Original Research Article

Population structure, leaf production and soil conditions of *Megaphrynium macrostachyum,* a key non-wood forest product in Central Africa

ABSTRACT

Aims: *Megaphrynium macrostachyum* is a key non-wood forest product (NWFP) in Central Africa. This study aims to describe the population structure, leaf production and soil conditions of *Megaphrynium macrostachyum* in a fallow in southeastern Gabon.

Methodology: Leaf growth was monitored weekly on a sample of 60 leaves for 10 weeks, after the unrolling of horns. Population structure and leaf production were quantified on 64 m² plots and then extrapolated to the hectare. Soil samples were collected at 30 cm depth.

Results: Leaf growth and stem enlargement were observed to take place during the horn stage, while stem elongation became active after this stage. The stem reached its maximum height about 60 days after the leaf had fully unrolled. Within the same population, leaf length and leaf width were less heterogeneous (on average 55.6 ± 5.9 cm and 35.5 ± 4.5 cm, respectively); whereas leaf area, stem diameter and stem height were quite heterogeneous (on average 1475 ± 328.3 cm², 9 ± 2.2 mm and 154 ± 33.3 cm, respectively). *Megaphrynium macrostachyum* was observed to colonise its environment quite well (148,646 ± 66,623 stems per hectare), thus explaining its high leaf production (104,167 ± 45,271 usable leaves per hectare). The soil sample analyzed revealed *Megaphrynium macrostachyum* to grow in sandy-silty or sandy-silty-clay soils (58.21% sand, 25.69% silt and 16.1% clay), and in soils that are wet (35% relative humidity), acidic (pH 4.01), low in phosphorus (9.38 ppm assimilable phosphorus) and total nitrogen (0.01% total nitrogen), and high in organic matter (19.3% organic matter).

Conclusion: These results may be useful for the domestication process of *Megaphrynium macrostachyum*, as they provide insights into the behaviour and needs of the species in its natural habitat.

Keywords: non-wood forest products (NWFP), Megaphrynium macrostachyum, Population structure, Leaf production, Soil conditions, Fallow, southeastern Gabon.

1. INTRODUCTION

Non-wood forest products (NWFPs) play an important rôle in nutrition and socio-economics for rural populations in Africa [1,2,3,4,5,6]. Among plant species commonly exploited, those of the Marantaceae family occupy a predominant place [5]. Their leaves are used in construction, traditional medicine, handicrafts (making baskets, baskets, mats and pods) and food [7,8,9,10]. Their use as packaging in local cassava stick production contributes to the household economy [11]. However, the poverty of NWFP collectors encourages over-exploitation of the resource, threatening its availability [12]. The majority of species providing NWFPs are subject to high anthropogenic pressure, which can reduce their reproductive capacity or natural regeneration. Ensuring that such goods and services continue to be provided by NWFPs therefore requires sustainable management of the species, while meeting the needs of rural populations [13]. The species *Megaphrynium macrostachyum* (K.Schum.) Milne-Redh is one of the most commercialised species of Marantaceae [14]. It has been identified as a priority NWFP in Central Africa [19], but few studies have investigated its regeneration dynamics. It is, therefore, important to increase and improve knowledge of this species' ecology and developmental characteristics. Furthermore, knowledge of development conditions *in situ* could facilitate the domestication, valorisation and conservation of the species, while increasing the income of those involved in its exploitation. Sustainable management of *Megaphrynium macrostachyum* will require prior knowledge of certain characteristics (e.g. regeneration mode) of the species and its environment [15].

The objectives of this study are (1) to characterise the exploitation of *Megaphrynium macrostachyum* by local populations in a rural village in southeastern Gabon, (2) to assess the population structure and leaf production of *Megaphrynium macrostachyum* in a fallow land in southeastern Gabon, and (3) to determine the soil conditions of this area.

2. MATERIALS AND METHODS

2.1 Study area

The study was conducted in a fallow land in the village of Moyabi (1-40.221'S and 13-19.681'E) located on the Franceville-Moanda road (south-eastern Gabon). The vegetation of Moyabi is dominated by savannah, interspersed with gallery forests (Fig. 1). The climate is equatorial, in a state of transition, marked by two rainy seasons (March–May and September–December) and two seasons with less rainfall (June–August and January–February). The average annual rainfall is about 1800 mm. The hilly terrain has vast undulating plains and a few moderate slopes. The area was chosen because of the presence of a stand of *Megaphrynium macrostachyum* and because of its proximity to urban centres. According to [16] and [17], it is at this interface between the forest ecosystem and urban centres that the exploitation and trade of NWFPs are important.

