Incorporation of Crop Residues into Soil: A Practice to Improve Soil Chemical Properties

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Abstract

Crop residues have the potential to enhance soil fertility, but this is dependent on their biochemical properties. This study aimed to evaluate the chemical composition, and nutrients release patterns of selected crop residues (corn stalk, rice straw, millet straw and sorghum stalk). Thus, 20 g of each crop residue were put in litter bags and placed in a plastic pot containing 10 kg of soil with a moisture content of 40% - 60%. Five replications were considered per type of residue and some samples were taken every 4 weeks. Results showed that crop residues got a pH varying between 5.09 and 6.5. The lowest C content (33.11%) and nitrogen (0.27%) were measured in sorghum stalk when the highest C content (47.6%) and nitrogen content (0.55%) were registered in corn stalk. The highest phosphorus content (0.58%) was got in corn stalk. Potassium content was higher in millet straw than in others. The highest calcium content (0.37%) and magnesium (0.29%) were found in rice straw. There was an increase of soil chemical composition after crop residues burial. Significant increase in carbon, nitrogen, and phosphorus content was noted in soil at week 4 with the highest at week 16. At the end of the experiment, the highest C content (53.1%) and the highest nitrogen content (0.88%) in the soil were observed after burial of rice straw. The highest phosphorus content (0.82%) registered in the soil was got with millet straw. Nutrient release efficiency of crop residues occurred in the following order: rice straw > millet straw > sorghum stalk > corn stalk. This study has demonstrated that rice straw and millet straw released nutrients faster and this is beneficial for early planted crops, while sorghum stalk and corn stalk released nutrients slowly which is appropriate for long-term availability of plant nutrients.

1. Introduction

In tropical countries, the problems of physical degradation of cultivated soils are alarming. Indeed, accentuated by climatic disturbances [1], erosion is more and more aggressive and rapid, thus causing the establishment of ravines, the uprooting of trees, the fall of crops, the leaching of soils, the deregulation of seeds germination, etc. The degradation of the physical structure of soils is also due to intensive agriculture, uncontrolled logging, population growth, urbanization and industrialization [2]. In Côte d'Ivoire, more than 75% of the forest area has disappeared in 30 years [3]. The conversion rate of natural habitats to agricultural lands was 43.3% between 1986 and 2015 and still continues [4]. Primary forests represent only a small part of the forested area (625,000 ha or 6%), the vast majority of which now consists of modified natural forests (9.4 million ha, or 91%) [5] [6]. However, farmers want to sustain their crop yields that push them to always pursue new and more fertile forest plots. Despite this notable increase in cultivated areas, there is still a decline in agricultural productivity due in large part to the deterioration of the physical, chemical and biological qualities of soils. This deterioration cannot be halted by chemical inputs utilization for financial, technical and environmental reasons [5]. In fact, intensive use of chemical fertilizers at the expense of organic inputs certainly increases immediately yields, but gradually destroys the soil (acidification of the environment, loss of mineral elements, release of heavy metals) [7]. In addition, these fertilizers are now increasingly expensive for small farmers with limited financial resources.

To cope with the physical degradation of soils, improvement of their structural stability through increasing soil organic matter content should be considered. This solution is the most relevant as organic matter is known to have an important role in the regeneration and stabilization of poor soil structure [8]. According to FAO [5], crop residues can be valuable resources for agriculture in developing countries. The use of crop wastes in agriculture is not only linked to their richness in nutrients but also to their ability to limit soil runoff and erosion and to increase water retention necessary for the development of plants and microorganisms [9]. The return of crop wastes to the soil is the main component that results in accumulation of nutrients, increases in organic matter and improvement of soil structure [10]. Incorporation of crop wastes into soil has the potential to provide a balanced supply of plant nutrients for crops [11] [12]. According to Scagnozzi [13] and Bauder [14], crop residues added to the soil decompose and can release significant levels of nutrients such as N, P and K.

