Influence of Soil Fertility on the Physiognomy of *Colophospermum mopane* in the South Luangwa Ecosystem, Zambia

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***Abstract*:-The study aimed to develop a new understanding of environmental mechanisms at work in *Colophospermum mopane* that lead to the development of distinct tree height gradient (variation in horizontal and vertical structure). Thus, we investigated soil fertility as a possible environmental factor influencing the physiognomy of *Colophospermum mopane*. The study site in the national park was selected to represent dwarf mopane ≤3 meters tall whereas the site in the game management area was selected to represent >13 meters tall mopane. Field work involved collection of soil samples to investigate on estimation of organic matter, pH, phosphorous, nitrogen, potassium, calcium, magnesium and sodium in soils under tall and dwarf mopane woodlands. IBM SPSS statistical package version 20 was used for data analysis. T-tests were used to show levels of significance in differences between dwarf and tall mopane woodlands. Findings of this study revealed that soils under coppiced mopane are nutrient richer with calcium, magnesium and sodium content than soils under tall mopane. These minerals may be influencing food quality *Colophospermum mopane* feed. However, phosphorous content in mg/kg is one and a fourth times more in tall mopane woodland of the game management area than in dwarf mopane woodland of the national park. Thus, it may be assumed that phosphorous deficiency in the national park is a possible environmental factor influencing the physiognomy of *Colophospermum mopane* since it can stunt plants. The management authority responsible for the national park should support further research and experiments to manipulate environmental stressors including addition of phosphorous fertilizer to understand the possible environmental factors influencing the physiognomy of *Colophospermum mopane*.**

***Keywords: Colophospermum mopane*, ecosystem, physiognomy, soil fertility, Luangwa valley, Zambia**

I. INTRODUCTION

The presence of nutrients in animal forage is important for the animals' metabolic functioning (Barboza *et al*., 2009; Soetan *et al*., 2010). Deficiency of nutrients in soil and forage can be a contributing factor for low production and reproduction problems in animals (Soetan *et al*., 2010). In plants, minerals play vital roles: they serve as structural components in carbohydrates and proteins and organic molecules in metabolism such as magnesium in chlorophyll and phosphorous a vital component of adenosine triphosphate (ATP), enzyme activators such as potassium and for maintaining osmotic balance (Soetan *et al*., 2010). Calcium is important for cell wall strength and firmness (Belakbir *et al*., 1998).

Research has been carried in out Luangwa valley (Astle *et al*., 1969; Astle 1971; Hanks, 1972; Caughly & Goddard, 1975; Berry, 1978; Banks 1985; Lewis 1986; 1991; Abel & Blaikie, 1986; Phiri 1989; Leader-Williams *et* al., 1990; Turnbull, 1991; Milner-Gulland *et al*., 1992; Jachmann & Billiouw1997; Anderson, *et al*., 2011; Hang'ombe *et al*., 2012) but no studies on soil fertility as a possible factor influencing the physiognomy of *Colophospermum mopane* have been done in the Luangwa Valley. Tall *Colophospermum mopane* (>15 m in height) largely occurs on deep nutrient-rich alluvial soils (Fraser et al., 1987) whereas dwarf mopane (1–2 m) occurs on sodium-rich soils or cracking clay soils derived from basalt (Mlambo 2006). The possible environmental factor influencing dwarf *Colophospermum mopane* is a subject for discussion.

Styles & Skinner (1997) and Smallie & O'Connor (2000) indicated that development of dwarf *Colophospermum mopane* is due to intense browsing by large herbivores such as elephants. This notion is based on the view that heavily utilised young woody plants do not recruit into larger size classes and fail to escape the feeding stratum of most herbivores (Mlambo 2006). In his account, Mlambo (2006) indicated that various woody species are resilient in the habitat and can maintain their stature for as long as the browser's demand on the plant biomass does not exceed the supply through resprouting. It is from this perspective that the physiognomy of *Colophospermum mopane* is understood to be influenced by large herbivores. Further, Koch (1997) and Lovelock *et al*. (2004) indicated that soil fertility can influence the physiognomy of woody vegetation. Thus, this present study is one of the first steps required to investigate whether soil fertility can reduce growth in *Colophospermum mopane* woodland of the South Luangwa Ecosystem in Zambia.

