

Effects of the Foam of Sugarcane (*Sacharum officinarum* L.) and Inorganic Fertilizer on the Chemical Characteristics of a Tropical Cambisol

ABSTRACT

Aim: For promoting an alternative source of nutrients for the restoration of 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 management, effects of sugarcane foam and inorganic fertilizer were assessed on a Cambisol.

Design: the study was laid out in a randomized complete blocks design.

Place and duration: In the forest/savanna transition zone of Côte d'Ivoire, the study was conducted at Zuenoula during the cropping seasons of 2011 and 2012.

Methodology: The soil was tilled and the different rates of Foam (0, 6, 12, 18 and 24 t/ha) and that (0, 150, 300, 450 and 600 kg/ha) NPK + Mg+S (18% - 9% - 14% - 2% - 2.5%) were incorporated in the soil.

Results: The foam has significantly ($p < .05$) affected soil contents of C, N, P and somewhat that of Ca^{++} with the most increase for 6 t/ha (C and P) and 18 t/ha (N and Ca^{++}) than that induced by 300 kg/ha and 600 kg/ha NPK according to variables.

Conclusion: Applying 18 t/ha of foam at once for two cropping seasons was deemed suitable for improving the quality of soils with N and P deficiencies but not for K^+ and Mg^{++} deficiencies prone agro-ecosystems. Applying 18 t/ha for two cropping years appeared as new and more economic strategy for the use of organic matter in agriculture.

Keywords: Sugarcane foam, organic matter, inorganic fertilizer, soil chemical characteristics

1. INTRODUCTION

Industrial agriculture requires intensification of agro-systems consisting essentially to a continue monoculture in most of the cases. However, such cropping system is well known for its degrading effect in the soils, inducing yield declining during successive cropping seasons, especially in the humid tropical zone [1]: Beside soil nutrients leaching, there are acidification and reducing organic matter content in the soil.

In the western centre of Côte d'Ivoire (West Africa), thirty years ago, land (Ferralsols and Cambisols) intensification for sugarcane production was occurring, and there is yield declining which is affecting the economy of sugar manufactures. There is requirement of soil fertility restoration. The use of inorganic fertilizer has limited effect, probably, due to leaching, unbalanced mineral in soil and the low compensation of exported nutrients [2, 3, 4]. In fact, the available chemical fertilizers (compound of

NPK) in the local market didn't always contained the micro-nutrients deficient in soil and the balance of their chemical elements may be unsuitable as site specific soil mineral diagnostic is often missing. Up to date, there is no adopted canvas of site specific fertility management [5], resulting an haphazardly use of chemical fertilizer [6]: only NPK + (Mg and S) fertilizer is used for sugarcane production in long-term meanwhile, soil deficiencies of Fe and Zn as well as excess of Mn are also characterizing tropical soil chemical degradation under continue cropping [1] in addition to soil erosion and compaction as consequences of the structural degradation [7, 8].

Organic amendment can improve soil structure and its nutrient exchangeable capacity in addition to its increasing effect on soil nutrient contents *via* mineralization [9, 10, 11, 12, 13, 14]. However, up to 12tha⁻¹ is required for optimum use of organic matter in agriculture [15], hence, the availability of organic matter is limiting this practice [16]. Indeed, only the animal manure which is already limited can be entirely available for agricultural purpose while, 90% of crop residue is use for domestic purposes in Africa [17].

About 19 tones of foam are annually available at Zuenoula in Côte d'Ivoire as derived product of sugarcane manufacture. This biowaste can be used for amending agricultural lands, hence, increasing the availability of organic source of nutrients [10]. In fact, a tone of sugarcane foam contains about 7 kg of nitrogen, 9 kg of phosphorus, 8.5 kg of Calcium and 20 kg of silicon [18].

However, there is little knowledge of this practice on tropical Cambisol, especially in the agro-ecosystems of Côte d'Ivoire. This shortage of knowledge can induce irrational use of sugarcane foam for the amendment of agricultural lands regarding to its silicon concentration that can enhance soil P bioavailability [19] and reducing Mn and Al toxicities in the soil [20] in addition to the release of 7 kgN/kg, 9 kgP/kg and 8.5 kgCa/kg. Thus, we assume the possibility to identify a low optimum rate (< 12 t/ha) of sugarcane foam for agricultural soil amendment.