In Côte d'Ivoire, precisely in the north, cereal crops (rice, corn, sorghum, mil-

let) are grown over large areas, thus producing enormous quantities of residues. Unfortunately, these wastes are generally neglected in farming programs due to the existence of inadequate information regarding the value of a lot of organic wastes as sources of plant nutrients for crop production. In fact, crop wastes are generally stocked outside the farms and may provide a refuge for disease spores and pests that attack plants resulting in low yields [15]. Moreover, crop wastes are burned in situ on the fields [16] and the ash is blown away by the wind or washed by the rain when the ash contained nutrients that could fertilize the soil and consequently reduce soil acidity. It is therefore timely to evaluate the agronomic potential of crop residues, particularly cereal residues available in large quantities, before recommending their use as fertilizer to producers.

This study aimed to improve soil chemical composition through incorporation of cereal residues into soil after crops harvest. We hypothesized that cereal crop residues improve soil chemical properties when decomposing.

2. Material and Methods

2.1. Study Site

This study was conducted at the University Peleforo Gon Coulibaly, Korhogo (Côte d'Ivoire). Korhogo is located between latitudes 9˚27 N - 9˚28 N and between longitudes 5˚37 W - 5˚46 W at 360 m above sea level. The site experiences an average annual minimum temperature of 24.6˚C and a maximum temperature of 28.9˚C. It receives an average annual rainfall of 1286 mm with a bimodal distribution. The relative humidity ranges between 72% and 86%. The months of July, August and September receive the highest precipitations and the months of November to March are the driest.

2.2. Treatments and Experimental Design

The crop residues used in this study were the straw of rice, millet, and the stalks of corn and sorghum. These wastes were collected randomly in farms and were air dried. They were crushed into small particles with a blender and 20 g of each crop residue was put in litter bags measuring 20 cm × 20 cm with 0.30 mm mesh. Five litter bags were retained per type of residue either a total number of 20 bags for the four types of wastes. Each litter bag containing crop residue was placed in a plastic pot, with a perforated base measuring 30 cm diameter and a height of 25 cm, filled with 10 kg of soil. The litter bags were placed vertically at 5 cm under the surface of the soil. A basin was placed underneath each pot and water level was maintained at 2 - 3 cm depth. The content of the pots was initially moistened with water and the moisture content was maintained between 40% - 60% to allow the survival of soil microorganisms responsible of the residue's decomposition [17]. The crop residues were incubated for four months. Five litter bags containing each crop residue were removed from each pot at a four-week interval. Then a sample of soil was taken from each pot and oven

dried at 60°C to constant weight and put in well labeled bags for laboratory analysis. This method was based on that of Fosu *et al.* [18]. The experiment took place in a room at a temperature of 30°C ± 1°C with an average relative humidity of 87.7%.

The residues of crops and the samples taken during the experiment were analyzed to evaluate the variation of nutrients during the decomposition at the Laboratory of Chemical Analysis of National Petroleum Operations Company of Côte d'Ivoire. Total organic carbon (TOC) and total nitrogen (TN) were performed using a TRUSPEC-CHN® (LECO, US) elemental analyzer [19]. Deionized water suspension of each waste was used to measure the pH after mechanically agitation for 30 min and filtration with a sieve. Calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P) were determined by means of atomic absorption spectrophotometer (AA-220 FS) after digestion of the samples with concentrated HNO3: concentrated HClO4 (4:1, v/v).

2.3. Data Analysis

Collected data were subjected to analysis of variance (ANOVA) using SPSS package, Version 16. The means were compared using the least significant difference (LSD) test at $p \le 0.05$. The principle component analysis was performed to determine the relationship between the different crop residues, and their nutrients content.

