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Local Scale Edaphic Surveys in and out of a *Pericopsis elata* (Harms) Meeuwen Natural Forest Stand in East Cameroon

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Abstract

One of the problems limiting high survival rates of *Pericopsis elata* (afrormosia, assamela), a high value timber species, is lack of data on its pedological requirements. A study was conducted in the East Region of Cameroon to identify possible soil properties favoring its spatial distribution. Two test areas, in and out of a *Pericopsis elata* natural forest stand were identified and in each sampling units of 50 × 50 m delineated. Thirty eight and sixteen quadrats in and out of the stands were respectively sampled for soil physico-chemical properties, number of stems and diameter at breast height. Soil samples in each quadrat were analyzed following standard laboratory procedures. Soil properties were tested for normality and compared for the two sites using Student's t-test. Principal component analysis and correlation analysis were performed on tree and soil data to identify soil factors responsible for spatial distribution. From our findings, key soil indicators favouring *Pericopsis elata* distribution appear to be acidity (soil pH and exchangeable acidity), base status (base saturation and exchangeable bases) and texture (clay content). More specifically, optimal soil conditions for growth and survival of *Pericopsis elata* are: pH (4.1 - 5.0), exchangeable acidity (<4.67 cmolc·kg^{-1}), base saturation (6.2% - 17.8%), and clay content (24.0% - 49.0%), which should be considered in site selection for reforestation with *Pericopsis elata*.

Keywords

Assamela, Afrormosia, Soil Properties, Rainforest, Cameroon

1. Introduction

Soil is an important component of forest and woodland ecosystems as it helps regulate important ecosystem processes such as nutrient uptake, decomposition, and water availability [1]. It has been reported that the influence of soil properties on plant communities within tropical forests is controversial [2]. However, the intrinsic link between distribution patterns of forest tree species and edaphic properties has been reported in many studies [3] [4] [5] [6], implying that soil properties are responsible for maintaining growth and survival of particular tree species within tropical forests [7] [8] [9]. The growth and survival of forest tree species as conditioned by soil fertility status, among other factors, will in the long run determine the abundance and distribution patterns at the landscape scale [8], and even at the local scale [10]. Emphasizing on plant species distribution patterns along environmental factors such as soils is important for several reasons [5], especially for successful ecological restoration and the establishment of plantations, where better insight into the environmental requirements of the species is needed [7]. Such relations are also very important for integrated and sustainable flora management programmes [11]. The distribution and abundance of plant species in any environment can also serve as indications of the variation in biophysical components of the environment such as soil, water and topography among others [9]. Soil properties are generally controlled by a combination of biotic and abiotic factors that vary across the landscape, and it is this variability that influences soil nutrient pools [12], which in turn account for differential patterns in plant growth and distribution through the availability of soil nutrients [13]. Additionally, the soil system remains an indispensable part of biogeochemical cycles wherein the soil continually acts as a source of nutrients for tree growth in tropical forests [14].

Pericopsis elata (Harms) Meeuwen (Fabaceae), commonly known as Afrormosia or Assamela, is a high value tropical timber species endemic to the Congo Basin and parts of West Africa that suffers regeneration problems [15]. It is considered as "Endangered A1cd" by the International Union for Conservation of Nature (IUCN), and is listed on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) [16]. Very few studies have been carried out with an attempt to explain the relationship that exists between edaphic properties and distribution patterns of *P. elata* within the Congo Basin. For example, earlier studies showed that *P. elata* was among species most representative on clay-rich soils in semi-deciduous forests of the Democratic Republic of Congo [2]. Field experiments aiming to assess the performance of nursery-raised seedlings of *P. elata* in logged forests in South-Eastern Cameroon revealed that the species tolerates a wide range of soil types but these were not specified [17] [18]. Rather, the studies revealed that the performance of *P. elata* seedlings was strongly influenced by light availability, an observation which is in line with that reported in the Democratic Republic of Congo by Unmunay *et al.* [19]. Again, the role of soil fertility was not considered by the latter. Furthermore, Bourland *et al.* [20] report that no data are available regarding the potential pedological requirements of *P. elata*. Thus, challenges in measuring edaphic conditions regulating *P. elata* survival and growth abound. Until now, there are no studies that have simultaneously examined the influence of soil physical and chemical properties on the distribution of *P. elata* alongside the establishment of edaphic requirements for its survival and development. Also, there is a debate on the origin of *P. elata* stems: anthropogenic disturbances [16] [21] versus edaphic properties. In this study, conducted at the local scale, we determine possible soil indicators suitable for survival of *P. elata*, through a survey in and out of a *P. elata* natural forest stand. The edaphic properties determined in this study will stimulate further research gearing towards the establishment of potential edaphic requirements of this valuable timber species.