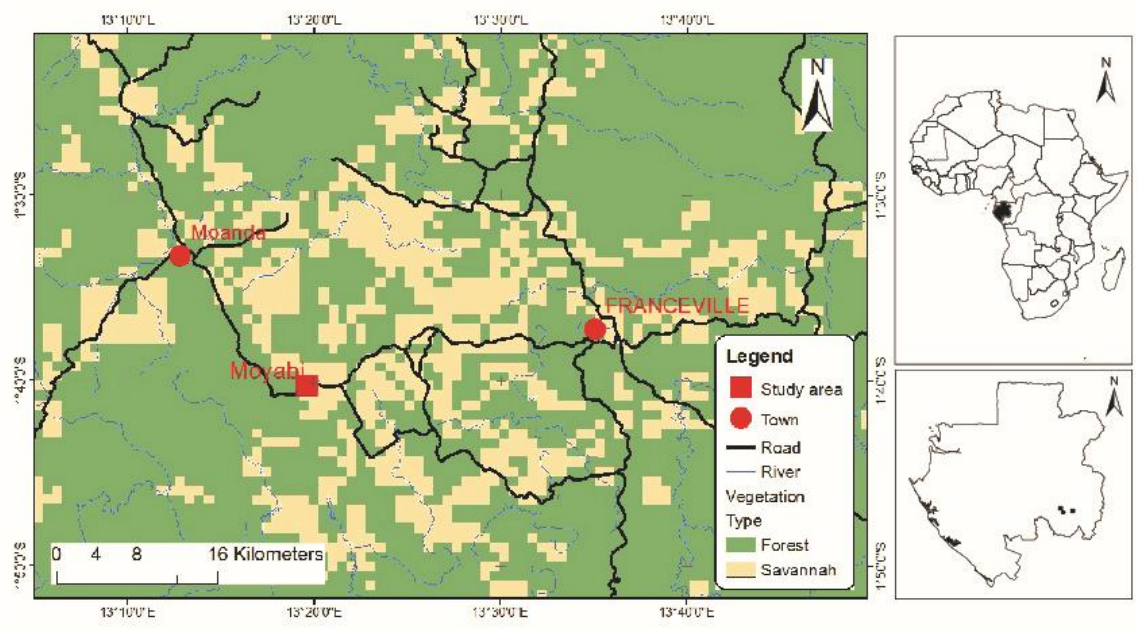

Fig. 1. Study area

2.2 Materials

The biological material studied included the target species *Megaphrynium macrostachyum* (K.Schum.) Milne-Redh of the Marantaceae family [18] and soil samples from a fallow land in the village Moyabi, where the target species grows.

2.3 Methods

2.3.1 Sampling and data collection

2.3.1.1 Sampling design

The sampling design consisted of six square plots, arranged in a line and perpendicular to the slope. The plots were separated by about 4–5 m, and resulted in an area of 64 m².

2.3.1.2 Sample collection

In each plot, we randomly selected two tufts. A tuft is an agglomeration on stems (Fig. 2b), and each stem is topped by a single leaf (Fig. 2a). For each tuft, two leaves were taken at random, for a total of 24 leaves. Soil samples were collected at 30 cm depth at the base of the same tufts.

Fig. 2. Horn stages and population structure
a: horn stages (a1- coiled leaf ; a2- unrolling leaf ; a3- leaf at end of unrolling ; a4- unrolled leaf); b: population structure

2.3.1.3 Sample processing

Soil was stored in plastic bags and leaves were tied in bundles for transport to the laboratory. In the laboratory, the soil was air-dried for one week, some of the leaves were dried in an oven at 105°C for a fortnight, and the remaining samples were kept in the freezer. Dried soil and leaves were subsequently sieved with three different mesh sizes (200 µm, 100 µm and 50 µm) according to the physico-chemical analyses to be performed. The sub-samples obtained were stored in plastic bags.