3. Results and Discussion

3.1. Initial Chemical Characteristics of Cereal Residues

The initial chemical properties of the substrate (soil) and the residues of rice, corn, millet, and sorghum are recorded in Table 1. One-way analysis of variance (ANOVA I) showed that the chemical characteristics differed significantly from one type of residue to another. Regarding the pH, it was acidic for the substrate and for all the crop residues. The lowest pH (5.09) was measured in the substrate and the highest (6.5) was registered in rice straw. According to the LSD test,

Table 1. Chemical characteristics of substrate and cereal residues. **C:** carbon, **N:** nitrogen, **C/N:** ratio carbon-nitrogen, **C/P:** ratio carbon-phosphorus, **P:** phosphorus, **K:** potassium, **Ca:** calcium, **Mg:** magnesium.

Substrate and cereal residues	Nutriments (%)								
	pH	C (%)	N (%)	C/N	P (%)	C/P	K (%)	Ca (%)	Mg (%)
Soil	5.09 ± 1.02[c]	1.46 ± 0.01[d]	0.12 ± 0.01[e]	12.18 ± 1.31[e]	0.03 ± 0.00[d]	48.67 ± 2.83[e]	0.67 ± 0.00[a]	0.23 ± 0.001[c]	0.09 ± 0.00[c]
Corn stalks	6.3 ± 1.25[a]	47.6 ± 13.17[a]	0.55 ± 0.01[b]	85.87 ± 9.64[cd]	0.58 ± 0.04[a]	82.06 ± 21.03[d]	0.29 ± 0.03[c]	0.13 ± 0.01[d]	0.19 ± 0.01[b]
Millet straw	6.2 ± 1.13[a]	35.27 ± 8.69[c]	0.34 ± 0.01[d]	101.33 ± 31.54[b]	0.3 ± 0.01[c]	117.56 ± 43.17[c]	0.34 ± 0.04[c]	0.23 ± 0.01[c]	0.28 ± 0.01[a]
Rice straw	6.5 ± 1.34[a]	40.13 ± 9.94[b]	0.45 ± 0.01[c]	89.16 ± 26.47[c]	0.31 ± 0.01[c]	129.45 ± 51.12[b]	0.21 ± 0.06[d]	0.37 ± 0.01[b]	0.29 ± 0.03[a]
Sorghum stalks	6.2 ± 1.21[a]	33.11 ± 11.10[c]	0.27 ± 00[e]	122.62 ± 51.42[a]	0.42 ± 0.01[b]	78.83 ± 19.68[d]	0.31 ± 0.01[c]	0.22 ± 0.02[c]	0.25 ± 0.01[a]

Values followed by the same letter in a column are not significantly different (p > 0.05) using LSD.

there was no significant difference ($p > 0.05$) between the pH of corn, millet, rice and sorghum residues. The acidic of the soil and the cereal crop residues could be linked to the growing conditions. In fact, producers used chemical minerals to improve their productivity and those fertilizers accumulated over past years might cause the acidity of the soil. According to Xie *et al.* [20], application of chemical fertilizers on soil provoked its acidity. Evidently, crops grown on acidic soil may have acidic pH. The highest content of carbon (47.6% ± 13.17%), nitrogen (0.55% ± 0.01%), phosphorus (0.58% ± 0.04%) were registered in corn stalks. Relatively to the content of potassium, it ranged from 0.21% ± 0.06% to 0.67% ± 0.00% and those of calcium and magnesium varied respectively from 0.13% ± 0.01% to 0.37% ± 0.01% and from 0.09% ± 0.00% to 0.29% ± 0.03%. C/N ratio oscillated between 12.18 ± 1.31 and 122.62 ± 51.42 when C/P ratio fluctuated from 48.67 ± 2.83 to 129.45 ± 51.12. These results attest to the nutrient richness of crop residues and they could be used to fertilize soil. In fact, crop residues are important natural resources, and their effective recycling improves the soil physical, chemical and biological properties. Similar results were obtained by Anguria *et al.* [21] in northeastern Uganda. Indeed, these authors observed high levels of nitrogen, phosphorus, and potassium in millet, sorghum, cowpea and peanut residues. The variation of nutrients in cereal crop residues could be justified by the soil they were grown on. The P contents in this study were higher than the critical limits (0.12% - 0.19%) defined for crop residues to pass from the state of immobilization to mineralization [22] and would result in rapid mineralization of residues by microorganisms. Thus, the different crop residues in this study will tend to decompose rapidly as their phosphorus contents are above the critical limits. According to Cattanio *et al.* [23], a low P content slows the rate of substrate decomposition due to nutrient immobilization. Baggie *et al.* [24] and Fosu *et al.* [18] indicated that crop residues with low biochemical composition tend to decompose slowly due to immobilization of nutrients.

