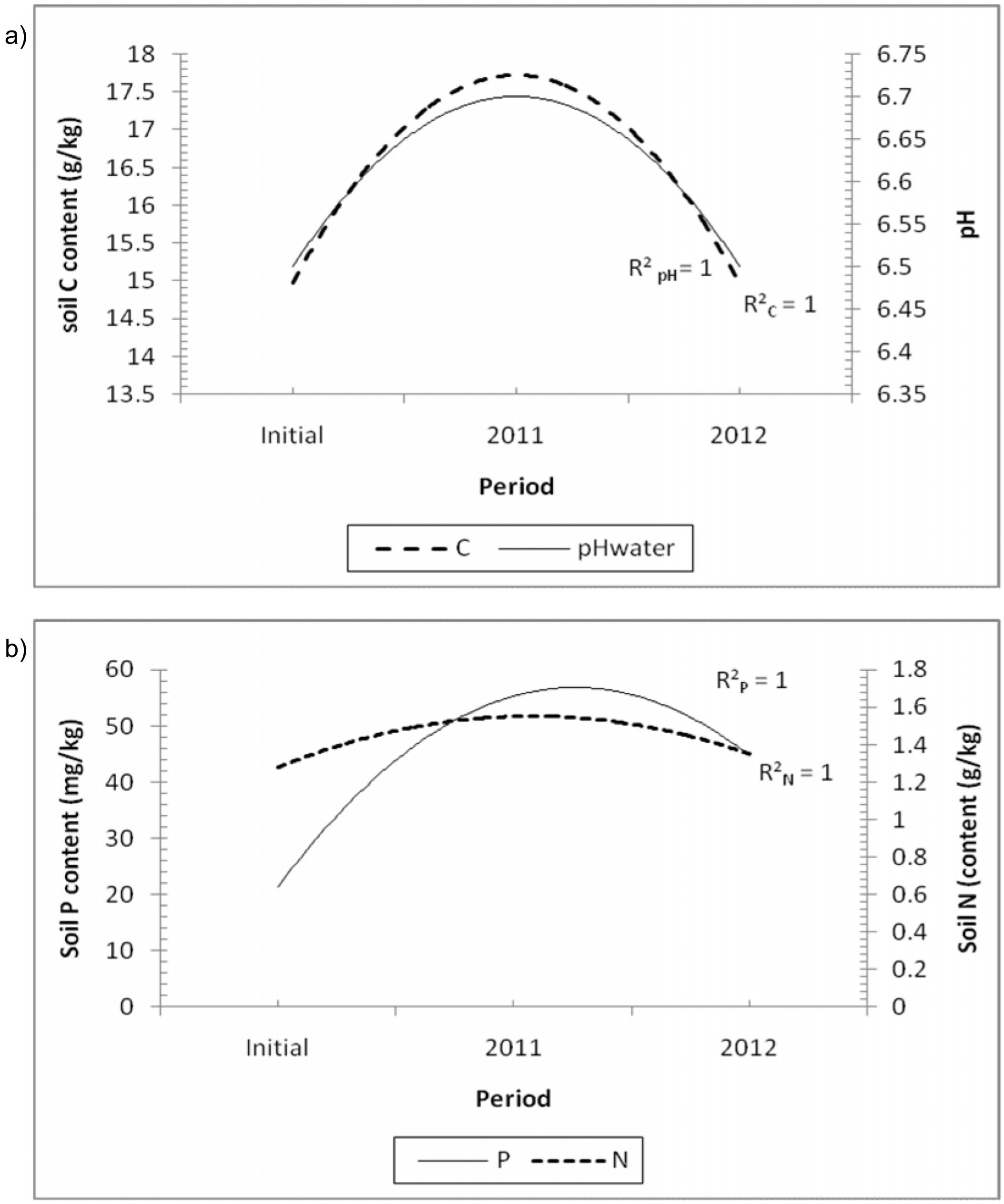

Fig. 1. Trends of soil pH_{water} and C content (a) as well as its contents of P and N (b) during the study period as influenced by sugarcane foam

Table 2. Mean values with standard deviation of soil pH_{water}, C, N, P and C:N ratio in 0–20cm depth after trial in 2011 and 2012 as influenced by the rates of the sugarcane foam