2. Materials and Methods

2.1. Description of Study Area and Sampling Sites

The study was carried out in a gathered forest management unit (FMU, 10-030 and 10-031) of PALLISCO Company in the East Region of Cameroon. The gathered FMU has a total surface area of 118,052 ha (FMU 10-030 = 76,850 ha and FMU 10-031 = 41,202 ha), located between latitudes 3˚05'N and 3˚30'N and longitudes 14˚00'E and 14˚30'E. The climate is the Equatorial Guinea sub-type with two seasons; the main wet season (September to November) and main dry season (December to February), and two minor seasons designated as short wet (March to May) and short dry (June to August). Mean annual temperature is 23.1˚C and mean annual rainfall is 1566 mm [22]. Altitude varies between 600 and 760 m above sea level. The area mostly has semi-deciduous forests, with a vegetation canopy dominated by *Meliaceae*, *Sterculiaceae* and *Ulmaceae* families [17]. The soils are mainly ferralitic (Ferralsols) [23] and are developed from various parent materials such as micaschists, gneisses and granites [24]. A dense hydrographic network exists with many streams while areas of low altitudes (<600 m) contain marshes and raffia swamps (**Figure 1**). Two sites located in the northeastern part of the FMU, about 8 km away from Makalaya (a forest camp in the gathered FMU), were chosen for the study, given that these sites had undisturbed (natural) forest. The two sites, adjacent to one another and separated by a distance of about 1000 m were chosen based on the abundance of *P. elata* stems in each site (Authors, field observation). From field observations, the site of high *P. elata* stems had a distinct reddish yellow soil colour (5YR 6/8) compared to the site of low *P. elata* stems which had a dark reddish colour (10R 3/6).

2.2. Field Methods, Data Collection and Soil Sampling

Data collection and soil sampling were done in October 2014. In each site, a rectangular plot of 10 ha (200 × 500 m) was demarcated and within each, square sub plots of 0.25 ha (50 × 50 m) were established, following procedures outlined by Picard and Gourlet-Fleury [25]. In all, thirty eight sampling units of 50 × 50 m were established inside the *P. elata* stand while sixteen sampling units were delineated outside the *P. elata* stand. In each sub plot, diameter at breast height

