



**GROWTH RESPONSE OF *EUCALYPTUS GRANDIS* TO MOISTURE IS ATTENUATED BY UNFAVOURABLE NUTRIENT CONDITIONS**

*Titus Fondo Amebe and Njoya Moses Tita Mogho*

**To cite the article:** Titus Fondo Amebe and Njoya Moses Tita Mogho (2021), Growth response of eucalyptus grandis to moisture is attenuated by unfavourable nutrient conditions, *Journal of Agricultural and Rural Research*, 6(1): 30-43.

**Link to this article:**

<http://aiipub.com/journals/jarr-210115-010115/>

**Article QR**



**Journal QR**



## GROWTH RESPONSE OF *EUCALYPTUS GRANDIS* TO MOISTURE IS ATTENUATED BY UNFAVOURABLE NUTRIENT CONDITIONS

Titus Fondo Ambebe<sup>1\*</sup>, Njoya Moses Tita Mogho<sup>2</sup>

\*Corresponding author E-mail: [ambtitus@yahoo.com](mailto:ambtitus@yahoo.com)

### ARTICLE INFO

**Article Type:** Research

**Received:** 11, Jan. 2021.

**Accepted:** 20, Apr. 2021.

**Published:** 22 Apr. 2021.

### Keywords:

*Bamenda Highlands, climate change, Eucalyptus grandis, growth, tropical montane forests*

### ABSTRACT

Montane forests of the Bamenda Highlands are threatened by changes in climatic and environmental conditions. To investigate the combined effect of moisture and nutrient availability on the growth of *Eucalyptus grandis* Hill ex Maiden, seedlings were raised under three moisture levels (low [20-30%], intermediate [45-55%], high [70-80%] FWC) and three nutrient regimes (low [10/4/6], intermediate [100/40/60], high [200/80/120] ppm NPK) for three months. The intermediate moisture treatment increased height, the biomass of plant fractions, and total biomass while reducing root mass ratio and root: shoot. Height, number of leaves, the biomass of plant fractions, total biomass, and stem mass ratio were augmented by the intermediate nutrient treatment that resulted in a decline in leaf mass ratio, root mass ratio, and root: shoot. There were significant moisture × nutrient interactions indicating that the effect of the intermediate moisture treatment on height was limited to the intermediate nutrient regime. As for the number of leaves, the decline from the intermediate to the other two nutrient levels was 25% at the low as opposed to 40.3% and 51.9% at the intermediate and high moisture levels, respectively. The findings suggest that nutrient content should be taken into account when designing strategies for adaptation of the species to variability in moisture conditions.

## 1. INTRODUCTION

The Bamenda Highlands consists of montane forests and grassland patches within the wider western Cameroon Highlands ecoregion that follows the chain of mountains along the Cameroon – Nigeria border. The patches that support a high diversity of animal and plant species are noted for having one of the highest levels of endemism among vascular plants in Africa (Ndenecho, 2011). The forests constitute a vital source of medicine, food, wildlife forage, building material, and raw materials for rural artisan industries. In addition, the Bamenda Highlands is endowed with a litany of catchments which constitutes the only source of drinking water for a significant part of the population. The high potential for the release of water from the landscape has triggered the development of many local community-based projects to meet variable human needs. However, most of the forest that once covered the landscape has been lost over the last few decades. A more than 50% decline in the wooded area since the 1960s is blamed on conversion for cultivation. The region is characterized by fertile volcanic soils and reliable rainfall, both of which have caused a high influx of a population that

<sup>1</sup> Titus Fondo Ambebe, Lecturer, The University of Bamenda, College of Technology, Department of Forestry and Wildlife Technology, Cameroon

<sup>2</sup> Njoya Moses Tita Mogho, Lecturer, The University of Bamenda, Faculty of Science, Department of Biological Sciences, Cameroon

is largely dependent on farming for subsistence (Stuart, 1986; Alpert, 1993). The forest remnants are under the enormous pressure of further degradation (Shidiki *et al.*, 2019). The situation will likely be accentuated by CO<sub>2</sub>-induced climate change. The need for protection of the remaining forested area and restoration of the degraded portions is gaining momentum. The success of such an effort depends on the availability of scientifically sound strategies for adaptation of the forest plants to climate change.

The earth is warming up as part of climatic response to atmospheric CO<sub>2</sub> elevation. The mean global temperature has increased by 1°C since the onset of the industrial revolution and is predicted to further rise by 1.5°C to 4.8°C by the end of the current century (Harris *et al.*, 2017). Changes in temperature and soil moisture are coupled at the ecosystem level. The rate and depth of evaporation increase with increasing temperature resulting in low soil water contents (Pregitzer and King, 2005). On the other hand, the evaporated water may condense and fall back as rainwater at volumes not necessarily reflective of the amount that was released from the soil. This has resulted in some areas becoming wetter and others drier. Although studies have shown a 2% overall increase in global land precipitation, rainfall characteristics vary considerably among regions (Huhó *et al.*, 2012). The important role of soil moisture for the establishment and growth of seedlings on reforestation sites has been demonstrated (Daniels and Veblen, 2004; Chadha *et al.*, 2019).