3.2. Variation of Chemical Characteristics of Substrate during Crop Wastes Decomposition

3.2.1. pH

The variations in the pH of the different crop residues during decomposition are shown on **Figure 1**. It appeared from the analysis that during the decomposition of the different residues, the pH of the substrate increased slightly. The pH of the substrate varied from 5.09 to 6 with corn residues, from 5.09 to 5.8 with millet straw, from 5.09 to 5.9 with sorghum residues and from 5.09 to 5.7 with rice straw. The increase in pH during the experiment might be linked to excess cations which indicate the concentration of organic anions within the materials. Increase in pH via the C cycle occur through H^+ association with organic compounds and the decarboxylation of organic anions in the residue [25]. Theoretically, H^+ association will occur if the pKa of the acid groups of the organic compounds is greater than the soil pH [26]. Through the N cycle, ammonification of organic N and nitrate uptake increase pH whereas nitrification and ammonium
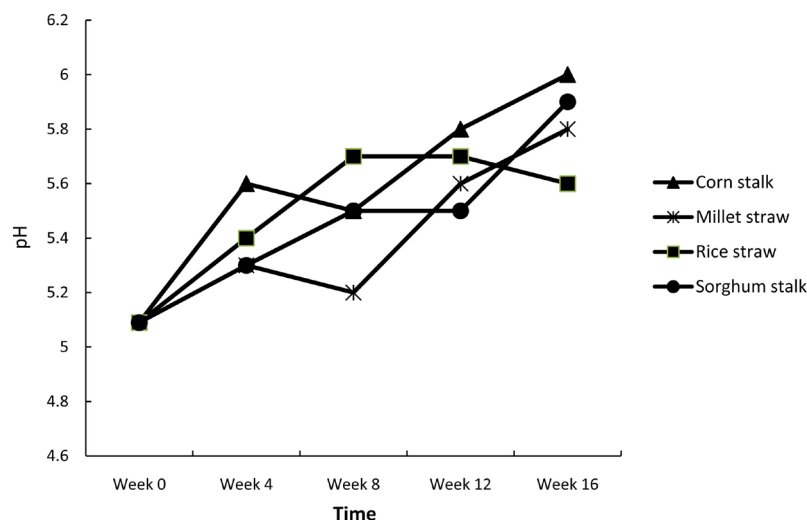
Figure 1. Variation of pH of substrate in function of time during crop residues decomposition.

uptake decrease pH [27]. Several laboratory incubations studies have shown that plant material increases pH [26] [28] [29] [30] [31]. However, the effect of residues on pH change varies widely between studies due to differences in residue composition and soils used. In particular, the initial pH of the soil is important for the pH change [25].

3.2.2. Carbon, Nitrogen and Phosphorus

The variation of carbon, nitrogen and phosphorus during the decomposition of the cereal crop residues are illustrated in **Figure 2**.

Soil organic carbon is the most important indicator of soil quality and agricultural sustainability. In this study, carbon content was 1.46% in the substrate at the start of the experiment. A month later, it increased to 10.7%, 16.5%, 13.2% and 15.2% respectively with corn stalk, millet straw, rice straw and sorghum stalk. After 8, 12 and 16 weeks of decomposition, the carbon content passed respectively to 23.4%, 36%, and 40.2% with corn stalk. At weeks 8, 12 and 16 respectively, carbon content was 30.1%, 44.6% and 50.8% in substrate with millet straw and 37.6%, 49.3% and 53.1% with rice straw. With sorghum stalk, carbon content was 23.4%, 38.7% and 41.7% respectively after 2, 3 and 4 months of decomposition.