The actual study was initiated to investigate the effects of different rates of the foam of sugarcane on a Cambisol affected by long-term cultivation in Zuenoula area under inorganic fertilizer (NPK) management.

2. MATERIAL AND METHODS

2.1. Site of experimentation

The study was conducted in 2011 and 2012 in the experimental station of the sugar manufacture of Zuénoula (7° 38' 53" N, 6° 9' 46" W, 218 m), in Côte d'Ivoire. It is a transition zone of forest and savanna. The rain fall pattern is bimodal with 1115.3 mm and 1295.1 mm recorded in 2011 and 2012 respectively with the average annual temperatures of 32.9°C and 32.4°C.

2.2. Studied soil

The soil of the experimental site is a deep (> 120 m) 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 is a silty-clay (36% and 33% respectively), stony (75%) with 40% - 70% of exchangeable cation saturation and 19 cmol/kg of cation exchangeable capacity. This soil was continuously under sugarcane cultivation during five years with annual application of 600 kg/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 next cropping.

2.3. Foam of sugarcane

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

2.4. Experiment layout and soil sampling

About 4518 m² of bush fallow was cleaned manually and the soil was sampled in 0 – 20 cm at the four corners and the centre of the plot using an augur. The five soil samples were mixed in order to take a composite soil sample of 500 g for site initial characterization before the experiment.

A tractor was used for soil tillage before setting 9 micro-plots (10 m × 7.5 m) in 3 replications according to a complete randomized blocks design.

In 2011 and 2012, five rates (0, 6, 12, 18 and 24 t/ha) of foam and four rates (150, 300, 450 et 600 kg/ha) of inorganic fertilizer composed of NPK + Mg + S (18.5% – 9% – 14% – 2 – 2.5) were applied every year incorporating them in 0 – 10 cm depth. The micro-plots were left under weather and biotic conditions of the site.

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

2.5. Laboratory analysis

Soil samples were sun dried, grounded and sieved (2 mm) 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 carbon-C (Wakley and 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 NH₄OAc (pH 7.0)) 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

Analyse of variances (ANOVA) of soil characteristics (N, P, K, Ca, Mg, Ca:Mg, Mg:K and CEC) was performed to compare the mean values for different rates of sugarcane foam and inorganic fertilizer respectively for every year of experiment and across years. The differences between the mean values of these variables as induced by different rates of inorganic fertilizer and sugarcane foam respectively, was 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 $\alpha = 0.05$.

3. RESULTS

3.1. Chemical characteristics of the soil and sugarcane foam

Table 1 reports the chemical composition (N, P, K, Ca and Mg) of the studied foam. There are high concentrations of Ca^{++} and Mg^{++} in the order of 2 to 20 times higher than the normal range respectively. Phosphorus (P) concentration (0.25 – 4 g/kg) is also high meanwhile, that of N (2.8 – 5.6 g/kg) is likely normal and low concentration of K (< 2.5 g/kg) is noticed.

Table 1 : Sugarcane foam concentration of N, P, K, Mg and Ca as well as soil chemical characteristics in 0 – 20 cm 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 studied soil content of nutrients (K^{+} , Ca^{++} and Mg^{++}) and its CEC were at high level with a value of +1.2 for ΔpH (Table 1). In spite of a moderate acidity, important 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 in C (> 10 g/kg) and N (> 1 g/kg) are observed, inducing an acceptable C/N ratio (11.5).

3.2. Treatment effects on soil pH, P, N and C/N

Tables 2 and 3 show the mean values of soil (0 – 20 cm) pH, C, N and P as well as for C:N ratio induced by the experiment in 2011 and 2012 for the different rates of foam and NPK respectively.

133 Except for soil pH, there is significant effects ($p<.05$) of foam treatment contrasting with that of inorganic
134 fertilizer which did not also affect significantly soil content of C in 2012.

135 Indeed, a significant increase of soil content in C is observed at least for the application of foam at 6
136 t/ha in 2011 and 12 t/ha in 2012. The minimum rate of 18 t/ha is required for significant increase of soil
137 content of N in 2011 while no significant difference was observed between the mean values of this
138 variable in 2012 (Table 2). Further significant increases of soil content of P and C:N ratio were observed
139 when applying 6 t/ha in 2011 whereas, 18 t/ha was required for increasing C:N ratio in 2012.

