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What Is the Impact of Ploughing on Eucalyptus Plantations in Bambou Mingali (Plateaux Batéké, Republic of Congo)?

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Abstract

Soil ploughing is an important stage in the preparation of planting, causing disturbance to the physical, chemical and biological properties of the soil. Soil ploughing can affect the availability of nutrients and water resources, and its effect can be short, medium or long-term. Soil ploughing accelerates surface heating and air circulation and encourages mineralisation by transforming organic matter into mineral salts, making nutrients soluble and accessible to plants. The aim of this study is to determine how soil ploughing affects the distribution of nutrients in the soil profile. The study focuses on nitrogen, carbon, phosphorus, calcium and magnesium, which are major elements of soil fertility on the Batéké plateaux in Congo. The results indicate that ploughing significantly modifies the distribution at depth des elements nutritifs: there is more accumulation at the surface than at depth (ei: nitrogen 1.34 t/ha ± 0.035 at 10 cm compared with 1.034 t/ha ± 0.098 at 50 cm) with a higher concentration of carbon (13.89 t/ha ± 0.87) followed by nitrogen (1.34 t/ha ± 0.035).

Keywords

Ploughing, Mineralization, Eucalyptus, Plateaux Batéké, Congo

1. Introduction

In order to meet the demand of the global wood market, forest managers strive to maximize wood yield per unit area as quickly and with the best quality as possible [1] [2]. However, the development of these forest plantations is associated with environmental requirements on carbon sequestration, the protection of biodiversity, and the conservation of soil and water quality [3] [4]. The increase in forest plantations around the world has modified landscapes with the partial replacement of subtropical grasslands [5] [6]; and agricultural areas leading to profound changes in production systems and agriculture land use [7]. Furthermore, soil organic matter is essentially located in the superficial horizon and its content decreases with depth [8] [9]. It constitutes a pool of nutrients for plants made available through various chemical, physical and biological processes [10]. Among the factors that most influence forest productivity, the physical properties of the soil can be either harmful or beneficial to forest trees [11]-[16].

Tillage destroys the galleries which serve as refuge or access to food reserves; modifies the distribution of resources: organic matter is buried at depth and waste is reduced due to soil compaction; changes environmental conditions: temperature and humidity [17] [18]. Tillage changes soil density, decreasing resistance to root penetration and increasing water retention levels [19] [20]. As global warming accelerates the decomposition of soil organic matter (SOM), ploughing might be a mean to protect OM by mixing it with mineral horizons compared to till-farming practices [21]. Tillage makes a soil homogeneous [22] [23]. In the study conducted by [24], the stock of SOC was found to be unaffected by tillage practices.

Ploughing, which is the most intensive form of tillage, is an important stage in plantation preparation, causing disturbances in the physical, chemical and biological properties of the soil [25]-[27]. Ploughing have an impact on the vertical distribution of soil nutrients of soil nutrients [28]. Ploughing which is the more intensive operation of tilling, inverts, covers or mixes the organic layer of the soil and the surface mineral A horizon, disrupting pedogenic processes [17].

Tillage can then affect the availability of nutrients and water resources as well as carbon stocks, and its effect can be on the short, medium or long term [16] [29] [30]. It redistributes nutrients by bringing pre-existing stocks of nutrients from organic matter to the surface, where they are mineralised [18] [31] [32].

Ploughing is also a management practice in forestry that aims to optimize nutrient use efficiency and increase productivity [33]. Despite the beneficial effects [34], there are drawbacks, including increased mineralization [35] and increased risks of nutrient leaching. Through ploughing, pedogenesis processes in forest ecosystems then disrupted and the soil profile is strongly modified compared to the soil layers created naturally by long processes of soil pedogenesis under a series of physical, chemical and biological processes. Intensive ploughing practices such as subsoiling have shown reductions in bulk density and increases in porosity of deep horizons [36] [37]. These general patterns are, however, modulated by soil types. For example, [38] in loamy soils observes no significant effect of ploughing practices on nitrogen transformation rates. Numerous studies claim that no-ploughing practices increase carbon storage in the soil [39]. For regularly ploughed soils, a vertical gradient of decreasing phosphorus content is established with depth [40]. Soil properties and dynamics are then directly affected by soil type and site preparation practices, and the choice of appropriate ploughing management, therefore, becomes crucial.