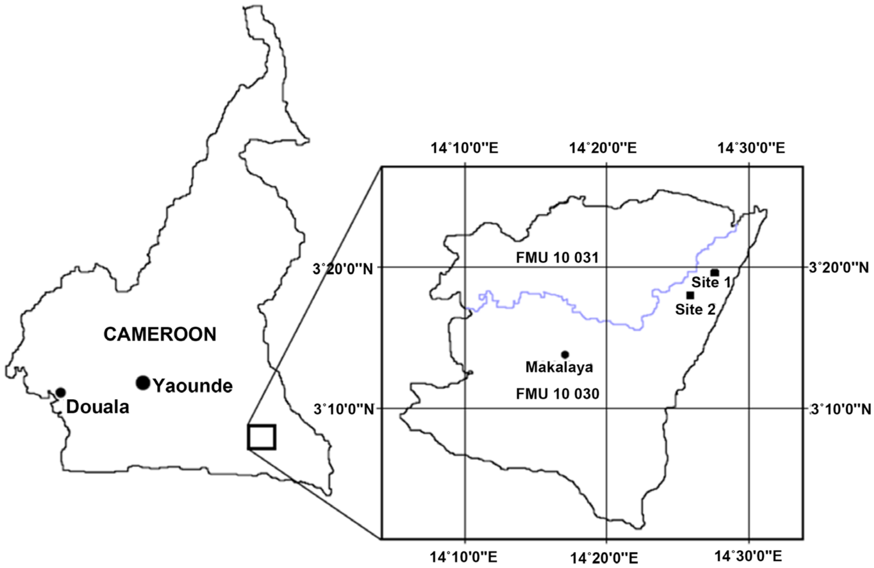

Figure 1. Location of the study area in the East Region of Cameroon showing the gathered FMUs (FMU 10-030 and FMU 10-031). The study sites are represented by the black squares in the north-eastern part of FMU 10-030. Site 1 is the area rich in *P. elata* stands while Site 2 is the area outside *P. elata* stands. The Boumba River (shown in blue) flows westbound across the study area and marks the boundary between the gathered FMUs.

(dbh) was measured and individual trees counted to obtain the number of stems per sub plot. Only trees with dbh > 30 cm were considered because dbh > 30 cm for the species constitute the minimum fertile and effective fruiting diameters [26], capable of reproducing. Within each sampling unit, soil samples were randomly collected at two depths: 0 - 20 cm and 20 - 40 cm, and bulked to obtain composite samples for each of the depths. These depths were chosen based on the fact that nutrient cycling within tropical forests occurs primarily within the upper layer of the soil, following decomposition of plant litter [14]. Soil samples were collected and stored in polythene bags.

2.3. Laboratory Analysis

Fresh soil samples from the field were air-dried at room temperature, crushed and sieved through a 2 mm sieve. The <2 mm soil fraction was analyzed for both physical and chemical properties. Particle size analysis was done following the hydrometer method [27]. Soil pH was determined electrometrically with a 1:2.5 soil:H_2O and 1:2.5 soil:KCl ratio. Organic carbon (OC) was determined by the Walkley and Black wet combustion method as described by Pauwels *et al.* [28]. Exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+, K^+) were determined following the Schollenberger method using a 1 M ammonium acetate solution buffered at pH = 7. The concentrations of Na^+ and K^+ in the extract were determined by flame photometry while Ca^{2+} and Mg^{2+} were determined by complexometry using a 0.002 M Na_2-EDTA solution. Cation exchange capacity (CEC) was determined as a direct continuation of the Schollenberger's method using a 1N KCl saturation solution. Exchangeable acidity (Al^{3+} + H^+) was determined following procedures outlined by Dipak and Abhijit [29] using a 1N KCl solution for soil leaching. Effective CEC (ECEC) and base saturation (BS) were determined by the summation method [28].

2.4. Statistical Analysis

Descriptive statistics were performed for soil physical and chemical properties in and out of the *P. elata* forest stand. Mean values of soil properties between the two sites were compared using the Student's t-test. The Shapiro-Wilk test [30] was used to test for normality of soil properties within each site. Based on the distributions obtained in the *P. elata* stand, optimal soil conditions for *P. elata* distribution were established for surface and subsurface soil properties using normally distributed properties. Optimal soil conditions within 0.25 ha sub plots with ≥ 5 stems, 3 - 4 stems, 1 - 2 stems and sparse (no stem) were respectively considered highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N) classes following the FAO land suitability classification [31]. The aforementioned was refined with soil data available in the literature for the Congo Basin. Correlation analysis was carried out to identify soil properties correlated with tree stems per sub plot. Principal component analysis was performed on tree and soil data in the *P. elata* stand to identify factors responsible for the variation in tree population and soil properties. Statistical analyses were facilitated with SPSS software for windows (Version 19).