140 Effects of inorganic fertilizer (NPK) on studied soil parameters are presented in Table 3. There is no
141 significant difference between the mean values recorded for the different rates of NPK except for soil
142 content of C in 2011 showing a significant increase when applying 450 kg/ha.

143 Significant difference between the overall effects of the rates of foam and NPK are summarized in Table
144 4 for soil contents of C, N and P. There are positive differences induced by the rates (> 6 t/ha) of foam,
145 particularly, when compared with 300 and 600 kg/ha of NPK.

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163 **Table 2 :** Mean values with standard deviation of soil pH_{water}, C, N et P as well as C : N ratio in 0 – 20 cm depth after trial in 2011 and 2012
 164 according to the rates of the foam

Foam rates (tha ⁻¹)	pH		C (gkg ⁻¹)		N (gkg ⁻¹)		P (mgkg ⁻¹)		C:N	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
0	6.3a±0.20	6.6a±0.17	15.7a±1.20	13.8a±2.33	1.4a±0.17	1.29a±0.34	17.3a±2.09	18.7a±7.23	10.92a±1.88	10.89a±1.25
6	6.4a±0.15	6.5a±0.06	17.6b±1.20	14.4a±0.67	1.3a±0.14	1.36a±0.18	29.3b±0.57	36b±2.65	13.29b±0.46	10.67a±0.97
12	6.5a±0.21	6.5a±0.26	17.2a±2.2	14.9b±0.81	1.5a±0.12	1.38a±0.17	58.7d±2.08	41b±14.00	11.27a±1.13	10.83a±0.79
18	6.5a±0.21	6.6a±0.17	17.7b±0.99	14.8b±0.80	1.8b±0.05	1.25a±0.18	43.0c±20.78	47b±23.00	10.09a±0.41	11.95b±1.31
24	6.5a±0.23	6.5a±0.15	18.4b±0.58	15.7b±1.10	1.6a±0.03	1.42a±0.17	90.3e±4.00	54.7c±6.81	11.49a±0.31	11.15b±1.44
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	.0001	.02	.001	.29	.000002	.0006	.03	.048

a, b, c, d, and e are indicating the mean values with significant difference.

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173 **Table 3.** Mean values with standard deviation of soil pH_{water}, C, N and P as well as C : N ratio in 0 – 20 cm depth after the experiment in 2011 et
 174 2012 according to the rate of NPK

NPK rates (kg/ha)	pH		C (gkg ⁻¹)		N (gkg ⁻¹)		P (mgkg ⁻¹)		C:N	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
0	6.3a±0.20	6.6a±0.17	15.7a±1.20	13.8a±2.33	1.3a±0.16	1.3a±0.34	17.3a±2.08	18.7a±7.23	10.9a±1.88	10.9a±1.25
150	6.4a±0.30	6.6a±0.36	16.4a±1.94	14.0a±1.55	1.4a±0.13	1.3a±0.06	18.3a±1.15	46a±36.5	11.2a±1.79	10.4a±0.97
300	6.4a±0.12	6.5a±0.35	15.5a±3.10	13.0a±0.87	1.3a±0.03	1.2a±0.09	15.7a±2.09	27a±15.7	12.2a±2.18	10.9a±0.84
450	6.5a±0.20	6.4a±0.20	17.8b±0.31	14.6a±1.16	1.3a±0.13	1.4a±0.20	14.7a±3.51	30a±12.5	14.1a±1.47	10.4a±1.16
600	6.5a±0.13	6.3a±0.17	16.0a±2.33	14.0a±1.91	1.3a±0.09	1.4a±0.11	13.7a±2.51	46a±33.6	12.0a±1.04	9.9a±0.57
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	.04	.85	.13	.58	.18	.57	.24	.67

a, and b are indicating the mean values with significant difference

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

Foam (tha ⁻¹)	NPK (kg ha ⁻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

However, Fig.1 highlights quadratic trends for studied soil parameters from the initial value to the end of the experiment (2012) under the effect of the foam treatment. Most decreasing trends were observed for soil pH and its content of C from 2011 to 2012 (Fig.1a) compared with the trends observed for P and N (Fig.1b).