The study aimed to investigate the possible influence of soil fertility on the physiognomy of *Colophospermum mopane* woodlands. The aligned objective was to investigate the influence of soil fertility on the physiognomy of *Colophospermum mopane* woodlands at habitat scale in the South Luangwa Ecosystem. This present study will assist greatly in provision of relevant information on the influence of soil fertility on the physiognomy of woodlands in ecosystems of the country. The hypothesis for this study stated that there is no correlation between soil fertility and the physiognomy of *Colophospermum mopane* woodlands in the South Luangwa ecosystem.

II. METHODS AND MATERIALS

Study area

The study sites were Chichele in South Luangwa National Park (SLNP) and Kakumbi in Lupande Game Management Area (LGMA) in the Luangwa Valley, eastern Zambia (Figure 1). The Luangwa Valley is a trough lying below the Muchinga Escarpment to the north and forms the Luangwa River catchment area. It stretches between 9^{o} 35'S to 15^{o} 41'S and 28^{o} 21'E to 33^{o} 44'E (Phiri 1989). The Valley is 40,000 km2 in extent, approximately 700 km in length and 90 km at its widest point, stretching through Muchinga escarpment hill floor, covering part of Eastern, Central and Lusaka Provinces of Zambia (Smith 1977; Phiri 1989; Phiri 1994).

SLNP is situated in the Luangwa Valley and is about 9050 km2 in extent (Smith 1977). The national park lies between 12^{o} 17' - 13^{o} 45' S and 31^{o} 00'- 32^{o} 08' E of which it is integral to the Great Rift Valley where the rift divides into the eastern arm encompassing Lake Malawi and the western arm forms the Luangwa Valley stretching north for some 700 km (Smith 1977; Phiri 1994). LGMA was established to buffer SLNP to the east. LGMA is 4,840 km2 in size and lies between 13^{o} 30' S and 14^{o} 45' E at 35^{o} m to 64^{o} m above sea level (Phiri 1989). The Muchinga Escarpment to the north of the national park rises to 1,200 m above sea level (Smith 1977).

The valley experiences three distinct seasons namely: hot rainy season (from late November to April); cool-dry season (from May-August); and a hot dry season (from September to early November). The average daily maximum temperature ranges from 32 to 36^{o}C. The average minimum temperatures are about 15^{O}C during months of June and July. The average annual rainfall ranges from 600 to 800 mm.

Surface water did not constrain plot use since blocks were located at 2 km minimum distance from the Luangwa River which separates to the two blocks where plots were marked in monotypic mopane woodland habitats. The approach for field work used by Mlambo & Nyathi (2008) was adapted. A field survey involving tall mopane and coppiced mopane woodland types was conducted to measure and compare possible soil nutrients influencing food selection in mopane woodland by elephants. This study is the first which seeks to investigate whether soil nutrients can be contributing to dwarf mopane growth form. We measured and compared nutrients in soils under *Colophospermum mopane* plants around Chichele in South Luangwa National Park and Kakumbi in Lupande Game Management Area in order to explain the possibility of soil fertility influencing the physiognomy of *Colophospermum mopane* woodlands.

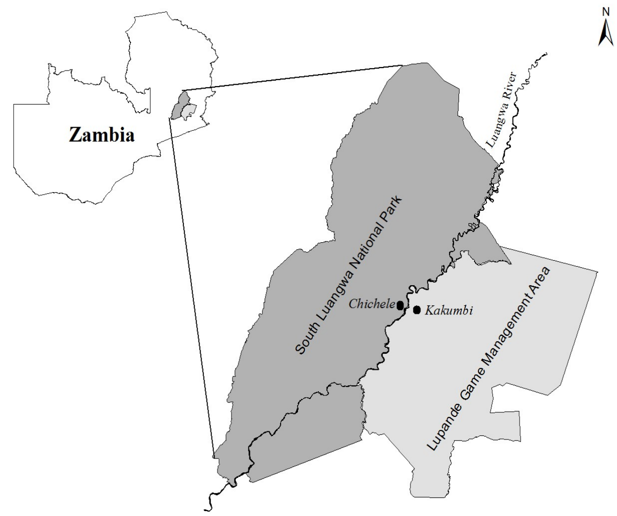

Figure 1: Map of the study area showing Zambia, South Luangwa National Park and Lupande Game Management Area. Chichele site in the national park and Kakumbi site in the game management area are also shown.