3. Results

Soil physical characteristics within 0 - 20 cm of soil depth showed that in both sites, the dominant soil fraction was clay. In the *P. elata* stand, clay content ranged between 24.0 and 49.0% (mean = 37.1%), silt ranged between 8.0 and 34.0% (mean = 16.8%), fine sand ranged between 3.0 and 37.0% (mean = 20.7) and coarse sand ranged between 11.0 and 40.0% (mean = 25.4%). Out of the *P. elata* stand, clay content ranged between 31.0 and 55.0% (mean = 43.6%), silt ranged between 10.0 and 26.0% (mean = 18.4%), fine sand ranged between 18.0 and 31.0% (mean = 24.5%) and coarse sand ranged between 7.0 and 17.0% (mean = 13.5%). Soils in the *P. elata* stand had a sandy clay texture while those out of the stand had a clayey texture. There was a significant difference in the mean values of clay and sand contents in and out of soils under *P. elata* stands ($p = 0.001$ for clay; $p = 0.004$ for fine sand; $p < 0.001$ for coarse sand) (**Table 1**).

Soils in the *P. elata* stand were generally less acidic than those outside. For surface soils at 0 - 20 cm soil depth, there was no significant difference in soil pH between both sites. However, there existed a significant difference in mean values of sub-surface soil pH (20 - 40 cm) ($p < 0.001$) (**Table 2**). Exchangeable acidity (Al^{3+} + H^+) was significantly higher out of *P. elata* stands ($p < 0.001$). In both sites, OC decreased with soil depth, ranging from 3.2% to 0.7% in the *P. elata* stand and 2.9% to 0.9% out of the stand.

Table 1. Comparison of mean (±SE) soil physical properties (0 - 20 cm) in and out of *P. elata* stands.

Soil characteristics	*P. elata* stand		t-value	Probability
	Inside (n = 38)	Outside (n = 16)		
Clay (%)	37.1 ± 1.1	43.6 ± 1.4	−3.42	0.001*
Silt (%)	16.8 ± 0.9	18.4 ± 1.0	−0.98	0.333
Fine sand (%)	20.7 ± 0.9	24.5 ± 0.8	−3.05	0.004*
Coarse sand (%)	25.4 ± 1.1	13.5 ± 0.7	9.4	<0.001*

Notes: *: Mean values are significantly different at $p < 0.05$.

Table 2. Comparison of mean (±SE) soil chemical properties between sites in and out of *P. elata* stands.

Soil characteristics	Depth (cm)	Unit	*P. elata* stands		t-value	Probability
			Inside (n = 38)	Outside (n = 16)		
pH-H_2O	0 - 20	-	4.18 ± 0.03	4.07 ± 0.06	1.99	0.06
pH-H_2O	20 - 40	-	4.79 ± 0.02	3.97 ± 0.02	23.03	<0.001*
OC	0 - 20	%	2.1 ± 0.1	2.9 ± 0.1	−5.38	<0.001*
OC	20 - 40	%	1.3 ± 0.1	2.0 ± 0.1	−5.49	<0.001*
Ca^{2+}	0 - 20	$cmolc \cdot kg^{-1}$	0.51 ± 0.02	0.58 ± 0.03	−1.77	0.083
Mg^{2+}	0 - 20	$cmolc \cdot kg^{-1}$	0.16 ± 0.01	0.26 ± 0.04	−2.44	0.025*
K^+	0 - 20	$cmolc \cdot kg^{-1}$	0.005	0.01	Nd	Nd
Na^+	0 - 20	$cmolc \cdot kg^{-1}$	0.004	0.01	Nd	Nd
$(Al^{3+} + H^+)$	0 - 20	$cmolc \cdot kg^{-1}$	4.02 ± 0.06	5.76 ± 0.07	−17.45	<0.001*
CEC	0 - 20	$cmolc \cdot kg^{-1}$	6.46 ± 0.14	7.79 ± 0.12	7.26	<0.001*
ECEC	0 - 20	$cmolc \cdot kg^{-1}$	4.7 ± 0.07	6.62 ± 0.09	−16.29	<0.001*
BS	0 - 20	%	10.6 ± 0.5	11.0 ± 2.7	−0.50	0.62

Notes: *: Mean values are significantly different at $p < 0.05$; SE: Standard error of means; Nd: Not determined.