3.3. Effects of treatments on soil exchangeable cations

Significant ($p < .05$) effects of foam treatment are observed only in 2011, especially on soil contents of Ca and Mg as well as for the ratio of Mg:K in the soil. Significant increases are observed for soil contents of Ca and Mg for the rates of 18 t/ha and 24 t/ha respectively (Table 5). Except for the ratio of Ca:Mg in the soil, there is no significant effect of treatment NPK was observed in 2011 and 2012 (Table 6). A significant increase of this parameter is only observed for the rate of 300 kg/ha (9.3) while no significant difference is noticed between the mean values of the control plot (0 kg/ha of NPK) and the other rates (150, 450 and 600 kg/ha of NPK) applied.

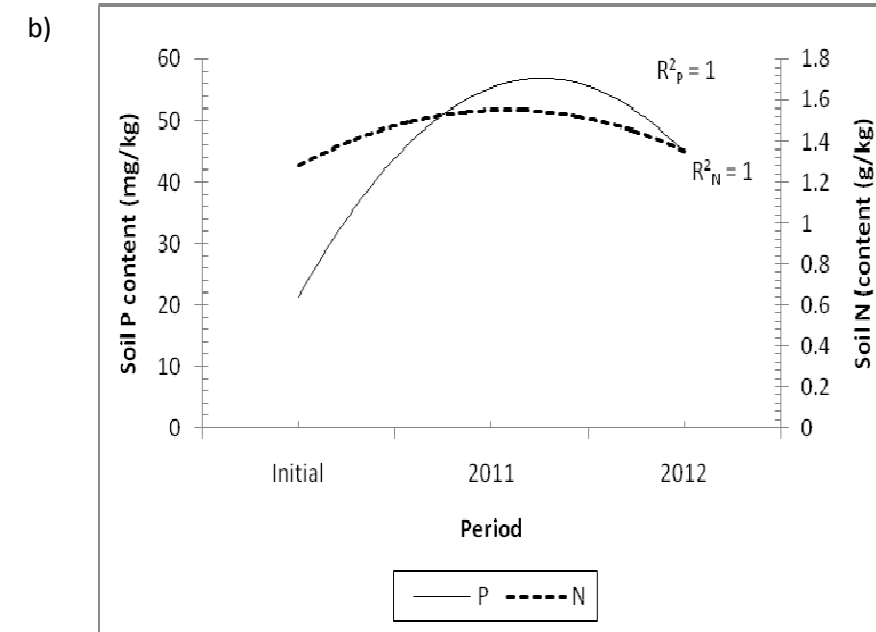
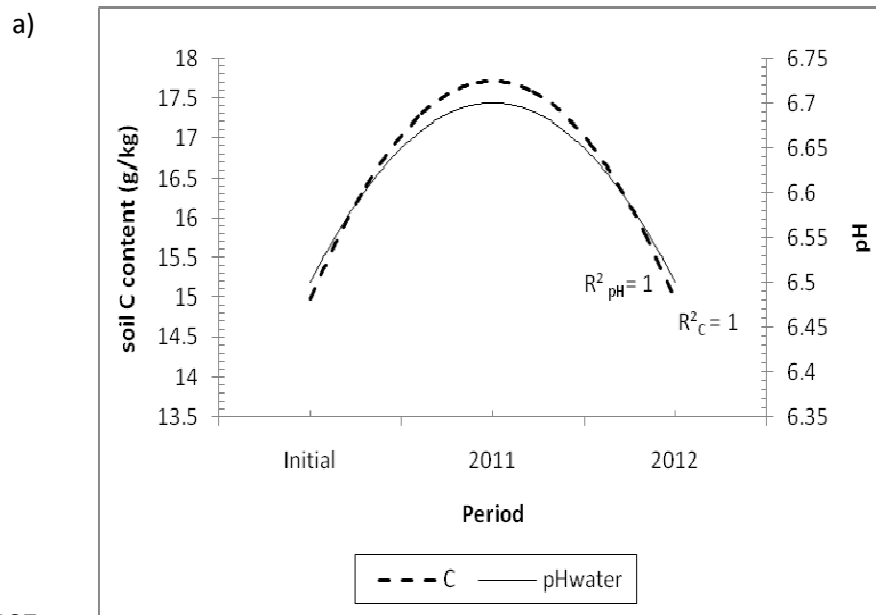