2.3.1.4 Physico-chemical analyses

Granulometric analysis was performed using the Robinson Khöhn pipette method, which is based on the law of stocks: the larger the particle, the faster it descends in water [20]. Soil moisture was determined by the ratio of the difference between fresh mass (mass before drying) and dry mass (mass after drying), to fresh mass, multiplied by 100 [21]. The organic matter (OM) content was estimated according to a method of physical loss on ignition [22,21]. Organic carbon content was calculated as the ratio of OM to a conversion factor [23,24]. pH(H2O) and pH(KCl) were measured using the electro-metric method [25]. Nitrogen was measured in two steps: mineralisation and distillation, according to the Kjeldhal method [26]. The determination of total phosphorus and assimilable phosphorus was carried out by colorimetry with a UV spectrophotometer visible at a wavelength of 712 nm [27].

2.3.1.5 Characterisation of the leaves used

Megaphrynium macrostachyum leaves are sold in bundles, with each bundle containing 22 to 40 leaves. Five bundles (a total of 114 leaves), randomly selected from Moyabi farmers, were used to

study harvested leaf dimensions. For each leaf, the maximum length (length of the main midrib) and maximum width were measured in centimetres with a double decameter. The dimensions of the smallest and largest leaves observed constituted the 'exploitable leaf range (ELR)' of the Moyabi populations. To measure leaf area, 14 leaves were randomly selected, and their widths were measured every 0.5 cm along the main midrib.

2.3.1.6 Study of population structure and leaf production

In the plots, the distances between neighbouring tufts were measured, to assess the spatial dispersion of the species, and counted the total number of tufts and the total number of stems, to assess stand density. Stand density was then used to estimate leaf production. The total number of leaves is equal to the total number of stems, because in the species *Megaphrynium macrostachyum*, a stem is topped by a single leaf [17]. The total number of leaves in each plot was taken as the gross production of that plot. The net production or useful production of a plot was the total number of leaves whose dimensions (maximum length and width) fit into the ELR. This variable was quantified within the plots.

2.3.1.7 Monitoring of leaf and stem growth

In each plot, 10 stems with unrolling leaves were randomly selected, resulting in a total of 60 stems. After complete leaf unrolling, the dimensions (maximum leaf length, maximum leaf width, stem length, stem diameter) of the 60 stems were recorded. Growth monitoring (measurement of leaf and stem dimensions) was subsequently carried out once a week for 10 weeks.

2.3.2 Statistical analysis

2.3.2.1 Leaf area estimation

The area of the harvested leaves was calculated using the formula $S = \beta \times L_{max} \times l_{max}$, where S is the estimated leaf area, β (= 0.7648) is the shape coefficient, L_{max} is the maximum leaf length and l_{max} is the maximum leaf width. This approach has been proposed by several authors [28,29,30,31,32,33,34,35]. The calculation of β is described in the Appendix.

2.3.2.2 Calculation of structure and production variables

The structure and production variables, quantified in the 64 m² plots, were extrapolated to the hectare. Their calculation is described in equations *Eq.1, Eq.2, Eq.3* and *Eq.4*.

$$nT = (1/n) \times \sum \{(10000/A_i) \times nT_i\} \quad (Eq.1)$$

$$nS = (1/n) \times \sum \{nT \times (nS_i/nT_i)\} \quad (Eq.2)$$

$$nL = (1/n) \times \sum \{nS \times (nL_i/nS_i)\} = nS \quad (Eq.3)$$

$$nUL = (1/n) \times \sum \{nT \times (nUL_i/nT_i)\} \quad (Eq.4)$$

nT: average number of tufts per hectare; n: number of plots; Ai: area of plot i; nTi: total number of tufts in plot i; 10000: conversion factor from nTi/Ai to nTi/ha; nS: average number of stems per hectare; nSi: total number of stems in plot i; nL: average number of leaves per hectare; nLi: total number of leaves in plot i; nUL: average number of usable leaves per hectare; nULi: total number of usable leaves in plot i.

2.3.2.3 Analysis of leaf growth

A cinetic curve of the weekly means and standard deviations of leaf characteristics was used to analyse the evolution of leaf and stem dimensions at the post-horn stage (in horn stage the leaf is coiled and in post-horn stage it is fully unrolled).

3. RESULTS

3.1 Dimensions of exploited leaves

The maximum length of exploited leaves was 22–64 cm, with an average of 54.3 ± 6.5 cm; while the maximum width was 16–43 cm, with an average of 34.6 ± 5.1 cm. This gives an average operational

leaf area of 1,380 ± 314.64 cm^2. The maximum operational leaf area observed (2,036.5 cm^2) was about four times the minimum observed (544.5 cm^2).