Relatively to nitrogen content, it increased significantly during residues decomposition. Nitrogen content after 4 months of decomposition was 4.25, 5.25, 6.33 and 4.58 times higher than the initial content when adding corn stalk, millet straw, rice straw and sorghum stalk respectively to the substrate.

Phosphorus content in the substrate varied significantly in function of time and type of waste during the decomposition of residues. The content of phosphorus in substrate ranged from 0.03% to 0.82% with corn stalk and from 0.03% to 0.72% with millet straw. In both cases, the highest phosphorus content was obtained at the end of the experiment. Statistical analysis showed that there was
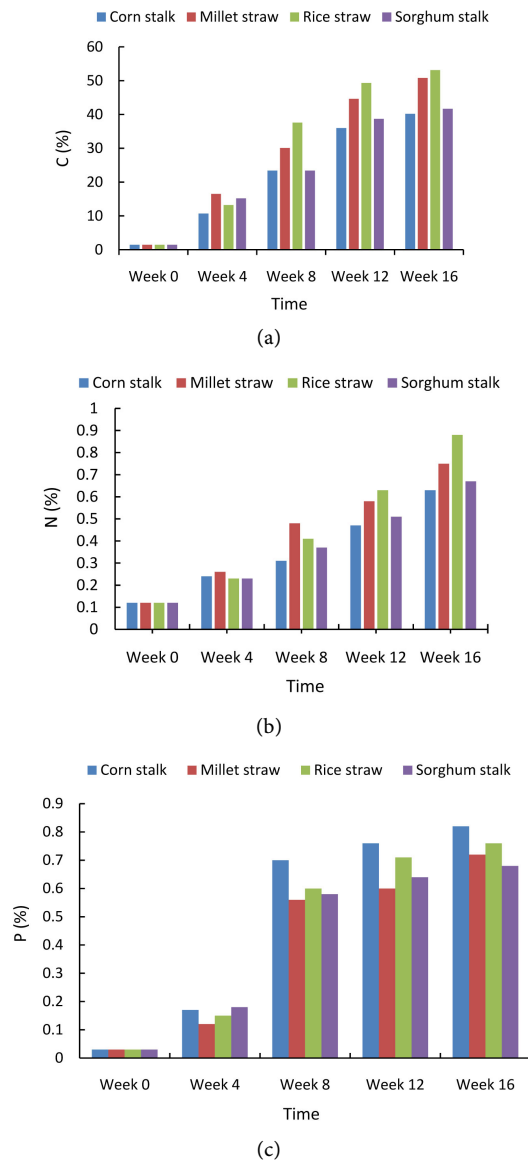
Figure 2. Variation of nutrients during decomposition of cereal residues. (a) C%; (b) N (%); (c) P (%).

no significant difference ($p > 0.05$) between the phosphorus content measured at week 8 and at week 12 when using corn stalk or millet straw. During the decomposition of rice straw and sorghum stalk respectively, phosphorus content varied from 0.03% to 0.76% and from 0.03% to 0.68%. The highest phosphorus content was obtained at week 16 with the two crop residues. However, the phosphorus content at week 12 and at week 16 were similar statistically with rice straw and sorghum stalk, respectively.