Fig. 1 : Trends of soil pH_{water} and content of C (a) as well as its contents of P and N (b) along the study duration under foam effect

205 **Table 5** : Mean values of soil contents of K^+ , Ca^{2+} and Mg^{2+} as well as the ratios of Ca : Mg and Mg : K in 0 – 20 cm depth in 2011 and 2012
 206 according to the rates of 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	0.34a±0.15	0.19a±0.13	5.5a±0.47	4.8a±0.76	1.9a±0.45	2.4a±0.73	3.1a±0.88	2.1a±0.30	5.9a±1.07	14.6a±7.36
6	0.26a±0.07	0.13a±0.06	6.2a±1.27	4.8a±0.42	2.2a±0.55	2.3a±0.63	3.1a±1.21	2.2a±0.47	9.4a±4.22	21.4a±13.6
12	0.32a±0.10	0.16a±0.08	5.8a±0.11	5.1a±0.83	2.4a±0.66	2.5a±0.57	2.5a±0.67	2.1a±0.13	8.0a±3.56	16.6a±3.54
18	0.21a±0.01	0.15a±0.03	8.1b±0.91	5.0a±0.64	2.4a±0.56	2.6a±1.25	3.6a±0.85	2.1a±0.69	11.2b±3.00	17.3a±8.27
24	0.20a±0.04	0.10a±0.06	6.6b±0.36	4.7a±0.60	2.5b±0.29	2.1a±0.59	2.6a±0.39	2.3a±0.37	13.0b±3.12	27.4a±17.7
Initial value	0.29	0.37	5.3	5.0	2.5	2.3	2.1	2.4	10.3	7.0
P>F	.27	.68	.01	.94	.04	.93	.61	.93	.02	.67

a, and b are indicating the mean values with significant difference

207 **Table 6** : Mean values of soil contents K^+ , Ca^{2+} and Mg^{2+} as well as the ratios of Ca : Mg et Mg : K in 0 – 20 cm depth in 2011 and 2012 according
 208 to the rates of NPK

NPK rates (kg/ha)	K^+ (cmol/kg)		Ca^{2+} (cmol/kg)		Mg^{2+} (cmol/kg)		Ca : Mg		Mg : K	
	201	2012	2011	2012	2011	2012	2011	2012	2011	2012
0	0.34a±0.15	0.20a±0.13	5.6a±0.48	4.8a±0.76	1.9a±0.45	2.4a±0.73	3.1a±0.90	2.1a±0.30	5.9a±1.07	14.6a±7.36
150	0.37a±0.14	0.21a±0.15	5.1a±0.24	4.8a±0.72	2.4a±0.60	2.3a±0.52	2.2a±0.60	2.2a±0.18	6.9a±2.11	18.4a±17.1
300	0.25a±0.03	0.15a±0.06	5.8a±0.62	4.4a±0.52	2.3a±0.13	1.9a±0.44	2.5a±0.33	2.4a±0.48	9.3b±1.44	13.6a±5.87
450	0.36a±0.09	0.19a±0.11	6.0a±0.73	4.9a±0.32	2.4a±0.65	2.3a±0.61	2.7a±1.01	2.2a±0.82	6.8a±2.5	14.2a±5.05
600	0.50a±0.12	0.17a±0.05	6.2a±1.67	4.6a±0.42	2.1a±0.68	2.4a±1.22	3.2a±1.25	2.1a±0.70	4.6a±2.61	13.4a±2.49
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	.03	.96

a, and b are indicating the mean values with significant difference

But significant and positive differences are observed between mean values of soil content of Ca^{++} when comparing the effect of 18 t/ha of the foam with all the studied rates of NPK. In the same manner, negative differences are significantly observed for soil K^+ content between the mean value of 24 t/ha as foam treatment and that of all the rates applied as NPK treatment. No significant difference is observed for soil content of Mg^{++} (Table 7). Indeed, there is decreasing trend of soil content of K^+ and a stable level of Mg^{++} in the soil under the effect of foam treatment during the experiment (Fig. 2).