The Batéké plateau is characterized by ferralitic soils leached of iron and clay, formed on a sandy-low clay material, poor in bases and with high permeability [41] [42]. The most remarkable characteristics of these soils are linked to the type of organic matter and its distribution in the profile. Deep humus penetration is possible due to the permeability nature of the original material [42]. The vegetation of the Batéké plateau is a mosaic of savannahs and gallery forests [43]. The organic matter in these soils is mainly derived from the decomposition of the root system of herbaceous and shrubby vegetation, as these savannahs are subject to bushfires that often occur several times a year [41]. Sometimes, this is more or less recent fallow land [41].

No studies have been carried out in this area on the impact of ploughing on the variation in mineral elements (carbon, nitrogen, phosphorus, magnesium, calcium) that would be beneficial to savannah afforestation. These elements are essential to the productivity of eucalyptus and acacia plantations. It is, therefore, important to know what happens to them in the soil after ploughing, in comparison with unploughed savannah soil. The objective of this study is to determine how ploughing affects the stock of nutrient distribution in the soil profile.

2. Materials and Methods

2.1. Presentation of the Study Area

The study site is located at 60 km in the north of Brazzaville in the Republic of Congo (3˚54'06"S 15˚30'13"E) (**Figure 1**). The site was established in Bambou-Mingali (2000 ha) in the PRONAR forest plantations, on the eastern edge of the Mbé plateau. The study area site is characterized by a marked dry season of 4 to 5 months, during which minimum precipitation is recorded from June to September and a small dry season from January to February. The main rainy season lasts approximately six to eight months, from October to June. The annual average precipitation is 1600 mm per year. The savannah soils of the Batéké plateaus are

Figure 1. Plowed plot of Bambou Mingali site (Pool department, Republic of Congo).

ferralitic soils leached of iron and clays, formed on a sandy-weak clay material, poor in bases and of high permeability [41] [42]. The original vegetation of the studied area is savannah dominated by *Hyparrhenia diplandra* (Hack.) Sapf., *Bridelia ferruginea* Benth.; *Chromolaena odorata* (L.) R. M. King., *Annona senegalensis* Pers. We also note the presence of herbaceous plants of which the following species have been identified *Loudetia demeusei* (De Wild.) C. E. Hubb., *Hymenocardia acida* Tul.

2.2. Experimental Device

To carry out this study, a one-hectare experimental plot was ploughed in two passes with a Massey Ferguson 440 agricultural tractor, coupled to a disc plough for the first pass and a sprayer for the second pass. The ploughing depth was 30 cm. The original vegetation thus fled into the ground at the end of the rainy season (in May). Depending on the slope gradient, the plot was divided into 4 blocks each comprising 4 plots of 25 m × 25 m leading to 16 plots for the ploughed area. Three distinct points in the savannah (contiguous unplowed plots) 100 m away from the plowed area were identified.

2.3. Sampling and Chemical Analysis

In the center of each of the 16 plowed plots and in the three points of the Savannah, soil samples for chemical analysis (organic carbon, nitrogen, phosphorus, magnesium and calcium) were taken using a soil auger at the depths: 0 - 10 cm, 10 - 20 cm and 20 - 50 cm, and for the apparent density at the single depth of 20 cm where the soil is compacted enough (in the ploughed plots) for easy sampling. The samples were taken one month after ploughing at the planting site. Composite samples were taken for each block and each depth in the ploughed area. In the savannah, for the 3 sampling points, individualized samples were maintained for each point at each depth. In total, there are 4 composite samples per depth and in each block in a ploughed plot; and 9 samples in the savannah (3 samples per depth in the 3 points collected). Chemical analyses were carried out in the laboratory.

2.4. Calculation of the Stock of Elements: Example of Soil Carbon Per Given Horizon

The carbon stock is evaluated for a given surface unit by multiplying the C concentration by the apparent density of the soil and by the depth of the horizon (layer) of the soil sampled. We then add up the stocks from different horizons to get the soil stock.

Soil carbon stock was determined from Equation (1).

$$Qi = Ci \times Da \times ei \times 10 \quad [44]. \tag{1}$$

- Qi, the organic carbon stock of a layer i, in kg/m^2,
- Ci, the organic carbon concentration of the layer, in %,
- Da, the apparent density of the layer, in g/ml,

- ei, thickness of the layer, in m.

Then the stocks obtained were converted into tons per hectare (t/ha).