In both sites, exchangeable bases were generally low in concentration. Na^+ and K^+ had the lowest concentrations, a trend similar to those observed in the humid forest soils of south southern Nigeria [9], in ferralitic forest soils of the Democratic Republic of Congo [2] and in most soils of lowland humid tropical forests [32] [33]. Between both sites, there was a significant difference in mean values of organic carbon ($p < 0.001$), Mg^{2+} ($p < 0.025$) and CEC ($p < 0.001$). There was a significant negative correlation between *P. elata* stems per sub plot and soil pH, OC and Ca^{2+} within 20 cm soil depth, and a positive correlation between tree stems and clay content (**Table 3**).

With respect to variation in soil properties and number of stems per sub plot, principal component analysis yielded 4 components (PC) and these were

Table 3. Correlation between *P. elata* stems and soil characteristics.

	pH-H_2O	pH-KCl	pH-H_2O#	pH-KCl#	OC	OC#	Ca^{2+}	K^+	Mg^{2+}	CEC	ECEC	BS	Clay	Silt	Sand
P. elata stems	−0.17	−0.37*	−0.12	−0.14	−0.33*	−0.18	−0.35*	−0.1	−0.16	−0.07	0.01	−0.31	0.36*	−0.22	−0.02

Notes: *: Correlation is significant at $p < 0.05$; #: 20 - 40 cm soil depth.

retained for interpretation of the variation in soil properties and number of stems. A total of 76% of the variation observed is explained by these 4 components (Table 4).

PC1 had high positive loadings on exchangeable acidity (0.97) and ECEC (0.93), and high negative loadings on sub-surface soil pH (−0.95) and coarse sand (−0.79). PC1 also had moderate positive loadings on surface soil CEC (0.67) and subsurface OC (0.61). The loading on number of stems was small and negative (−0.3). PC1 explained up to 45% in the variation and was named soil acidity/saturation factor. Considering the grouping of number of stems mentioned earlier, units with ≥ 5 stems/sub plot will have an exchangeable acidity range of 3.3 - 4.7 cmolc·kg^{-1} (mean = 4.0 cmolc·kg^{-1}) and pH range of 4.6 - 5.0 (mean = 4.8). Sites out of the *P. elata* stand will have exchangeable acidity ranging between 5.3 - 6.3 cmolc·kg^{-1} (mean = 5.76 cmolc·kg^{-1}) and a pH range of 3.8 - 4.2 (mean = 3.97). These pH ranges fall within the range of acidic soils reported by Amani *et al.* [2] in acidic forest soils of the Democratic Republic of Congo where high *P. elata* stands were observed. PC2 was named as base status factor because it had high positive loadings on base saturation (0.96), Ca^{2+} (0.8) and Mg^{2+} (0.76). Threshold values for these three variables in the *P. elata* stand range from 0.04 - 0.31 cmolc·kg^{-1} Mg^{2+} (mean = 0.16 cmolc·kg^{-1}), 6.2% - 17.8% BS (mean = 10.6 %) and 0.32 - 0.88 cmolc·kg^{-1} Ca^{2+} (mean = 0.51 cmolc·kg^{-1}). Out of the *P. elata* stand, values for these variables range from 0.04 - 0.56 cmolc kg^{-1} Mg^{2+} (mean = 0.26 cmolc·kg^{-1}), 7.6% - 15.9% BS (mean = 11%) and 0.4 - 0.8 cmolc·kg^{-1} Ca^{2+} (mean = 0.58 cmolc·kg^{-1}). PC3 had a high positive loading on surface soil pH (0.82) and a moderate negative loading on number of stems per sub plot (−0.6) and was named topsoil-pH/tree factor. This component indicates that a high number of stems per sub plot is antagonistic to surface soil pH (0 - 20 cm), contrary to that of sub-surface pH (20 - 40 cm). Following the arguments raised in the first component, it is suggested that *P. elata* distribution is greatly influenced by subsurface soil pH. Soil pH provides a good indication of the chemical status of the soil and can be used in part to determine potential plant growth in forest milieu, given that soil pH greatly influences plant nutrient availability [33]. PC4, known as the texture factor indicated that high silt contents do not favour *P. elata*. The edaphic properties have been reported in four suitability classes (Table 5).