Table 7 : Significant changes in soil (0 – 20 cm) as observed between different rates of Foam and NPK after experiment according to soil contents of Ca, Mg and K

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

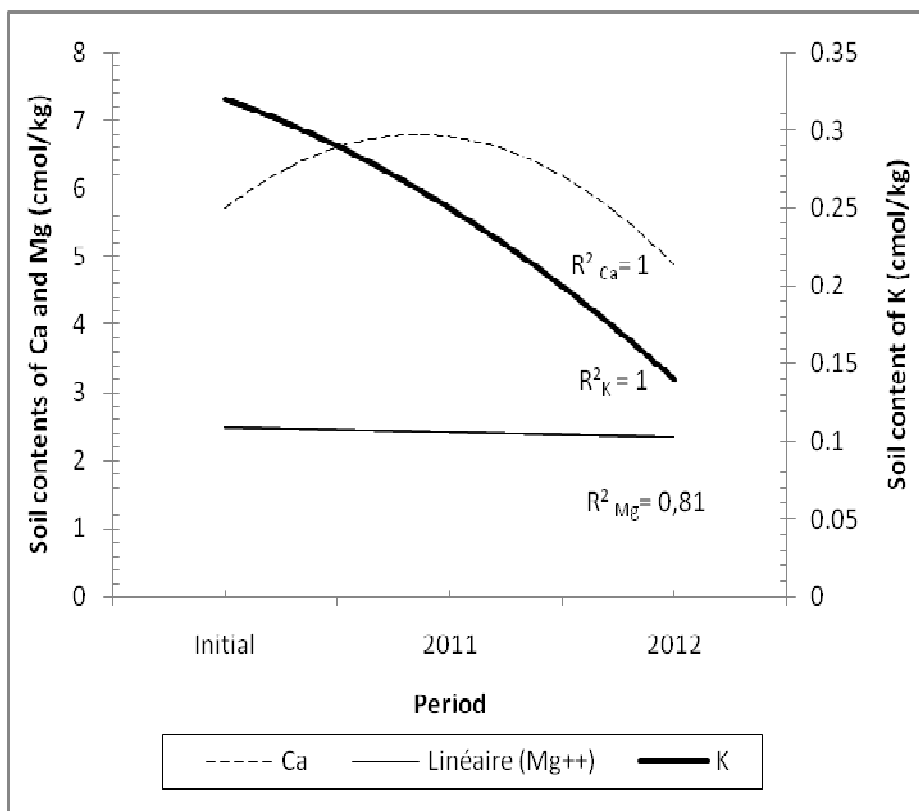


Fig. 2 : Trends of soil contents of Ca, Mg and K along the study duration under foam effect

4. DISCUSSION

4.1. Quality of sugarcane foam

At least, 54 kg N, 20 kg P_2O_5 and 56 kg K_2O are annually lost from agricultural lands in Africa [23]. These lost can be balanced for P_2O_5 with only 6 t/ha of sugarcane foam (Table 1). However, 10 t/ha of this raw material is required for soil N recapitalization and a greater rate of 44 t/ha is necessary for the replenishment of soil K_2O content. Comparing with the recommended rate of 12 t/ha for organic amendment of the soils in Africa [15], the use of the sugarcane foam can be a restricted strategy as organic source of K for agriculture. Despite of the low concentration of 2.3 – 4% of K^+ in the cane juice [24], low concentration of K (< 5 g/kg) was also determined in the foam as a particular result comparing with that observed in other vegetal raw materials [25]. Regarding to the high initial soil content of K^+ (0.30 cmol/kg) which was suitable for most of the crop nutrition (Table 1), we presume a low efficiency of K^+ nutrition in sugarcane cropping in the studied eco-system. Such constraint related to nutrient use efficiency needs to be tackled by future study.

In return, the high concentrations of Mg^{++} and particularly of Ca^{++} in the foam, can improve colloid formation in the soil [26]: Monovalent cations (K^+ and Na^+) have breaking up effect on soil colloid contrasting 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 sugar foam on soil colloid as considered can be crucial in managing humid tropical agro-ecosystems where strongest weathering conditions of the soils are prevailing. Although compost use can be recommended in such conditions [29], no pre-treatment is required for the use of the sugarcane foam as a comparative advantage.

We drew from these analyses the fact that sugarcane foam is an affordable source of nutrients with high potential of maintaining soil fertility and its chemical restoration, especially for N, P, Ca and Mg. This point is a significant improvement of the knowledge concerning the recycling of industrial waste that is recommended for environment protection [30] and additional motivation for the practice of organic amendment in the tropical soils, especially in the location of Zuenoula, where about 19 – 20 000 tonnes of sugarcane foam are left on the ground annually.