3.2 Population structure and leaf production capacity

The population structure and leaf production results for *Megaphrynium macrostachyum* are shown in Table 1. The spatial dispersion of the tufts was very irregular with the distance between two consecutive tufts (97 ± 86.4 cm) varying on average by 89.1%. The spatial occupation of the species appeared to exhibit a very irregular mosaic pattern, with densely populated and very sparse areas. This irregularity in tuft distribution leads to highly variable estimates of stand density. In the fallow lands of Moyabi, an average population density of 14,583 ± 8512 tufts per hectare of *Megaphrynium macrostachyum* was observed; with an average fluctuation of 58.37%, indicating that this species is invasive and colonising in fairly open environments. Variation in population density leads to a variation in leaf production. The gross leaf production of *Megaphrynium macrostachyum* was estimated to be about 148,646 ± 66,623 leaves, i.e. an average of 11 ± 3 leaves per tuft. Of this total gross production, about ¾ will be exploitable, i.e. on average 104,167 ± 45,271 exploitable leaves of *Megaphrynium macrostachyum* per hectare; this corresponds to about 7 ± 6 exploitable leaves per tuft. The number of harvestable leaves was found to be highly variable between tufts, indicating an uneven distribution of useful production within a stand.

Table 1. *Megaphrynium macrostachyum* population density and leaf production

		Mean ± standard deviation	Variation Coefficient (%)
Population density	Spread (cm) between tufts [1]	97 ± 86,4	89.1
	Number of tufts per hectare	14,583 ± 8,512	58.4
	Number of stems per tuft [2]	11 ± 3	27.3
	Number of stems per hectare [2]	148,646 ± 66,623	44.8
Gross production	Number of leaves per tuft [2]	11 ± 3	27.3
	Number of leaves per hectare [2]	148,646 ± 66,623	44.8
Exploitable production	Number of usable leaves [3] per tuft	7 ± 6	85.7
	Number of usable leaves [3] per hectare	104,167 ± 45,271	43.5

(1) a tuft is an agglomeration of stems ; (2) since a stem yields only one leaf, the number of leaves is therefore equal to the number of stems ; (3) quantity of leaves of size exploited by Moyabi farmers (see section 3.1)

3.3 Growth performance

The post-horn growth dynamics of *Megaphrynium macrostachyum* were studied using maximum leaf length (Fig. 3a), maximum leaf width (Fig. 3b), diameter at 10 cm of the stem (Fig. 3c) and height of the stem (Fig. 3d).

At the end of the horn stage, i.e. when the leaf limb is fully expanded, the average leaf size was 55 ± 5.9 cm, 35.36 ± 4.5 cm and 1474.7 ± 328.86 cm² for maximum length, maximum width and area, respectively. Monitoring these leaves over a period of 70 days revealed that growth (in length and width) was almost zero. Growth (elongation and widening) of the leaf limb of *Megaphrynium macrostachyum* was observed to take place during the horn stage. The development of the leaves in the post-horn stage does not influence the dimensions of the leaf limb, but rather other characteristics

(vegetation, resistance, etc.) which remain to be studied. Similarly, the diameter of the stem was almost maximal at the end of the horn stage, with an average weekly growth less than 0.5 mm (Fig. 3c). On the other hand, the stem continued to elongate considerably at the end of this stage (Fig. 3d). Stem elongation occurred in four phases: the first phase of accelerated growth took place during the first 28 days after leaf limb unrolling, with an average weekly growth of 25.7 ± 8.3 cm; the second phase was characterised by slow growth between the 28th and 42nd days after leaf limb unrolling, with an average weekly growth of 9.4 ± 2.2 cm; the third phase consisted of very slow growth between the 42nd and 56th days after leaf limb unrolling, with an average weekly growth of 3.5 ± 1.6 cm; and the last phase, exhibiting almost no growth, occurred after the 56th day, with an average weekly growth of 0.25 ± 0.35 cm. The stem reached its maximum length about 60 days after limb unrolling. The elongation of the stem was linked to the development of the leaf blade. In Fig. 2, a difference in colouring of the leaf blade can be seen. In the horn stage, the leaf blade shows a purplish tint (Fig. 2a/ a1), which changed to light green at the end of the horn stage (Fig. 2a/ a2-a3-a4), and finally became dark green on older leaves (Fig. 2b). This gradient of colouring that increases with stem elongation allows the leaf blade to access more light.