Foam rates (tha^{-1})	pH_{water}		C (g/kg)		N (g/kg)		P (mg/kg)		C:N	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
0	6.3±0.20a	6.6±0.17a	15.7±1.20a	13.8±2.33a	1.4±0.17b	1.29±0.34a	17.3±2.09d	18.7±7.23c	10.92±1.88b	10.89±1.25a
6	6.4±0.15a	6.5±0.06a	17.6±1.20a	14.4±0.67a	1.3±0.14b	1.36±0.18a	29.3±0.57d	36±2.65b	13.29±0.46a	10.67±0.97a
12	6.5±0.21a	6.5±0.26a	17.2±2.2a	14.9±0.81a	1.5±0.12b	1.38±0.17a	58.7±2.08b	41±14.00b	11.27±1.13b	10.83±0.79a
18	6.5±0.21a	6.6±0.17a	17.7±0.99a	14.8±0.80a	1.8±0.05a	1.25±0.18a	43.0±20.78c	47±23.00b	10.09±0.41b	11.95±1.31a
24	6.5±0.23a	6.5±0.15a	18.4±0.58a	15.7±1.10a	1.6±0.03b	1.42±0.17a	90.3±4.00a	54.7±6.81a	11.49±0.31b	11.15±1.44a
Initial value	6.6	6.7	15.0	13.5	1.3	1.01	19.6	15.3	11.31	13.37
P>F	.70	.93	.33	.50	.01	.87	.000003	.05	.04	.70

a, b, c, and d are indicating the mean values with significant difference P<0.05.

Table 3. Mean values with standard deviation of soil pH_{water}, C, N and P as well as C:N ratio in 0–20cm depth after the experiment in 2011 and 2012 as influenced by rates of NPK

NPK rates (kg/ha)	pH_{water}		C (g/kg)		N (g/kg)		P (mg/kg)		C:N	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
0	6.3±0.20a	6.6±0.17a	15.7±1.20a	13.8±2.33a	1.3±0.16a	1.3±0.34a	17.3±2.08a	18.7±7.23a	10.9±1.88a	10.9±1.25a
150	6.4±0.30a	6.6±0.36a	16.4±1.94a	14.0±1.55a	1.4±0.13a	1.3±0.06a	18.3±1.15a	46±36.5a	11.2±1.79a	10.4±0.97a
300	6.4±0.12a	6.5±0.35a	15.5±3.10a	13.0±0.87a	1.3±0.03a	1.2±0.09a	15.7±2.09a	27±15.7a	12.2±2.18a	10.9±0.84a
450	6.5±0.20a	6.4±0.20a	17.8±0.31a	14.6±1.16a	1.3±0.13a	1.4±0.20a	14.7±3.51a	30±12.5a	14.1±1.47a	10.4±1.16a
600	6.5±0.13a	6.3±0.17a	16.0±2.33a	14.0±1.91a	1.3±0.09a	1.4±0.11a	13.7±2.51a	46±33.6a	12.0±1.04a	9.9±0.57a
Initial value	6.6	6.7	15.0	13.5	1.3	1.01	19.6	15.3	11.3	13.4
P>F	.75	.60	.67	.85	.13	.58	.18	.57	.24	.67

a is indicating the mean values with no difference at P<0.05

Table 4. Significant changes in soil (0–20cm) contents of C, N and P as observed between the rates of sugarcane foam versus NPK fertilizer after the experiment in 2012

Foam (tha^{-1})	NPK ($kgha^{-1}$)	C-org (gkg^{-1})		N-total (gkg^{-1})		P-olsen ($mgkg^{-1}$)	
		Dif	**Pr**	**Dif**	**Pr**	**Dif**	**Pr**
12	150	0.85	.32	0.05	.63	17.67	.09
12	300	1.77	.04	0.22	.03	28.50	.008
12	450	-1.12	.89	0.11	.25	27.50	.009
18	300	1.95	.02	0.27	.008	23.67	.02
18	450	0.07	.93	0.16	.11	22.67	.03
24	150	1.87	.03	0.10	.29	40.17	.0003
24	300	2.78	.002	0.28	.006	51.00	<.0001
24	450	0.90	.29	0.17	.09	50.00	<.0001
24	600	2.07	.01	0.14	.16	42.50	.0001