4. Discussion

4.1. Influence of Edaphic Properties on Distribution of *P. elata*

The correlation between *P. elata* stems and clay content gives evidence that the distribution of *P. elata* is a function of soil texture. Clay is generally considered

Table 4. Rotated component matrix[a] of principal components.

Soil properties	Component			
	1	2	3	4
$(Al^{3+} + H^{+})$	0.971			
pH-H_2O (20 - 40 cm)	−0.950			
ECEC (0 - 20 cm)	0.932			
pH-KCl (20 - 40 cm)	−0.884			
Coarse sand (0 - 20 cm)	−0.793			
CEC (0 - 20 cm)	0.674		0.334	
OC (20 - 40 cm)	0.610		0.336	0.306
OC (0 - 20 cm)	0.575		0.397	
BS (0 - 20 cm)		0.962		
Ca^{2+} (0 - 20 cm)		0.806	0.344	
Mg^{2+} (0 - 20 cm)	0.410	0.766		
pH-KCl (0 - 20 cm)			0.829	
P. elata stems	0.307		−0.608	−0.386
Silt (0 - 20 cm)				0.902

Notes: [a]: Extraction method, principal component analysis; Rotation method: Varimax with Kaiser normalization. Component 1 is the soil acidity/saturation factor; Component 2 is base status factor; Component 3 is the topsoil-pH/tree factor; Component 4 is the texture factor.

Table 5. Edaphic properties in and out of *P. elata* natural forest stand.

Soil properties	Suitability classes			
	S1	S2	S3	N
pH-H_2O (0 - 20 cm)	4.10 - 4.30	4.00 - 4.40	4.00 - 4.60	<4.00 and >5.00
pH-H_2O (20 - 40 cm)	4.60 - 4.90	4.70 - 4.90	4.60 - 5.00	<4.0 and >5.00
OC (0 - 20 cm) (%)	1.51 - 1.90	1.23 - 2.97	1.01 - 3.19	<1.00
OC (20 - 40 cm) (%)	0.73 - 1.34	1.08 - 1.85	0.73 - 1.96	< 0.73
Ca^{2+} (0 - 20 cm) ($cmolc \cdot kg^{-1}$)	0.32 - 0.41	0.34 - 0.64	0.33 - 0.88	<0.33 and >0.88
Mg^{2+} (0 - 20 cm) ($cmolc \cdot kg^{-1}$)	0.08 - 0.25	0.05 - 0.18	0.04 - 0.31	<0.04 and >0.31
(Al + H) (0 - 20 cm) ($cmolc \cdot kg^{-1}$)	3.78 - 4.43	3.71 - 4.31	3.33 - 4.67	>4.67
CEC (0 - 20 cm) ($cmolc \cdot kg^{-1}$)	4.99 - 6.59	4.98 - 8.64	4.85 - 8.00	<4.85 and >8.64
ECEC (0 - 20 cm) ($cmolc \cdot kg^{-1}$)	4.26 - 4.92	4.35 - 4.88	3.85 - 5.46	<3.85 and >5.50
BS (0 - 20 cm) (%)	6.9 - 9.6	6.6 - 11.5	6.2 - 17.9	<6.2 and >17.9
Clay (0 - 20 cm) (%)	34.6 - 45.6	32.6 - 46.6	24.6 - 48.6	<24.0 and >50.5
Silt (0 - 20 cm) (%)	9.0 - 20.0	10.0 - 26.0	8.0 - 34.0	<9.0 and >37.0
Fine sand (0 - 20 cm) (%)	14.7 - 26.3	9.7 - 29.1	3.2 - 36.9	<10.0 and >37.0
Coarse sand (0 - 20 cm) (%)	20.1 - 29.1	12.5 - 33.5	10.9 - 39.7	<11.00 and >40.00