Data collection

The layout of plots followed a randomised block, plot and sampling design with three replicate treatments. First site was marked in coppiced *Colophospermum mopane* woodland in Chichele Area of South Luangwa National Park. Second site was marked in tall *Colophospermum mopane*-dominated open woodland in Kakumbi of Lupande Game Management Area (Figure 1).

Colophospermum mopane-dominated stands in South Luangwa National Park and Lupande Game Management Area were identified through a reconnaissance survey. The stands were categorized into two physiognomic forms: short mopane ≤3 m in height and tall mopane >13 m high. One 20 x 20 m plot (Mapaure & Mhlanga 2000; Mlambo 2006) was allocated to each woodland site at habitat scale and this was replicated 10 times in in Chichele site in the national park and 10 times in Kakumbi site in the game management area.

The distance between mopane woodlands demarcated in each site was 6.1 km linear distance. Plots were positioned to cover as much as possible soil properties within each mopane woodland.

In each site, ten plots systematically marked along a 1 km transect line and had three widely spaced focal trees selected randomly from five trees at the edges and center of the plot and marked. Each plot contained three focal trees and underneath each tree crown (inner zone), soil samples were collected in four directions (N, E, S and W). Soil samples were collected midway between tree bole and canopy edge. Soil samples were collected starting from 0.5 m to 1 m from the tree bole under the tree canopy. Soil samples from four cardinal directions underneath each tree were pooled and mixed thoroughly and a composite sample derived.

Thus, three soil samples were collected within half four radii underneath each of the three randomly chosen trees for pH, nitrogen, phosphorous, potassium, calcium, magnesium, sodium, organic matter and electoral conductivity test. The result was 30 combinations of soil samples from 10 plots in each block were collected.

Each focal tree had one zone of influence - soil under the crown within half radius from the crown edge. Plots were marked at least 20 m away from the nearest road. Soil samples were derived from each site using a 6 cm diameter stainless steel soil auger underneath focal trees. Samples were collected to a depth of 0 to 20 cm in 2015.

To prevent sample contamination and loss of soil moisture, soil samples were packed in self-zipping plastic bags and kept in a well-ventilated roofed shelter at Chinzombo Research Station in Mfuwe. Soil samples from Chichele site of South Luangwa National Park and soil samples from Kakumbi site of Lupande Game Management Area were collected in a space of two days. The samples were then transported to Lusaka for laboratory analysis.

One kilogram samples were collected from soils underneath each focal tree, stored and transported to the Department of Soil Science Laboratory at the University of Zambia for pH, electrical conductivity, organic matter, nitrogen, phosphorus, calcium, potassium, magnesium and sodium content test. Since the parameters were not normally distributed, the Mann-Whitney non-parametric test for independent pairs of samples of coppiced and tall mopane was used.

Data analysis

IBM SPSS Release 20 Software was used for analysis of soil samples under tall mopane woodland trees in Kakumbi Site of Lupande Game Management Area and soils under dwarf mopane woodland trees in Chichele Site of South Luangwa National Park. A t-test analysis was for equality of means between two mopane woodlands ($n = 30$ for each treatment or $n = 60$ in total). Differences between means were tested with a Confidence level of 95%. The analysis provided a comparative measure for possible variance between soil mineral records from tall and coppiced mopane and hypothesis testing.

This study is the first which seeks to investigate whether soil nutrients can be contributing to dwarf mopane growth form in the Luangwa valley, Zambia. We measured and compared nutrients in soils under *Colophospermum mopane* plants around Chichele in South Luangwa National Park and Kakumbi in Lupande Game Management Area in order to explain the possibility of soil fertility influencing the physiognomy of *Colophospermum mopane* woodlands.

III. RESULTS

Table 1 shows that available phosphorous (cmol/kg), calcium (cmol/kg), magnesium (cmol/kg) and sodium (cmol/kg) content are significantly different ($p < .05$) between dwarf and tall mopane. Available calcium (cmol/kg), magnesium (cmol/kg) and sodium (cmol/kg) content were higher in coppiced mopane in the national park than in tall mopane of the game management area.

Table 1 and 2 show that soil pH measurements were not significantly different between dwarf mopane woodland (μ=6.36, σ=0 .28) and tall mopane woodland (μ=6.25; σ=0.32), p-value = 0.255. Using the 5 percent level of significance, the required p-value for the rejection of the null hypothesis (t(df = 1,58) = 1.4797 (p >0.255) was greater than the 0.05. Thus, the p-value is not in the region of rejection of the null hypothesis. We conclude that there is no significant difference in soil pH of coppiced mopane woodland and tall mopane woodland.