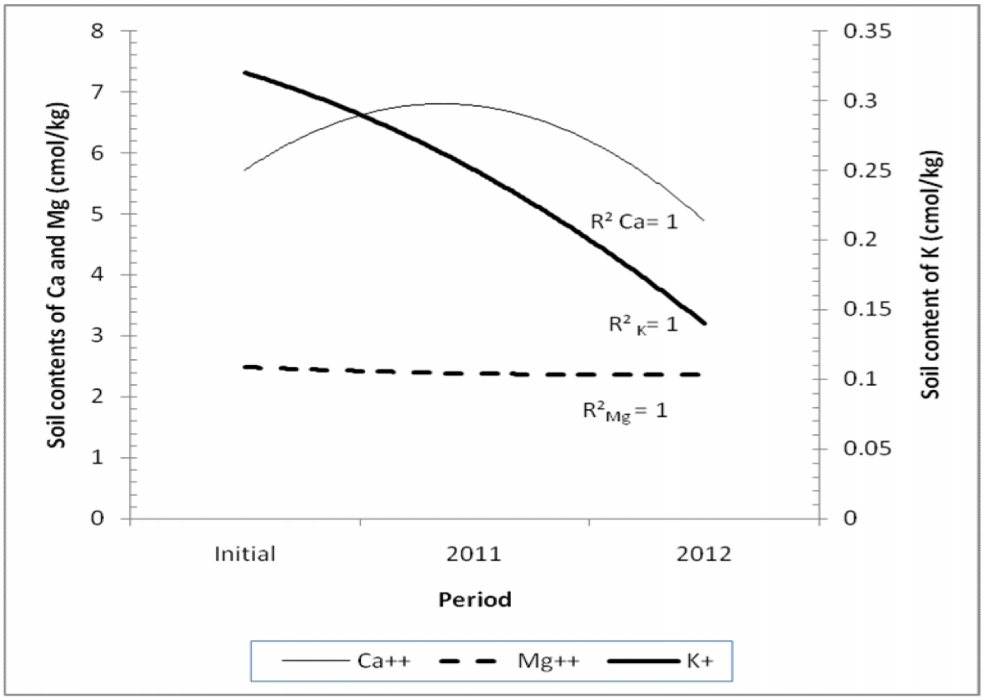

Fig. 2. Trends of soil exchangeable Ca, Mg and K during the study period under sugarcane foam effect

Table 5. Mean values of soil exchangeable K^+, Ca^{2+} and Mg^{2+}contents, and ratios of Ca:Mg and Mg:K in 0–20cm depth in 2011 and 2012 as influenced by rates of sugarcane foam

Foam rates (tha^{-1})	K^+ (cmol/kg)		Ca^{2+} (cmol/kg)		Mg^{2+} (cmol/kg)		Ca:Mg		Mg:K	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
0	0.34±0.15a	0.19±0.13a	5.5±0.47c	4.8±0.76a	1.9±0.45a	2.4±0.73a	3.1±0.88a	2.1±0.30a	5.9±1.07a	14.6±7.36a
6	0.26±0.07a	0.13±0.06a	6.2±1.27b	4.8±0.42a	2.2±0.55a	2.3±0.63a	3.1±1.21a	2.2±0.47a	9.4±4.22a	21.4±13.6a
12	0.32±0.10a	0.16±0.08a	5.8±0.11c	5.1±0.83a	2.4±0.66a	2.5±0.57a	2.5±0.67a	2.1±0.13a	8.0±3.56a	16.6±3.54a
18	0.21±0.01a	0.15±0.03a	8.1±0.91a	5.0±0.64a	2.4±0.56a	2.6±1.25a	3.6±0.85a	2.1±0.69a	11.2±3.00a	17.3±8.27a
24	0.20±0.04a	0.10±0.06a	6.6±0.36b	4.7±0.60a	2.5±0.29a	2.1±0.59a	2.6±0.39a	2.3±0.37a	13.0±3.12a	27.4±17.7a
Initial value	0.29	0.37	5.3	5.0	2.5	2.3	2.1	2.4	8.3	7.0
P>F	.27	.68	.02	.94	.70	.93	.61	.93	.13	.67

a, b and c are indicating the mean values with significant difference at $P < 0.05$.