Notes: S1: Highly suitable (≥5 stems/0.25 ha); S2: Moderately suitable (3 - 4 stems/0.25 ha); S3: Marginally suitable (1 - 2 stems/0.25 ha); N: Not suitable (no stems). Source: Modified from Boyemba [34].

as the active part of soil because it plays a role in the supply and availability of nutrient elements [35]. The impact of edaphic heterogeneity on species assembly has been reported in rainforests of the Congo Basin, where differences in soil texture (clayey versus sandy soils) considerably influence biodiversity and habitat preference [2] [36] [37]. According to Silver *et al.* [38], soil texture is primarily responsible for nutrient availability in lowland tropical forests. Also, the observed effect of silt in this study is in line with observations made by Iwara *et al.* [9], where silt content was observed to have a strong influence on the distribution of some particular tropical lowland forest species such as *Anthonota macrophylla*. Although the soils in our study area are dominated by low activity clays such as kaolinite and Fe and Al oxides [24], it is suggested that clay content in this case plays an important role in the availability of acidic elements such as Al^{3+} in the soil solution. This observation is in accordance with the relationship between *P. elata* stems and soil pH, indicating that a high number of *P. elata* stems may not be favoured at particular pH values (pH between 4.0 and 5.0). It has been observed that Al^{3+} in acidic soils has a distinct negative effect on survival of some forest tree species [39] through Al toxicity. Increasing aluminum levels in the soil solution have been reported to decrease uptake and translocation of calcium, magnesium, and potassium [40]. The primary target of Al toxicity is the root apex and aluminium affects a host of different cellular functions. Exposure to Al causes stunting of the primary root and inhibition of lateral root formation in some plants. This phenomenon is still to be verified for *P. elata*. The resulting restricted root system is impaired in nutrient and water uptake, making the plant more susceptible to drought stress [40] [41]. However, Boyemba [34] observed that high concentrations of Al^{3+} inhibited proper growth and survival of *P. elata* in a humid tropical forest in the Democratic Republic of Congo. With respect to availability and uptake of Nitrogen, it has been reported that *P. elata,* being a *Fabaceae*, is a nitrogen-fixing plant thanks to its symbiotic relationship with some bacteria [42]. The supply of Nitrogen has been reported to exert strong control over the composition, diversity and productivity of many ecosystems [43]. This is because nitrogen metabolism is one of the most important factors often limiting plant growth in natural ecosystems [44]. Nitrogen-fixing trees such as *P. elata* have tree sources of inorganic N (nitrate, ammonium and atmospheric nitrogen) fixed by symbiotic bacteria, even though we did not determine nitrogen in this study. However, Nitrogen supply can be greatly reduced at high aluminium concentrations through the inhibition of specific enzymes responsible for nitrogen assimilation [45]. Soil pH also has an indirect influence on organic matter decomposition and nutrient availability by affecting soil microorganisms [32]. The relationship observed between *P. elata* stems and exchangeable Ca^{2+} is striking. Although calcium is one of the most abundant mineral elements in soil, this is not the case in tropical soils. Calcium has several distinct functions in higher plants [46], but Ca^{2+} concentration in this case seems to affect *P. elata* stems negatively. It has been observed that tree communities are greatly influenced by exchangeable bases (Ca^{2+} and Mg^{2+}) [9],

[39]. Also, Iwara *et al.* [9] observed that low base saturation is suitable for establishment of particular tree species in humid tropical forests. The negative correlation between *P. elata* stems and soil pH suggests that high pH conditions (pH > 5.0) reduce tree population, and so, *P. elata* is suggested to have a well defined acidity range necessary for its survival. John *et al.* [4] identified soil pH as the strongest factor that influenced the distribution of tree species in three tropical forests.