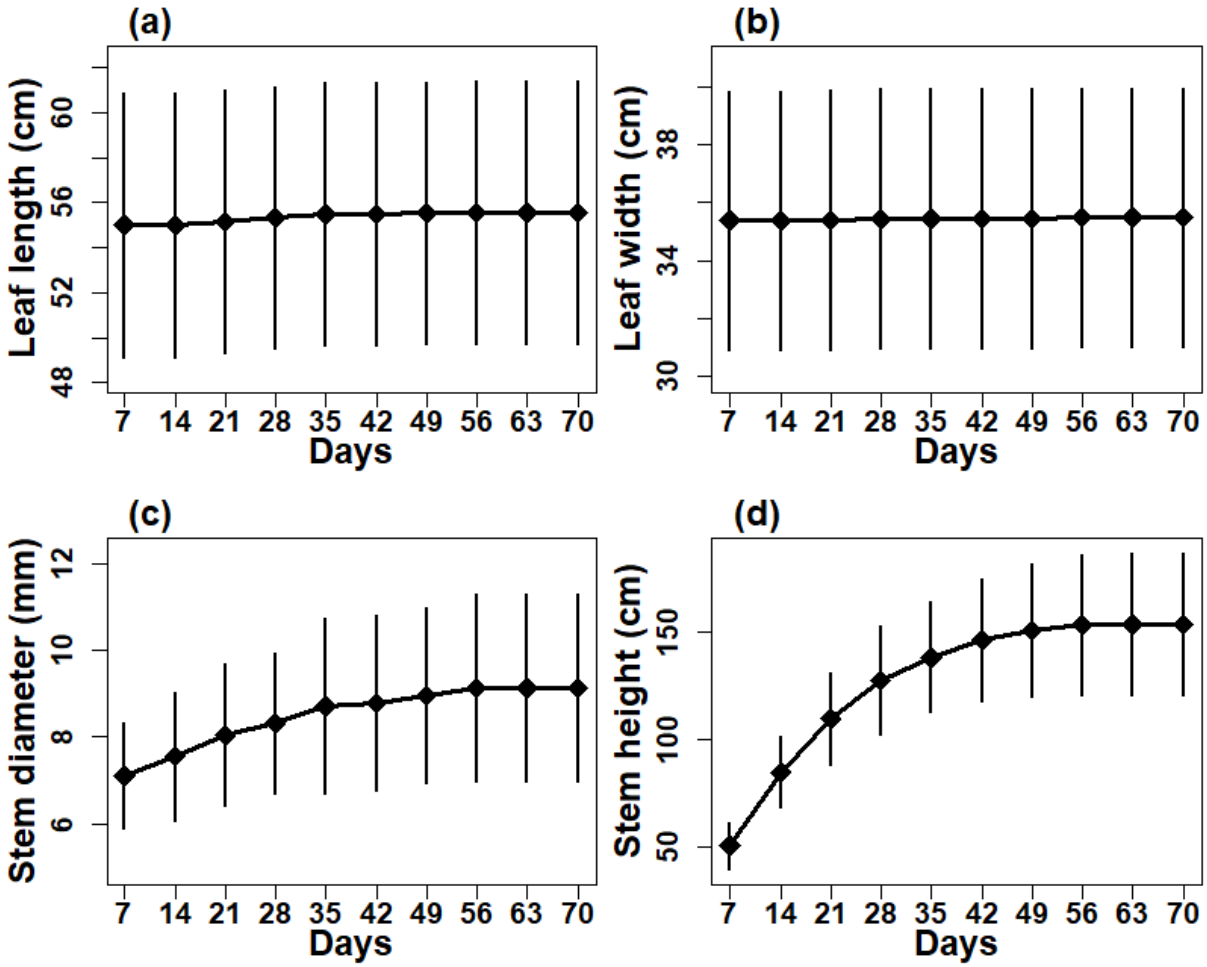

Fig. 3. Average growth of leaf characteristics after unrolling of horns
a: maximum leaf length (cm); b: maximum leaf width (cm); c: stem diameter (mm) at 10 cm; d: stem height (cm); The error bars represent the standard deviation

3.4 Soil conditions

The granulometric analysis of the soil indicated a sandy to sandy-silty texture (nearly 60% sand, of which about 50% was coarse sand, and 24% silt), with a relatively low clay content (16%) (Table 2). *Megaphrynium macrostachyum* grows in acidic (pH ≤ 4), relatively dry soils (35% relative humidity).