An analysis of electrical conductivity (EC) in soils in coppiced mopane woodland (μ=0.42; σ=1.2) mS/cm) and soil EC in tall mopane woodland soils (μ=0.08; σ=0.12) in mS/cm were not significantly different (Table 1; 2). Analysis of EC showed a test statistical T-test (t(F value of 1.12) while the F-critical value at 5 percent significance level was 4.04. Since the statistical value, F-1.12 < 4.04 (p >0.05), there is no evidence that results for EC in coppiced mopane woodland and tall mopane woodland are different (F 1.12, p >0.05).

Analysis results for organic matter in dwarf mopane woodland (μ=2.00; σ=0.33) in percentage and tall mopane woodland (μ=2.33; σ=0.51) in percent did not show any significant difference (Table 1; 2). Analysis done using 5 percent level of significance showed that the required F value was not in the region of rejection of the null hypothesis that organic matter in dwarf mopane woodland and tall mopane woodland are the same (F 0.37, p >0.05). Thus, there is no evidence of significant difference in organic matter between dwarf mopane woodland and tall mopane woodland in the South Luangwa Ecosystem.

Analysis for correlation of soil phosphorus content in dwarf mopane woodland (μ=4.23; σ=2.43) in mg/kg in and soil phosphorus content in tall mopane woodland (μ=5.96; σ=8.23) in mg/kg showed a significant difference (Table 1; 2). The difference between soil phosphorus in dwarf mopane woodland and soil phosphorus in tall mopane woodland was significant since the calculated F value is greater than the table-value. The calculated F value F 9.37 > 7.20 (F 1.49, p <0.01). This shows that there is strong evidence of significant difference in soil phosphorus content between coppiced mopane woodland and tall mopane woodland. Phosphorous content in mg/kg is one point four times more in tall mopane woodland of the game management area than in dwarf mopane woodland of the national park. Thus, the hypothesis that stated that phosphorous content in dwarf mopane woodland and tall mopane woodland were different was not rejected.

The average soil nitrogen content in dwarf mopane woodland (μ=0.099; σ=0.022) in mg/kg and the soil nitrogen content in tall mopane woodland (μ=0.15; σ=SD 0.21) in mg/kg were not significantly different (Table 1; 2). At 5 percent level of significance, the required test F ratio for rejection of the null hypothesis which states that soil nitrogen content in coppiced mopane woodland and soil nitrogen content in tall mopane woodland are not the same (df = 1,49) = 1.97 < 4.04 was not met. The calculated F value is not in the region of rejection of the null hypothesis. Nitrogen content in mg/kg is point one six times more in tall mopane woodland of the game management area than in dwarf mopane woodland of the national park. Thus, we conclude that there is no evidence of significant difference in soil nitrogen content between coppiced mopane woodland and tall mopane woodland in the Luangwa Valley, eastern Zambia.

Soil potassium content in dwarf mopane woodland (μ=0.62; σ=0.26) in cmol/kg and in tall mopane woodland (μ=0.58; σ=.36) in cmol/kg was not significantly different (Table 6.1; 6.2). For soil potassium content two way analysis of variance, the test statistic F value was 4.07 while the critical value was 4.04 at 5 percent significance level (F 4.07, $p > 0.05$). Potassium content in mg/kg is point six times more in dwarf mopane woodland of the national park than in tall mopane woodland of the game management area. We conclude that there is no sufficient evidence of significant difference in soil potassium content in coppiced mopane woodland and tall mopane woodland. Thus, the calculated F value is not in the region of rejection of the null hypothesis.

Soil calcium content in dwarf mopane woodland (μ=18.81; σ=8.04) in cmol/kg while the average soil calcium content in tall mopane woodland was 12.24 (SD 7.12) in cmol/kg were significantly different (Table 1; 2). For the soil calcium content in mopane woodland, a two way analysis of variance statistic F value was 11.41 while the F-table value was 7.20 at 1 percent (df = 1, 49). Since 11.41 > 7.20 ($p < 0.01$), there is sufficient evidence that calcium in coppiced mopane woodland soils and soil calcium content in tall mopane woodland are significantly different (F11.41, $p < 0.01$). Calcium content is one and half times more in dwarf mopane woodland of the national park than in tall mopane woodland of the game management area. Thus, the calculated F value is in the region of rejection of the null hypothesis that soil calcium content in coppiced mopane woodland and in tall mopane woodland are the same. This means that there is higher content of calcium in dwarf mopane woodland than in tall mopane woodland.