2.5. Data Processing and Statistical Analysis

R software [45] has been used for the statistical analyses. The analyzes were carried out at the 5% threshold after checking the normality of the distributions and the homogeneity of the average variances obtained. The sample size was small, so the Kruskal-Wallis test was used to analyze the difference in carbon and nitrogen contents as well as soil organic carbon stocks depending on the horizons. The non-parametric Kruskal-Wallis test uses a post hoc Dunn Bonferroni correction for a pairwise comparison of means. This analysis allowed us to conclude whether the differences in soil carbon contents and stocks per plot or per horizon are significantly different or not between savanah and the ploughed area.

3. Results

3.1. Impact of Ploughing on Soil Density

The apparent density of the soil in the plowed plot (1.25 ± 0.15) is significantly higher ($p > 0.01$) than that of the savannah (1.03 ± 0.02) (**Figure 2**).

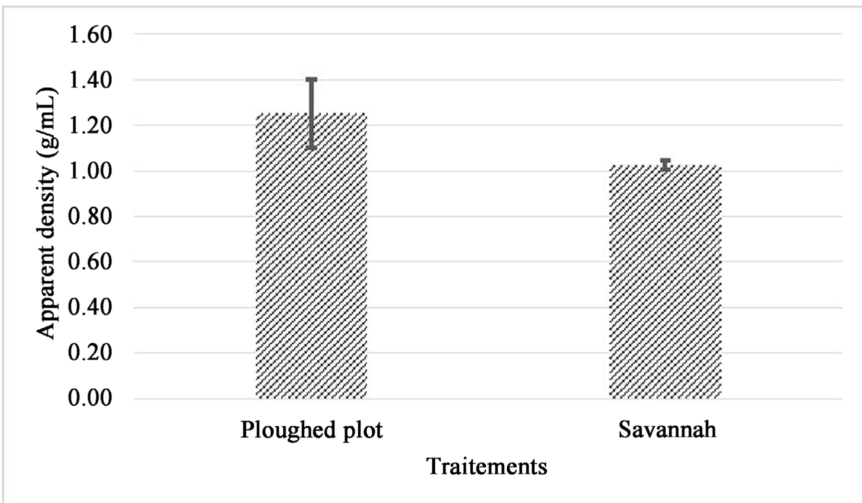

Figure 2. Apparent density at the single depth of 20.

3.2. Soil pH Units

The measured water pH of the soil remains acidic in both environments. However, we have a higher acidity ($p > 0.01$) in plowed plots (3.4 ± 0.21) than in savannah (4.7 ± 0.45) (**Figure 3**).

3.3. Comparative Effect of Mineral Element Dynamics between Ploughed Plot and Savannah

Calcium is absent in the deep horizon (20 - 50 cm) in both sites. In the surface horizons, the stock difference remained insignificant (**Figure 4(a)**).

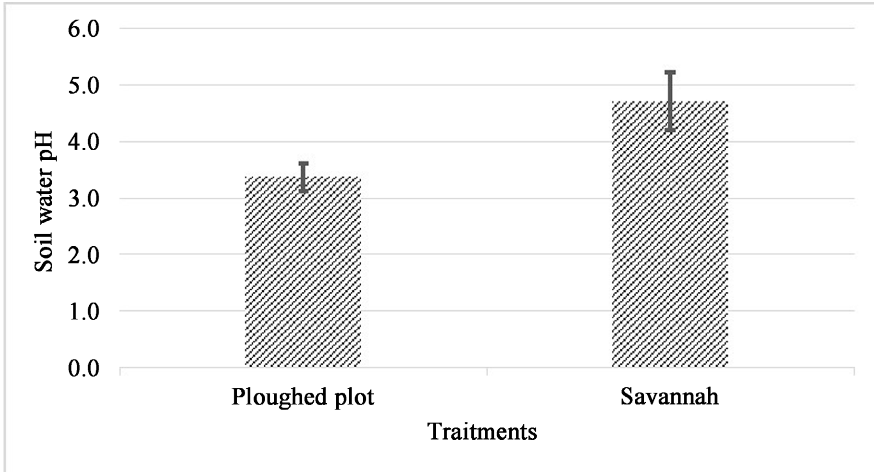

Figure 3. Soil water pH at 10 cm depth.