The high sand content, especially of coarse sands, accompanied by the low proportion of clay, is associated with the relatively low water content of the soil.

In terms of chemical composition, the soil revealed a lack of essential elements (Table 2): it comprised less than 20% organic matter (OM), less than 10% organic carbon, almost no total nitrogen, and low total phosphorus (52.56 ppm) and assimilable phosphorus (9.38 ppm).

The analysis of *Megaphrynium macrostachyum* leaves revealed a complex phenomenon. The low availability of certain elements (relative humidity, organic matter, organic carbon and total phosphorus) in the soil was associated with a high content of the same elements in the leaves (68% humidity, 74.42% OM, 43.27% organic carbon and 1082 ppm total phosphorus) (Table 2). In view of this observation, sustained growth and development of the species would require an abundance of these elements in the soil; however, this did not seem to be the case for total nitrogen which was more abundant in the soil (0.0103%) than in the leaves (0.0047–0.0075%).

Table 2. Physical-chemical properties of the soil and nutritional needs of *Megaphrynium macrostachyum*

	Soil	Leaves
Coarse sands (%)	48.47	
Fine sands (%)	9.74	
Coarse silts (%)	14.76	
Fine silts (%)	10.93	
Clays (%)	16.1	
pH water	4.01	
pH KCl	3.44	
Relative humidity (%)	35	68.00
Organic matter (%)	19.29	74.42
Organic carbon (%)	9.64	43.27
Total azote (%)	0.0103	0.0047–0.0075
Total phosphorus (ppm)	52.56	1,082
Assimilable phosphorus (ppm)	9.38	
Bioavailable phosphorus (ppm)		488.3–1308.9

4. DISCUSSION

4.1 Stand density and leaf production capacity

4.1.1 Stand density

The average density found in this study covers the densities of the genus *Megaphrynium* spp identified by [8] in various types of plant formations, including in disturbed forests, rocky forests and recently colonized savannahs. However, it is higher than the densities reported for mixed forests, marshes and streams, and lower than the density for Marantaceae forests. Population dynamics are influenced by the natural environment and the type of plant formation. The most favourable environments for this species are Marantaceae forests and recolonized savannahs. This explains the average density recorded in Moyabi fallows, as Moyabi has a predominance of savannah, with some forest galleries. Fallows in this geographical area can therefore be considered recently colonized

savannahs. The same observation has been recorded in Marantaceae forests in the northern forest mosaic of the Republic of Congo [36]. The author demonstrated that, within a plant formation, spatial occupation is relatively heterogeneous from one environment to another. This would explain the high value of the standard deviation obtained in this study. This heterogeneity in the invasion dynamics of the species *Megaphrynium macrostachyum* could be explained by several factors, such as the rate of leaf removal, interactions with other plant species, and the physico-chemical characteristics of the soil.

4.1.2 Leaf production capacity

Although highly variable, leaf production of *Megaphrynium macrostachyum* in fallow land in Moyabi village is high, in comparison to that reported in different types of forests in the Lopé reserve in Gabon [9]. Leaf production of *Megaphrynium macrostachyum* varies with season [9] and soil type [37].

4.2 Soil conditions

Moyabi soil is similar to that of the Yangambi forest [38] and tree-lined forests of Marantaceae and Afromomum [36] in the Democratic Republic of Congo. The high level of coarse sand in this substrate renders it filtering, light, of low structural stability and highly sensitive to physical (erosion) and chemical degradation [39]. This leads to low water and mineral availability, and results in the low levels of moisture and assimilable phosphorus observed. According to [36], this type of soil exhibits reduced fertility because it has low phosphorus and exchangeable bases. The high humidity of *Megaphrynium macrostachyum* leaves is believed to be due to the humid climate of the study area, thus promoting non-limiting water availability [36]. Also, the high presence of bioavailable phosphorus in the leaf organ compared to soil-assimilable phosphorus is partly related to the rainy climate. This leads to the transfer of nutrients, including phosphorus, from the soil to the plant, which is influenced by the mineralization of organic matter, the root or micorhizian activity, the biomass produced and the perpiratory flow [40]. This is also due to a high dynamic transfer of the phosphorus element from the soil to the plant organs [41].