Soil magnesium content in dwarf mopane woodland (μ=9.55; σ=5.02) in cmol/kg soil magnesium content in tall mopane woodland (μ=2.87; σ=1.20) in cmol/kg were significantly different (Table 1; 2). The mean difference for magnesium content was significant since the calculate F value was greater than the table F value. The F-critical level 7.20 was less than the calculated F value 57.60. The required F value (calculated) for the rejection of the null hypothesis which states that magnesium content in coppiced mopane woodland and tall mopane woodland are the same is (df = 1, 49) = 57.60. Magnesium content is three times more in dwarf mopane woodland of the national park than in tall mopane woodland of the game management area. Thus, there is sufficient evidence for significant difference in magnesium content in soils under dwarf mopane woodland and tall mopane woodland in the South Luangwa Ecosystem (F 57.60, $p < 0.001$). There is more magnesium soil content in coppiced mopane woodland than in tall mopane woodland soils.

Soil sodium content in dwarf mopane woodland (μ=2.19; σ=1.95) in cmol/kg and in tall mopane woodland (μ=0.96; σ=1.74) in cmol/kg were significantly different (Table 1; 2). For sodium analysis results, the test statistic (calculated) F value at 5 percent significance level was F 2.45 while the F-critical level was 4.04. Since 2.45 < 4.04 ($p > 0.05$), there is strong evidence that soil sodium content in dwarf mopane woodland and tall mopane woodland are different. Sodium content is two times more in dwarf mopane of the national park than in tall mopane of the game management area. Thus, we fail to reject the null hypothesis which states that soil sodium content in dwarf mopane woodland and tall mopane woodland are not the same.

Table 1: Measurements of soil factors in coppiced mopane woodland and tall mopane woodland in the Luangwa Valley

Soil Factors	Coppiced Mopane	Tall Mopane
	Mean (SD)	Mean (SD)
pH	6.3640 (.28791)	6.2543 (.32795)
EC	.4150 (1.63952)	.0767 (.12397)
OM	2.0000 (.33018)	2.3347 (.51467)
P	4.2387 (2.43910)	5.9620 (8.23064)
N	.0990 (.02249)	.1563 (.21977)
K	.5853 (.36128)	.6203 (.26047)
Ca	18.8147 (8.04254)	12.2490 (7.12954)
Mg	9.5503 (5.02020)	2.8743 (1.20221)
Na	2.1943 (1.95891)	.9633 (1.74463)

Table 2: Two Way ANOVA results for measurements of soil factors in coppiced mopane woodland and tall mopane woodland in the Luangwa Valley

Soil factors	ANOVA	F-critical	F-critical	p-value
	(Calculated F-value)	(5%) level	(1%) level	
pH	F(treatments)=1.823913	4.04	-	>0.05
EC	F(treatments)=1.1251647	4.04	-	>0.05
OM	F(treatments)=0.37357	4.04	-	>0.05
P	F(treatments)=9.371388	-	7.20	<0.01
N	F(treatments)=1.97217	4.04	-	>0.05

K	F(treatments)=4.072607	4.04	-	>0.05
Ca	F(treatments)=11.4186	-	7.20	<0.01
Mg	F(treatments)=57.60253	-	7.20	<0.001
Na	F(treatments)=2.450614	4.04	-	>0.001

Note: All critical F-value from the tables were obtained using df=(1,49) for treatments at 5% and 1% significance levels.

IV. DISCUSSION

In comparing means, an assumption of equal variance was made. Findings of this study, suggested that soils under coppiced mopane are nutrient richer in calcium, magnesium and sodium content than tall mopane and may have a positive influence on improved food quality in Chichele site of the national park compared to Kakumbi belt of the game management area.

pH and electrical conductivity (EC) are indicators of soil acidity and nutrient condition (Smith & Doran 1996). They can be indicators of the effects on biological activity in microbial mediated processes that may be affected by changes in pH or EC (Smith & Doran 1996). Findings of this present study showed that differences in pH and EC between mopane woodland in the national park and in the game management area were not statistically significant ($p>0.05$) across the two mopane woodland habitats and may therefore, not be contributing factors to the altered physiognomy of *Colophospermum mopane*.