The low content of carbon, nitrogen and phosphorus observed at the start in the substrate could be due to its exploitation by farmers through cultivation and tillage. In fact, producers cultivated the soil since years without any proper conservation practices. According to Liu *et al.* [32], soil cultivation and tillage can

reduce its content in carbon and nitrogen, and therefore lead to its deterioration. The increase in soil organic carbon, nitrogen and phosphorus during the experiment could be linked to crop residues decomposition under microorganism's activity which consists of immobilization and mineralization [33]. Crop residues decomposition increases soil organic matter, which is a major terrestrial pool for plant nutrients, and consequently improves soil physical properties, conserving water, and increasing available nutrients [34]. Also, soil organic matter is not only an important source of carbon for soil processes but also a sink for carbon [32]. Crop residues are rich in nutrients and when they are incorporated into the soil, they constitute a form of organic restitution and therefore the first and best advance that enriches the soil before cultivation. Returning crop residues to soil, in contrast to its removal or burning, has been shown to increase the organic matter content of topsoil in many long-term field experiments [35] [36]. The findings of our experiment are in conformity to those of Azmal *et al.* [37] who observed an increase in soil chemical composition after incorporation of rice straw. Singh *et al.* [38] noted an important increase in organic matter, organic carbon, nitrogen, and phosphorus when incorporating rice and wheat crop residues in soil than burning them.

3.2.3. C/N and C/P Ratios

The C/N ratio is frequently used as a quality index to evaluate the potential of crop residues in nutrients [39]. The carbon-nitrogen ratio during the decomposition of the various residues varied as a function of time (Table 2). Initially, the C/N ratio was 12.16 in the substrate. Four weeks after the start of the experiment, C/N ratio increased in the substrate with all the crop residues. With corn stalk, week 8 and 12 registered the highest C/N ratios statistically. A significant decrease of 16.69% in C/N ratio was observed at week 16. The C/N ratio ranged from 12.16 to 76.89 with millet straw, from 12.16 to 91.70 with rice straw and from 12.16 to 75.88 with sorghum stalk. The highest C/N ratio was measured at week 16 with millet straw, at week 8 with rice straw and at week 12 with sorghum stalk. The increase in C/N ratio during the decomposition of crop residues could be explained by the fact that these residues contained more carbon than nitrogen. Also, during the decomposition, less carbon was mineralized in the form of CO_2 or assimilated by the soil microflora.

Table 2. Variation in C/N ratio during crop residues decomposition.

Type of crop residues	Time (week)				
	0	4	8	12	16
Corn stalk	12.16 ± 0.87[d]	44.58 ± 5.72[c]	75.48 ± 3.26[a]	76.59 ± 3.15[a]	63.80 ± 5.17[b]
Millet straw	12.16 ± 0.11[c]	63.46 ± 11.53[b]	62.70 ± 6.32[b]	62.70 ± 8.1[b]	76.89 ± 2.81[a]
Rice straw	12.16 ± 1.51[d]	57.39 ± 2.67[a]	91.70 ± 4.17[a]	78.25 ± 9.57[b]	60.34 ± 8.15[c]
Sorghum stalk	12.16 ± 0.6[c]	66.08 ± 4.21[b]	63.24 ± 7.41[b]	75.88 ± 3.6[a]	62.23 ± 2.84[b]

Values followed by the same letter in a row are not significantly different (p > 0.05) using LSD.

The carbon-phosphorus ratio varied as a function of time, and type of crop residue during the decomposition (Table 3). At the start of the experiment, the C/P ratio was 48.66 and it increased with all the crop wastes. The highest C/P ratio was 62.94 ± 12.03 obtained at week 4. With millet straw, rice straw and sorghum stalk, the highest C/P ratio was 74.33 ± 10.12 got at week 12, 88 ± 4.72 at week 4, and 84.44 ± 4.21 at week 4, respectively. The decrease in C/P ratio after the increase could explained microorganism's activity that accelerate the decomposition process and therefore liberate nutrient as phosphorus.

Table 3. Variation in C/P ratio of substrate in function of crop wastes decomposition.