Table 6. Mean values of soil exchangeable K^+, Ca^{2+} and Mg^{2+} content and the ratios of Ca:Mg and Mg:K in 0–20cm depth in 2011 and 2012 as influenced by the rates of NPK

NPK rates (kg/ha)	K^+ (cmol/kg)		Ca^{2+} (cmol/kg)		Mg^{2+} (cmol/kg)		Ca : Mg		Mg : K	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
0	0.34±0.15a	0.20±0.13a	5.6±0.48a	4.8±0.76a	1.9±0.45a	2.4±0.73a	3.1±0.90a	2.1±0.30a	5.9±1.07a	14.6±7.36a
150	0.37±0.14a	0.21±0.15a	5.1±0.24a	4.8±0.72a	2.4±0.60a	2.3±0.52a	2.2±0.60a	2.2±0.18a	6.9±2.11a	18.4±17.1a
300	0.25±0.03a	0.15±0.06a	5.8±0.62a	4.4±0.52a	2.3±0.13a	1.9±0.44a	2.5±0.33a	2.4±0.48a	9.3±1.44a	13.6±5.87a
450	0.36±0.09a	0.19±0.11a	6.0±0.73a	4.9±0.32a	2.4±0.65a	2.3±0.61a	2.7±1.01a	2.2±0.82a	6.8±2.5a	14.2±5.05a
600	0.50±0.12a	0.17±0.05a	6.2±1.67a	4.6±0.42a	2.1±0.68a	2.4±1.22a	3.2±1.25a	2.1±0.70a	4.6±2.61a	13.4±2.49a
Initial value	0.29	0.37	5.3	5.06	2.5	2.3	2.1	2.4	10.3	7.0
P>F	.20	.97	.61	.92	.75	.91	.65	.95	.15	.96

a is indicating the mean values with no significant difference at $P < 0.05$.

Table 7. Significant changes in soil (0–20cm) contents of Ca^{2+}, Mg^{2+}, and K^+ as observed between rates of sugarcane foam versus NPK after the experiment in 2012

Foam (t/ha)	NPK (kg/ha)	Ca (cmol/kg)		Mg (cmol/kg)		K (cmol/kg)	
		Dif	Pr	Dif	Pr	Dif	Pr
6	600	0.28	.51	-0.008	.98	-0.14	.01
18	150	1.57	.001	0.16	.64	-0.11	.06
18	300	1.42	.002	0.38	.29	-0.02	.69
18	450	1.11	.010	0.16	.64	-0.09	.09
18	600	1.11	.010	0.22	.53	-0.16	.006
24	150	0.72	.09	-0.02	.96	-0.14	.02
24	450	0.25	.56	-0.02	.95	-0.12	.03
24	600	0.25	.55	0.04	.91	-0.19	.001

Dif : difference, Pr : probability

4. DISCUSSION

4.1 Quality of Sugarcane Foam

At least, 54kg N, 20kg P_2O_5 and 56kg K_2O are lost annually from one hectare agricultural lands in Africa [23]. The loss of P_2O_5 can be replenished with application of only 6t/ha of sugarcane foam Table 1. However, 10t/ha of this raw material was required for soil N recapitalization and a greater rate of 44t/ha was necessary for the replenishment of soil K_2O content. Compared with the recommended rate of 12t/ha for organic amendment of the soils in Africa [15], the use of the sugarcane foam could be a limited organic source of K for agriculture. Although low K^+ concentration of 2.3–4% in the cane juice has been reported [24], the concentration of K^+ (<5g/kg) was also low in the sugarcane foam compared with the values observed in other vegetal raw materials [25]. Regarding the high initial soil content of K^+ (0.30cmol/kg) which was considered sufficient for most crop nutrition, we presume a low efficiency of K^+ nutrition in sugarcane production in the studied agro-ecosystem. Such constraint related to low K-use efficiency in sugarcane needs to be addressed in future studies.

In contrast, the high concentrations of Mg^{++} and Ca^{++} in the sugarcane foam, can improve colloid formation in the soil [26]. Monovalent cations (K^+ and Na^+) have breaking up effect on soil colloid in contrast with that of Mg^{++} and Ca^{++}. Therefore, we assume that the chemical composition of sugarcane foam can contribute to the improvement of soil structure affecting positively water and mineral uptake by the crops [27]. This assertion is supported by the work done by Perez-de-los-Reyes et al. [28]. Furthermore, this potential effect of sugarcane foam on soil colloidal properties could be crucial in managing humid tropical agro-ecosystems where the strongest weathering conditions of the soils prevail. Although the use of compost can be recommended in such conditions [29], the comparative advantage for the use of sugarcane foam was that no pre-treatment was required, making it easier and cheaper to use by smallholder farmers.