Organic matter plays an important role in binding soil cations and in ameliorating soil structure, thus providing a favorable condition for plant growth. Correlation analysis indicates that a high number of *P. elata* stems is favoured by low amounts of organic matter. This correlation could be explained by the classical relationship between clay and organic matter [47], given that there was a positive correlation between *P. elata* stems and clay content. The low organic matter content is certainly due to high rates of organic matter decomposition as influenced by the quality of litter type, which favours nutrient cycling [14] with the consequence of making nutrients available for immediate uptake by plants. Additionally, soil organic matter contains a large number of exchange sites (high surface area and hence high cation exchange capacity) that increase the capacity of the soil to adsorb these nutrients and prevent them from leaching below the rooting zone [48]. It has been reported that present *P. elata* patches in the study area considered in southeastern Cameroon are related to anthropogenic disturbances (most likely resulting from shifting cultivation that occurred ca. two centuries ago) [16]. However, other studies reveal that not all patches of African light-demanding tall trees (such as *P. elata*) are caused by human-induced disturbances [49]. In our study sites, no signs of anthropogenic disturbances (e.g. presence of charcoal or pottery sherds) were observed in the soil layers, contrary to the observations made by Bourland *et al.* [16] about 30 Km away from our study site, where they found a link between anthropogenic disturbances and *P. elata* population. Among other factors, edaphic properties have been reported to significantly affect the distribution of many tree species within humid rainforests and semi-deciduous forests of the Congo Basin [2] [37] [42]. In a study of within-plot relationships between tree species occurrences and hydrological soil constraints in a lowland rainforest of French Guiana, it was reported that soil hydrological conditions (particularly soil drainage), were the main structuring factors of the local multispecies spatial pattern observed [50]. However, our study did not take into account groundwater availability (which could probably influence the spatial distribution of *P. elata*) due to the complexity in quantifying groundwater availability and also because the species has been reported to tolerate a wide range of water regimes ranging from well drained soils to seasonally waterlogged ones [7].

4.2. Local Scale Edaphic Requirements for Survival of *P. elata*

In the literature, the controversy that exists with respect to the influence of soil properties on the distribution of forest tree species has been argued either through experimentation or field exploration. For the case of *P. elata*, the survival rate within forest environments has been attributed to factors such as light availability [15] [17], influence of pests [20], herbivory [51] and edaphic heterogeneity [2] [34] [42]. The findings in the present study derive from field observation, wherein the distribution of *P. elata* is certainly influenced by soil properties among others. Therefore, the edaphic properties identified in this study could serve as a starting point for studies seeking to establish edaphic requirements for the survival of *P. elata*. The values of pH, CEC, BS and exchangeable bases observed in this study permit us to suggest that slightly acidic soils within a pH range from 4.10 - 4.30 in surface soils (0 - 20 cm) and 4.60 - 4.90 for sub-surface soils (20 - 40 cm), could be considered as baseline information that can guide or stimulate further research aiming at establishing pedological requirements of *P. elata*. In this study, our values for exchangeable acidity do not exceed 4.67 $cmolc \cdot kg^{-1}$ within 40 cm soil depth, and so, further studies are highly recommended in order to complement these findings in other *P. elata* natural forest stands within the Congo Basin.

5. Conclusion

The results obtained show that site selection of *P. elata* is a function of varying nutrient concentrations at particular ranges of tolerance and are strongly influenced by soil acidity and texture. This study also shows that there is a link between soil properties and distribution of *P. elata.* Additionally, the results suggest that the main soil characteristics to be considered in plantation establishment are soil pH, base status (CEC, base saturation and exchangeable bases), exchangeable acidity, OC and clay content. Since forest environments are very complex, coupled to the complex nature of the soil system, *P. elata* may grow on soils outside the ranges proposed in this study. Notwithstanding, values of soil properties reported indicate where *P. elata* may have the best chances of survival. The edaphic characteristics proposed serve as baseline information for the stimulation of future research within other sites endemic to this valuable species so as to complement the results reported in this study. Based on the results obtained, the following are suggested: the setup of experiments to monitor and evaluate the effects of different concentrations of acidic elements such as Al and Fe on *P. elata* seedling performance in nurseries.

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