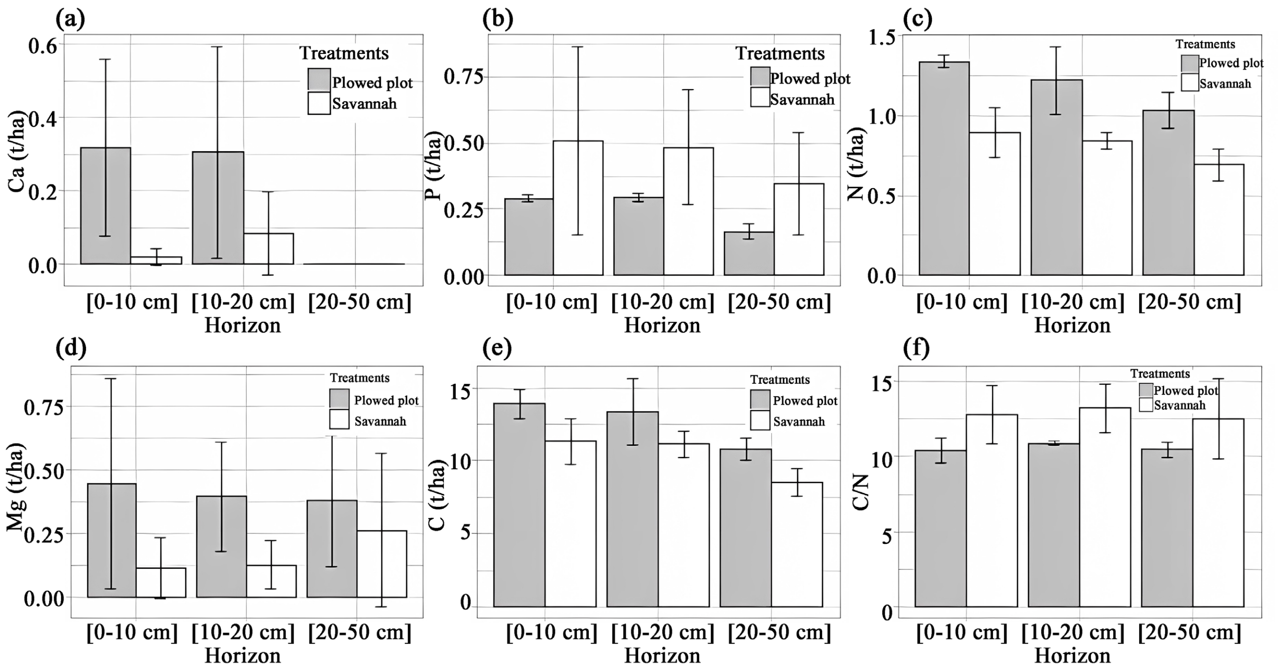

Figure 4. Stock of mineral elements in soil horizons. (a) Calcium; (b) Phosphorus; (c) Nitrogen; (d) Magnesium: (e) Carbon; (f) Carbon/Nitrogen ratio.

The phosphorus stock in ploughed plots and in savannahs decreases with depth. There is a significant difference in the phosphorus stock in the ploughed plot where the surface horizons have a larger stock: 0 - 10 cm and 20 - 50 cm ($p > 0.04$) and 10 - 20 cm and 20 - 50 cm ($p > 0.01$) (Figure 4(b)). However, the gap between the savannah and the ploughed plots remains insignificant (Table 1).

Nitrogen stocks decrease with depth in the two treatments. Nitrogen stock in the ploughed plots remains higher with savannah ($p > 0.01$) (Table 2). Significant differences ($p > 0.05$) in treatments are again observed between the 0 - 10 cm and 20 - 50 cm horizon in ploughed plot and then 10 - 20 cm and 20 - 50 cm in savannah (Table 1, Figure 4(c)).

Table 1. Comparison test of the horizons effect for each mineral element.

Stock (tons per ha)	p-Value		
	[0 - 10 cm]	[10 - 20 cm]	[20 - 50 cm]
Azote (N)	0.02	0.02	0.02
Calcium (Ca)	0.14	0.24	0.00
Carbon (C)	0.08	0.38	0.02
Magnesium (Mg)	0.08	0.08	0.66
Phosphore (P)	0.88	0.19	0.14
Rapport C/N	0.08	0.02	0.25

The Magnesium stock in plowed plots as in savannah does not show any difference between horizons ($p > 0.06$) (Table 1) or even between plowed plots and savannah at all horizons ($p > 0.08$) (Table 2, Figure 4(d)).

Table 2. Comparison test of the horizon effect by treatment for each mineral element.