Type of crop residue	Time (week)				
	0	**4**	**8**	**12**	**16**
Corn stalk	48.66 ± 1.21^b	62.94 ± 12.03^a	33.42 ± 2.61^b	47.36 ± 3.24^b	49.02 ± 3.43^b
Millet straw	48.66 ± 1.34^b	37.5 ± 2.33^c	53.75 ± 3.02^b	74.33 ± 10.12^a	70.55 ± 8.47^a
Rice straw	48.66 ± 1.74^c	88 ± 4.72^a	62.66 ± 6.11^b	69.43 ± 7.68^b	69.86 ± 6.52^b
Sorghum stalk	48.66 ± 1.02^c	84.44 ± 4.21^a	40.34 ± 8.24^c	60.46 ± 6.94^b	61.32 ± 7.11^b

Values followed by the same letter in a row are not significantly different ($p > 0.05$) using LSD.

3.3. Correlation between Plant Nutrients in Crop Residues

The relationships between the type of crop residues used in this study and their chemical characteristics were performed thanks to the principal component analysis (Figure 3).
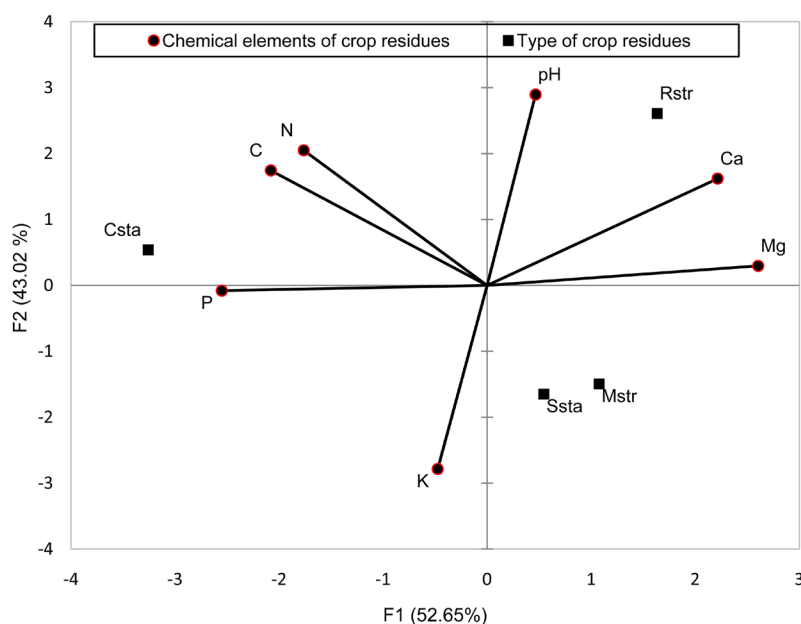

Figure 3. Correlation between cereal crop residues and chemical elements. Csta: corn stalk, Rstr: rice straw, Ssta: sorghum stalk, Mstr: millet straw, C: carbon, N: nitrogen, Ca: calcium, Mg: magnesium, K: potassium, pH: hydrogen potential.

The principal component analysis revealed that the different type of crop residues differed by their chemical characteristics. Crop residues were clustered into three groups based on their chemical composition. Group 1 and group 2 were constituted of corn stalk and rice straw respectively when group 3 gathered millet straw and sorghum stalk. Also, it appeared that C and N were strongly correlated on one hand and pH, Ca, and Mg were correlated on the other hand. A correlation was suspected between P and K. The three groups in crop residues in function of their chemical composition could be due to the cultivated area. In fact, in the north of Côte d'Ivoire, sorghum and millet are always cultivated side by side. The availability of the same nutrients for both plants might explain the similarity in their residue's chemical elements. The correlations between nutrients in this study agreed with the results of Ogidi *et al.* [40] when they were working on soil-plant nutrients.

4. Conclusion

This study demonstrated that corn stalk, millet straw, rice straw and sorghum stalk with higher N, and P have a potential to supply higher amounts of N and P nutrients. Millet straw and rice straw could be beneficial for fast-growing and early planted crops. In contrast, corn stalk and sorghum stalk release nutrients slowly which would be beneficial for longer availability of the nutrients.

Acknowledgements

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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