Soils under coppiced mopane woodland in the national park were associated with higher mean calcium, magnesium and sodium relative to soils under tall mopane woodland ($p < 0.05$). However, no significant differences in mean nitrogen and potassium were observed between coppiced mopane woodland in the national park and tall mopane woodland in the game management area ($p > 0.05$). Although more leaf fall and fruit drop were deposited in tall mopane from about the month of May, a phenomenon which can contribute to higher content in OM, tall mopane woodland contained lower calcium, magnesium and sodium possibly due to rate of removal by biota (Mlambo, *et al*., 2005), especially by impala, bush baby, mopane squirrel and hornbill which were observed in Lupande Game Management Area. However, research on the leaf fall and occurrence of small mammals and avi-fauna in mopane woodland, Zambia is non-existent. Soils rich in organic matter are reported to be well aerated since they provide for soil biota habitats that play a crucial role in mediating soil structure and sustainability of an ecosystem (Dangerfield, 1990). Higher organic matter in tall mopane vegetation of Lupande Game Management Area (Table 1; 2) did not appear to influence the physiognomy of *Colophospermum mopane*.

Nitrogen and phosphorous content account for production of proteins in browse (Ben-Shahar & Macdonald 2002) but nitrogen was not significantly different (>0.05) between soils under tall mopane woodland trees of the game management area and coppiced mopane vegetation in the national park. Therefore, it is suggested that nitrogen may not be a factor influencing the physiognomy of *Colophospermum mopane*.

In Hwange National Park, sodium plays an important role in attracting elephants, thus affecting distribution and habitat use patterns (Holdø, *et al.,* 2002). It appeared that continual browsing of coppiced mopane by elephant compared to tall mopane was probably because the soils were nutrient-rich thereby providing more quality food in dwarf *Colophospermum mopane* woodland trees. It is suggested that soils under tall mopane vegetation lost calcium, magnesium and sodium nutrients through leaching since sandy soil structure characterised mopane woodland in the game management area. Coppiced mopane woodland in the national park contained soils ranging from clay to silt which implied that there was limited loss of calcium, magnesium and sodium nutrients.

Phosphorus is an essential macronutrient for plants since it plays an important role of energy transfer in plants (Soetan *et al.* 2010). Further, sufficient availability of phosphorus in plants stimulates early growth and promotes maturity (Sharma *et al*., 2008). In this present study, dwarf *Colophospermum mopane* stand of the national park was associated with low phosphorous relative to tall mopane woodland stand of the game management area. In their account, Koch (1997) and Lovelock *et al*. (2004) indicated that low phosphorous concentration in scrub mangrove habitats influences the physiognomy of mangrove by limiting growth to dwarf *Rhizophora mangle* L. tree. But under phosphorous fertilization dwarf mangrove plants manifested enhanced stem elongation and hydraulic conductance (Koch (1997; Lovelock *et al*. 2004).

Phosphorus content of cereal plant is largely influenced by the availability of phosphorus in the soil (Soetan *et al*. 2010). Thus, low-quality range plants are naturally low in phosphorus as the browse matures and the seeds fall, signifying phosphorus deficient in range soil (Merck (1986) cited in Soetan *et al*. 2010). There was a significant difference ($p<0.05$) in content of phosphorous between soils under dwarf mopane of the national park and tall mopane of the game management area. Thus, it may be assumed that phosphorous is a possible environmental factor influencing the physiognomy of *Colophospermum mopane* by limiting growth to dwarf mopane.

V. CONCLUSIONS AND RECOMMENDATIONS

High content of calcium, magnesium and sodium attract herbivores to dwarf mopane of the national park thereby trapping it short class. However, this assertion requires to be ascertained in the Luangwa Valley. We however, can conclude that phosphorous deficiency is the possible environmental factor influencing the physiognomy of Colophospermum *mopane* by limiting growth in dwarf mopane. Thus, experiments on fertilization could promote the growth of dwarf *Colophospermum mopane*. The management authority responsible for the South Luangwa Ecosystem should support further research and experiments to manipulate environmental stressors including addition of phosphorous fertilizer to understand the possible environmental factors influencing the growth form in dwarf *Colophospermum mopane* in the national park.

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