Treatments	Stock (tons per ha)	p-Value		
		[0 - 10 cm]	[10 - 20 cm]	[20 - 50 cm]
Plowed plot	Azote (N)	0.78	0.05	0.19
	Calcium (Ca)	1	0.06	0.13
	Carbon (C)	1	0.04	0.09
	Magnesium (Mg)	1	1	1
	Phosphore (P)	0.92	0.05	0.01
	Rapport C/N	0.73	1	0.64
Savannah	Azote (N)	1	0.06	0.11
	Calcium (Ca)	0.56	0.33	0.05
	Carbon (C)	1	0.04	0.02
	Magnesium (Mg)	1	0.98	0.83
	Phosphore (P)	1	0.52	0.49
	Rapport C/N	1	0.94	1

The carbon stock in plowed plots and in savannah follows the same trend as the evolution of nitrogen in the soil (Figure 4(e)). Carbon stocks decrease with depth in the two treatments. Carbon stock in the ploughed plots remains higher than in which savannah ($p > 0.02$) (Table 2). The difference in carbon stock in plantations is significantly different between the 0 - 10 cm and 20 - 50 cm horizons ($p > 0.03$); and in savannah the difference is significant between the 0 - 10 cm and 20 - 50 cm horizons ($p > 0.03$) and the 10 - 20 cm and 20 - 50 cm horizons ($p > 0.02$) (Table 1).

3.4. C/N Ratio

The C/N ratio in each treatment remained constant, regardless of the depth. The values of the carbon/nitrogen ratio (C/N) range from 10 in the ploughed plot to 12 - 13 in the savannah. The comparison between treatments on the (C/N) ratio is significantly different ($p > 0.01$) at the 10-20 cm horizon between the ploughed plot and the savannah (**Figure 4(f)**).

4. Discussion

On sandy and very draining soils, the Ploughing carried out (0 - 30 cm) was used to prepare the plot by fighting against the burial of the primitive herbaceous vegetation. This technique does not invert the grasses and other organic matter on the surface, but mixes the upper soil horizons with the organic matter that was on the surface.

The mineral element contents measured in this study show that there is a gradation between horizons in the sense that stocks decrease with depth [8] [46] in both environments (ploughed soil and intact savannah) except for magnesium in savannah. Stocks remain high in plowed soil compared to savannah except for phosphorus.

It is noteworthy that the pH level in ploughed land is notably elevated. Prior research has demonstrated that the pH of soil does not undergo significant alteration when a high concentration of CO_2 is introduced into the soil [47]. In fact, some studies have even observed a decline in soil pH following the injection of CO_2 into the soil [48]. In hot and humid environments, soil pH decreases over time as a result of acidification due to leaching [49]. It may therefore be inferred that soil pH increases with the aridity that would have characterised the ploughing period up to the collection of soil samples.

4.1. C/N Ratio in Plowed Plots and in Savannah

Soil C/N ratios decrease with depth, which reflects greater humus maturity in depth horizons [50]. But do these C/N ratios have a link with the land management method in the case of the plot where the soil has been returned?

For good humification of organic matter, it is very important that the richness in carbon and nitrogen is between certain values, because the edaphic microfauna, microflora and microfungus, which act in the decomposition and mineralization of organic matter, require carbon as a source of energy, and nitrogen as an intermediate in the synthesis of their proteins. With the C/N ratio < 15, the nitrogen production rate increases; it is at its maximum for a C/N ratio = 10 [51].

Considering the results of this study, we have values of C/N = 10 in unplowed savannah soil, which promotes accelerated mineralization [52] and storage by deep drainage of mineralization products. The organic matter buried by Ploughing is also very quickly mineralized, the values of the C/N ratio remain between 12 - 13 for 3 horizons. In the space of one-month, plowed soils have a high carbon concentration higher than non-plowed soils whatever the horizon, the C/N ratio being close to 10 (12 - 13) also promotes mineralization. And according to [53], soil carbon contents are not linked to nitrogen fluxes. Nitrogen production in soil results from microbial denitrification and nitrification [54], with the intensity of both processes being strongly dependent on soil pH [55] [56].

4.2. Evolution of the Elements in the Returned Soil of Bambou Mingali

Ploughing resulted in overturning of the surface layer of the soil. In plowed soil, there is an increase of almost 1/3 in carbon and nitrogen stocks and more than 2/3 for calcium, with no significant difference for Mg. Following the decreasing order of the average stocks of mineral elements in the soil, the results obtained show that carbon is the most abundant element in the soil, on each horizon of the soil. This can be explained by the fact that the soil is mainly made up of organic matter, knowing that carbon represents 58% of the organic matter in the soil [57].