Soil acidity disrupts the mineralizing activity of microorganisms [42], the main mineralizers of organic matter in soil [43]. This would account for the high rate of organic matter observed in the soil, and its nutrient deficiency [44], resulting in low total nitrogen. Organic matter levels are primarily dependent on soil texture, and a sandy texture contains a lower rate than salt-clay soil [45]. This further explains the high level of organic matter observed in Moyabi soil. The high rate of organic matter in the leaves would result from the plant biomass produced during photosynthesis [46,47].

4.3 Growth performance

The leaves of *Megaphrynium macrostachyum* achieve all their growth (elongation and widening of the leaf and magnification of the diameter of the stem) during the horn phase (coiled leaf). Only stem lengthening becomes active after limb deployment. Therefore, if this species is being cultivated, it should be well maintained during the horn phase to promote optimal productivity. The species exhibits a heliophile characteristic [36], and, in competition for solar radiation, growth in height is undoubtedly a determining factor [48,49]. It is also possible that the elongation of the stem is necessary to improve the colouring of the leaf blade. It seems that as the stem lengthens, the greenness of the leaf blade intensifies. In a stand of sugar maple (*Acer saccharum*), one study found a difference in chlorophyll content between overstory and understory leaves, with chlorophyll being more concentrated in the former [50]. The leaves of *Megaphrynium macrostachyum*, which are fragile after unrolling, need access to more light to increase their chlorophyll content and thus their resistance.

5. CONCLUSION

The locally exploited range of the leaf area of *Megaphrynium macrostachyum* is relatively large. The species is less demanding on the edaphic conditions. On poor, acidic soils, its leaf production capacity, although fluctuating, remains high. However, from a cultivation perspective, the horn stage would be decisive, as all leaf growth takes place there.

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APPENDIX

Calculation of the shape coefficient to estimate leaf area of leaves exploited by Moyabi people

Calculating leaf area can be extremely complex. Many authors [28,29,30,31,32,33,34,35] have proposed a simplified approach based on the maximum dimensions (length and width) of the leaf and a shape coefficient. More precisely, these authors estimate leaf area by multiplying the product of the maximum length and the maximum width by an estimated shape coefficient. The same approach was used in this study on a sample of 14 leaves. On each leaf, the maximum leaf area (S_{max}) and the real leaf area (S_r) were determined. The maximum leaf area is the product between the maximum length L_{max} (length of the midrib) and the maximum width l_{max} (*Eq.5*). To determine the real leaf area, trapezoids 0.5 cm high were drawn along the midrib of the leaf. Next, the area of each trapezoid was calculated (*Eq.6*). The sum of the areas of all the trapezoids gives the real leaf area (*Eq.7*).

$S_{max} = L_{max} \times l_{max}$ *(Eq.5)*
$s_i = [(B_i + b_i) \times h]/2$ *(Eq.6)*
$S_r = \sum s_i$ *(Eq.7)*
S_{max}: maximum leaf area in cm²; L_{max}: maximum leaf length in cm; l_{max}: maximum leaf width in cm; s_i: surface of trapezoid i in cm²; B_i: large base (or maximum width) of trapezoid i in cm; b_i: small base (or minimum width) of trapezoid i in cm; h: height of trapezoid i (it is 0.5 cm); S_r: real leaf area in cm².

Subsequently, estimating the shape coefficient consisted of fitting a regression equation of the real leaf area (response variable) on the maximum leaf area (predictor variable) from the 14 pairs of points using R software to fit the model.

The model was first tested with an intercept. Since the intercept was not significantly different from zero (*P = 0.47*), the model was updated by removing it (*Eq.8*).

$S_r = \beta \times S_{max} + \varepsilon_i$ *(Eq.8)*
β: parameter (shape coefficient) to be estimated; ε_i: independent and identically distributed errors.

The updated model (*Eq.8*) was better and showed a good performance, with a residual standard deviation of *24.76 cm²* and an R^2 of *0.99*. The shape coefficient β was highly significant (*P = 0.15e-24*) with a value of *0.7648* and a 95% confidence interval of *[0.7581; 0.7715]*. The shape coefficient β represents a ratio between the maximum leaf area, calculated by considering the base rectangle in which the leaf fits, and the actual leaf surface. The value of β is included in the interval]0; 1[, indicating that the actual leaf surface is smaller than that of the base rectangle. The resulting value also shows that the leaf surface is about 3/4 of the surface of the base rectangle.