We can infer therefore, from this study that sugarcane foam is an affordable source of nutrients with high potential of maintaining soil fertility through the supply of nutrients, especially N, P, Ca and Mg. Thus, the study expounded on the knowledge of recycling of industrial waste such as sugarcane foam, a bi-products of sugar industry that could be recommended for enhancing environmental protection [30]. In addition, this study will motivate farmers to practice organic amendment particularly in Zuénoula, the location of the study, where 19,000–20,000 tonnes of sugarcane foam are disposed off annually by the sugar industry.

4.2 Soil Fertility Potential of Sugarcane Foam

The enhanced soil N content from the initial 1.3 to 1.8g/kg observed with application of 18 t/ha sugarcane foam treatment compared with the control plots without foam or plots treated with NPK (300kg/ha) fertilizer indicated the potential benefit of using this organic waste for crop production. The difference was ranging from 0.05 to 0.2gN/kg when applying 12t/ha of sugarcane foam although, only 1/100 of N could be released at the initial stage of foam mineralization as consequence of slowness of this process according to edaphic and climatic conditions and can occur as long as possible [27,31,32]. Further loss of N could have occurred as consequence of leaching process resulting to the high rain fall recorded during the experimentation (1115.3mm and 1295.1mm). These facts can justify the application of higher rate of 18t/ha instead of 12t/ha to increase significantly soil content of N in spite of the losses, as observed in 2011 during the actual study Table 2. In fact, optimum increase of soil content of N by application of sugarcane foam when compared with 300kg/ha NPK was observed for 18t/ha (0.27g N/kg) in the current study Table 4.

Despite the high concentrations of Ca^{++} and Mg^{++} in the foam, up to 18t/ha was required to cause positive difference in soil content of Ca^{++} compared with the effect of the rates of NPK studied. However, the best rate of sugarcane foam to restore soil contents of Ca^{++} and Mg^{++} should be based on Mg:K (2:3) ratio to give the optimum balance of these nutrients in the soil for crop production [33].

Our study indicated that sugarcane foam could be a good alternative source of N and Ca for agricultural purpose when applied at 18t/ha. This rate could contribute to increasing the potential of Sub-Saharan Africa agro-ecosystems where nitrogen deficiency is widespread [34] coupled with soil acidification caused by excessive leaching of cations [35]. Therefore, the use of sugarcane foam could be recommended for amending acidic soils (pH<5.5) characterized by P-deficiency [36] with application of only 6 t/ha of sugarcane foam that was found to release 22kg P/ha needed to meet the P requirement of some cereal crops [37].

However, the use of sugarcane foam could increase K and Mg deficiencies in cultivated soil, especially, in the humid forest agro-ecosystem of Africa [33]. In fact, soil Mg content remained stable under the effect of the sugarcane foam during the experimentation, while there was a decreasing soil K content compared with that of the other nutrients which were increased in 2011 before declining in 2012. This decreasing soil K content observed under the effect of the sugarcane foam could be a consequence of excess of microbial population in the soil, consuming some of the available nutrients especially K for their energy sources [38]. This might suggest that sugarcane foam should not be applied twice in successive years to rationalize microbial population to maintain the advantage induced by the first application of the foam as observed in 2011. If confirmed by further studies that the application of 18t/ha of the foam be recommended for two cropping seasons, the best strategy could be an annual application of 9t/ha of the foam instead of the recommended 12t/ha for organic matter for agricultural purpose. It is envisaged that as previously recommended for semiarid Mediterranean region [39]. The foam of sugarcane will be more available as organic source of nutrients for agriculture land improvement thereby reducing farmers' labor by half in Sub-sahara Africa. Further studies would also be needed to evaluate the integrated use of sugarcane foam and mineral fertilizer to supply the needed macronutrients such as K and Mg that were limited in the use of sugarcane foam.

5. CONCLUSION

The study has revealed the potential for use of sugarcane foam to restore the fertility of tropical Cambisols especially to supply N, P and Ca after long-term cultivation using only inorganic NPK fertilizer. The application of 18t/ha was recommended, likely for two successive cropping seasons, but would need to be augmented with mineral K and Mg which are in limited supply in the sugarcane foam for crop production in the humid forest agro-ecosystem of West Africa that are prone to Mg and K deficiencies. .

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COMPETING INTERESTS

The authors have declared no existing competing interests exit.

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