It was observed that soil carbon stocks were significantly higher in ploughed soils. However, a negative gradation with depth was also observed in both sites, which is in accordance with the findings of [16]. This is contrary to what [18] found where stocks are significantly greater as we go deeper due to the continuous accumulation of carbon in the plowed soil, and due to mineralization in the absence of physical disturbance (ploughing) in the deep layers of the soil. The short observation period of one month shows rapid mineralization in the soils studied. In unplowed savannah soil, the surface organic matter (litter in particular) is first found in the soil and is then only partially transferred into the soil, unlike what is observed in the plowed plot. The increase in stock can be explained by the reversal of the volume of the roots which were at depth and which are found on the surface and which must have mineralized very quickly. The plowed soil having the ease of allowing water to penetrate deep, accelerated the mineralization process of buried plant matter [58] and humidity which is a critical environmental factor that affects the mineralization of organic carbon in the soil. ground. In peats Below mineral horizons, mineralization was affected by a slowdown in water infiltration [8].

The results of nitrogen stocks in plowed and non-plowed control plots decrease with depth. However, stocks increased significantly in the plowed plot following the same trend for carbon. If nitrogen mineralization was as rapid as for carbon, this indicates high soil energy reserves and active biology in the tilled soil [54]. The contribution of organic matter which was on the surface and probably the rootstocks at depth easily stimulated biological activity and contributed to the rapid mineralization of nitrogen [59]. This microbial action was certainly facilitated by the chemical composition of the organic matter [60]. Microbial metabolism being inhibited under low soil water conditions by leading to a reduction in microbiological activity [61] and thus inhibiting the rate of soil nitrogen mineralization; abundant rainfall promoted the dissolution rate of soluble organic matter, which is beneficial for N mineralization in the plowed soil [58].

Phosphorus stocks in plowed soil horizons decreased significantly compared to phosphorus stocks in control soils. According to [40], the absence of ploughing reduces particulate phosphorus losses. Knowing that phosphate ions are difficult to mobilize in the soil [62], it is only through the mineralization of plant residues under the effect of microbial activity that can increase the assimilable phosphorus content of the soil (labile phosphorus and dissolved phosphorus). According to [63], phosphosphe in the environment is characterized by a strong affinity for the solid mineral phase: the ionic forms (orthophosphates, denoted ortho-P) and certain organic forms are actively fixed by soil particles, suspensions and sediments. Ionic forms can also be precipitated, generally in poorly crystallized or amorphous forms, in particular with Al, Fe and Ca3, which would justify the low level of phosphorus in plowed soils. [64] states that decreasing soil pH results in the dissolution of phosphorus through the physicochemical processes of adsorption onto constituents bearing positive charges, such as metal oxides, clays and organic matter.

The stock of calcium and magnesium is higher in plowed plots than in control plots. It is common to find higher concentrations of calcium, magnesium and organic carbon in the surface organic matter of the soil [65] [66]; in other conditions, the opposite behavior would be observed [65].

5. Conclusion

Working the soil accelerates surface heating and air circulation and promotes mineralization through a transformation of organic matter which leads to the formation of mineral salts where the fertilizing elements become soluble and accessible to plants. The availability of mineral elements such as nitrogen, carbon, and calcium in plowed soils and across all horizons is obvious. Nitrogen is the element that comes in second position, in fact, nitrogen is the second most important element for the plant, followed by phosphorus, after that comes magnesium and lastly before calcium. Soil mineral resource stocks in turned soil and savannah soil on the Mbé plateaus in the Bambou-Mingali forest reserve show significant elemental variation. But the object of our research is to determine the dynamics of stocks of carbon, nitrogen, phosphorus, magnesium and calcium in the returned soil and to compare the results with those of the soil of these two environments, the largest stock of mineral elements is noted in the soil returned for each element. The differences are significant between these two ecosystems. And it is found that carbon is more abundant for both types of soil; after that it's nitrogen; Comes phosphorus; Then magnesium and calcium. Finally, these results give a first numerical indication of the stocks of mineral elements in the returned soil and in the savannah control soil in the Bambou-Mingali zone. In summary, the results of this study indicate that Ploughing modifies the depth distribution and concentration of mineral elements by accelerating mineralization which promotes their accumulation in horizons offering a better opportunity to sequester soil carbon, to increase soil microbial biomass and improve nutrient cycling.

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Conflicts of Interest

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

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