4.2. Foam effects on soil potential fertility

More increase of soil content of N was observed for the treatments of foam compared with the control plot and the effect of the treatments NPK respectively: The difference was ranging from 0.1 to 0.2 g N/kg when applying 12 t/ha of foam in spite of the slowness of the mineralization process releasing only about 670 g N of 67 kg N at the initial stages, while this process can occurred as long as possible according to the edaphic and climatic conditions [27, 31, 32]. Further lost of N could occurred as consequence of leaching process resulting to the high rain fall recorded during the experimentation (1115.3 mm and 1295.1 mm). These facts can justify the application of higher rate of 18 t/ha instead of 12 t/ha to increase significantly soil content of N in spite of the lost, as observed during the actual study (Table 4). However, the increase of soil content of N as induced by 12 t/ha (0.22 g N/kg) and 18 t/ha (0.27 g N/kg) of foam compared with the effect of 300 kg/ha of NPK are almost similar in the current study.

Despite of the high concentrations of Ca^{++} and Mg^{++} in the foam, up to 18 t/ha was also required for inducing positive difference in soil content of Ca^{++} compared with the effect of the studied rates of NPK while similar effects was observed for soil content of Mg^{++} when applying 24 t/ha. However, the best rate of foam when restoring soil contents of Ca^{++} and Mg^{++} should be according to Mg:K ratio in order to fit the optimum balance (2:3) of these nutrients which was not suitable initially.

According these analyses, the foam of sugarcane can be a good alternative source of N and Ca for agricultural purpose when applied at 18 t/ha. This output can contribute for increasing the potential of Sub-Saharan Africa agro-ecosystems where nitrogen deficiency is widespread [33] coupled with soil acidification as result of cations leaching [34]. Moreover, the application of 6 t/ha of foam has significantly increase soil content of available-P and this effect was higher for 12 t/ha was higher than that of 300 kg/ha and 450 kg/ha of inorganic fertilizer (NPK). As consequence, the use of sugarcane foam can be recommended for amending acidic soils ($\text{pH} < 5.5$) characterized by P-deficiency [35]: applying 6 t/ha of foam can release 22 kgP/ha to meet the requirement of some cereal crops [36].

However, the use of sugarcane foam could increase K and Mg deficiencies in cultivated soil, especially, in the humid forest zone of Africa [37]. In fact, soil content of Mg remained stable under the effect of the foam during the experimentation while most decreasing trend was observed for soil content of K compared with that of the other nutrients which were increased in 2011 before declining in 2012 (Fig. 1 and 2). The decreasing of soil nutrient contents as observed under the effect of the foam can be a consequence of excess of microbial population in the soil, consuming more available nutrients in soil for recovering energy for their activities [38]. This assumption coupled with the results in Fig.1 can justify the fact that sugarcane foam should not be applied twice in successive years for optimizing microbial population, hence, saving the advantage induced by the first application of foam as observed in 2011 during the experiment. If confirmed by further study, the application of 18 t/ha of foam will be

recommended for two cropping seasons. This strategy will be related to 9 t/ha of foam per year instead of 12 t/ha for organic matter as already recommended for agricultural purpose. Then, the foam of sugarcane will be more available as organic source of nutrients for agriculture land improvement when reducing farmers' labor by half in Sub-sahara Africa and semiarid Mediterranean region [39].

5. CONCLUSION

The study has revealed highest potential of sugarcane foam to restore Cambisol fertility after long-term cultivation compared with inorganic NPK fertilizer, especially for N, P and Ca supplying. For this purpose, the application of 18 t/ha is recommended, likely for two successive cropping seasons.

However, the use of sugarcane foam is less suitable for soil amendment in the humid forest ecosystems of West Africa prone Mg and K deficiencies.

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COMPETING INTERESTS

The authors declare no existing competing interests.

AUTHORS' CONTRIBUTIONS

Dr Brahima KONE has conceived the protocol of this study and has supervised this report which was entirely conducted by Bouadou oi Bouadou Felix. Yao Kouakou and Prof Yao-Kouame Albert have contributed to writing the paper.

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