Nutrient availability is another factor limiting the growth and function of seedlings in the field. The hydrologic changes can influence nutrient availability and uptake (Mishra, 2003; Lambers *et al.*, 2013). For instance, repeated drying/wetting cycles can be beneficial for P availability through enhanced phosphatase activity (Song *et al.*, 2007). In addition, sustained wet conditions can foster N and P contents of soil solution by increasing heat dissipation down the soil profile (Lipson *et al.*, 2012). The warming favours organic matter decomposition by increasing the movement of soluble substrates in the soil (Fierer *et al.*, 2005) and stimulating the activities of mineralizing micro-organisms (Fang *et al.*, 2005). Furthermore, soils are subject to anthropogenic nutrient deposition under global change (Clark and Tilman, 2008). Although more drastic changes in temperature, rainfall, and soil nutrient contents are expected in the future, the actual nutrient content of a particular area is often determined by other site conditions.

*Eucalyptus grandis* Hill ex Maiden (family Myrtaceae) is a popular plantation tree in the tropics and subtropics. The evergreen tree grows to a height of 55 m but exceptionally 75 m with a straight, unbranched bole for up to 50-75% of the height and a diameter of 120-300 cm (Tropical Plants Database). It is grown from sea level up to 2500 m altitude, in areas with 14-26°C mean annual temperature and 700-4000 mm average annual rainfall (Nyunai, 2008). The eucalypt performs best in deep, well-drained, fertile loam or clay-loam soils but it is tolerant to impoverished and marginal soils (Ssenku *et al.*, 2014). It is an important component of the Bamenda Highlands forest and offers a variety of services to inhabitants of the area and beyond. The wood that is moderately strong but softer and lighter than that of many other eucalypts is used for general construction, joinery, utility poles, furniture, and plywood. The leaves yield 0.3-4.7% essential oil that contains secondary compounds with larvicidal activity against the mosquito. With an energy value of 18,100-19,400 kJ/kg (Nyunai, 2008), large quantities of wood are also used for fuelwood and charcoal. Economic returns from the sale of this eucalypt and its products have been quite encouraging.

The Bamenda Highlands is characterized by an undulating relief that has created a wide array of microclimates. This has resulted in variable moisture and nutrient conditions across the landscape which may interact to affect plants. The interactive effect may not be equal to the sum of individual

effects (van Heerden and Yanai 1995). The combined effect of these environmental factors on the growth of *Eucalyptus grandis* has not been experimentally examined. This study was designed to fill that gap. We expected a positive growth response to soil moisture addition to be attenuated by stressful nutrient conditions.

## 2. MATERIALS AND METHODS

### 2.1 Study site

The experiment was conducted at the Regeneration Task Force (RETAFO) nursery, Bamenda III Sub Division, North West Region, Cameroon. Bamenda III is located between latitudes 5°56" and 5°58" North of the equator and longitudes 10°09" and 10°11" East of the Greenwich Meridian. Characterized by two main seasons, the rainy season goes from April to October and the dry season begins in November and ends in March. Of recent, however, the timing and duration of the seasons are inconsistent due to changing climatic conditions. The average annual rainfall is 2145 mm while the mean annual temperature is 21.5 °C. During the months of July, August, and September 2018 when the experiment took place, the mean monthly temperature was 21, 20, and 21 °C while rainfall was 690.8, 678.4, and 794.4 mm, respectively.

### 2.2 Experimental design

Seedlings of *Eucalyptus grandis* were transplanted from a seedbed to polythene bags filled with a 1:1 mixture of sand and sawdust. They were all of uniform size and without visible signs of defect at the time of transplant. The potted plants were then placed under a wooden frame overlaid with a transparent plastic sheet to prevent the growth medium from receiving precipitation water. A woven wooden mat placed beneath the bags allowed for the free drainage of irrigation water.

Treatments were comprised of three moisture levels (20-30%, 45-55%, 70-80% field water capacity) and three nutrient regimes (10/4/6, 100/40/60, 200/80/120 ppm NPK). The experiment followed a split-plot design with two replications. In the layout, replication was the field, moisture the plot, and nutrient the split-plot. There were ten 2-month-old seedlings per treatment combination. To maintain the target moisture levels, the moisture content of the growth medium was measured daily with a soil moisture probe (Vegetronix VG-METER-200) and augmented with normal tap water when necessary. The nutrient fertilization was done once every three weeks. The treatments were commenced on July 1 and terminated on September 30, 2018.

### 2.3 Measurements

At the end of the experimental period, five seedlings were randomly selected from each treatment and replication for data collection. The height and number of leaves were determined. The root system was rinsed free of growth medium and the seedling was separated into leaf, stem, and root. The plant components were packaged in envelopes and transferred to a laboratory of the College of Technology of The University of Bamenda (6.01° N/10.25° E latitude/longitude) where they were oven-dried to constant weight and weighed. Biomass allocation parameters were computed as the ratio of the dry mass of the plant fractions to total dry mass as well as that of root to shoot.

### 2.4 Statistical analysis

The data were examined graphically for normality and homoscedasticity before being subjected to split-plot ANOVA untransformed. When the main or interactive effect of treatments was significant for a given parameter, Scheffe's test was used for pairwise means comparison. The statistical tests were performed in Data Desk 6.1 at  $p = 0.1$ .

### 3. RESULTS

#### 3.1 Morphology

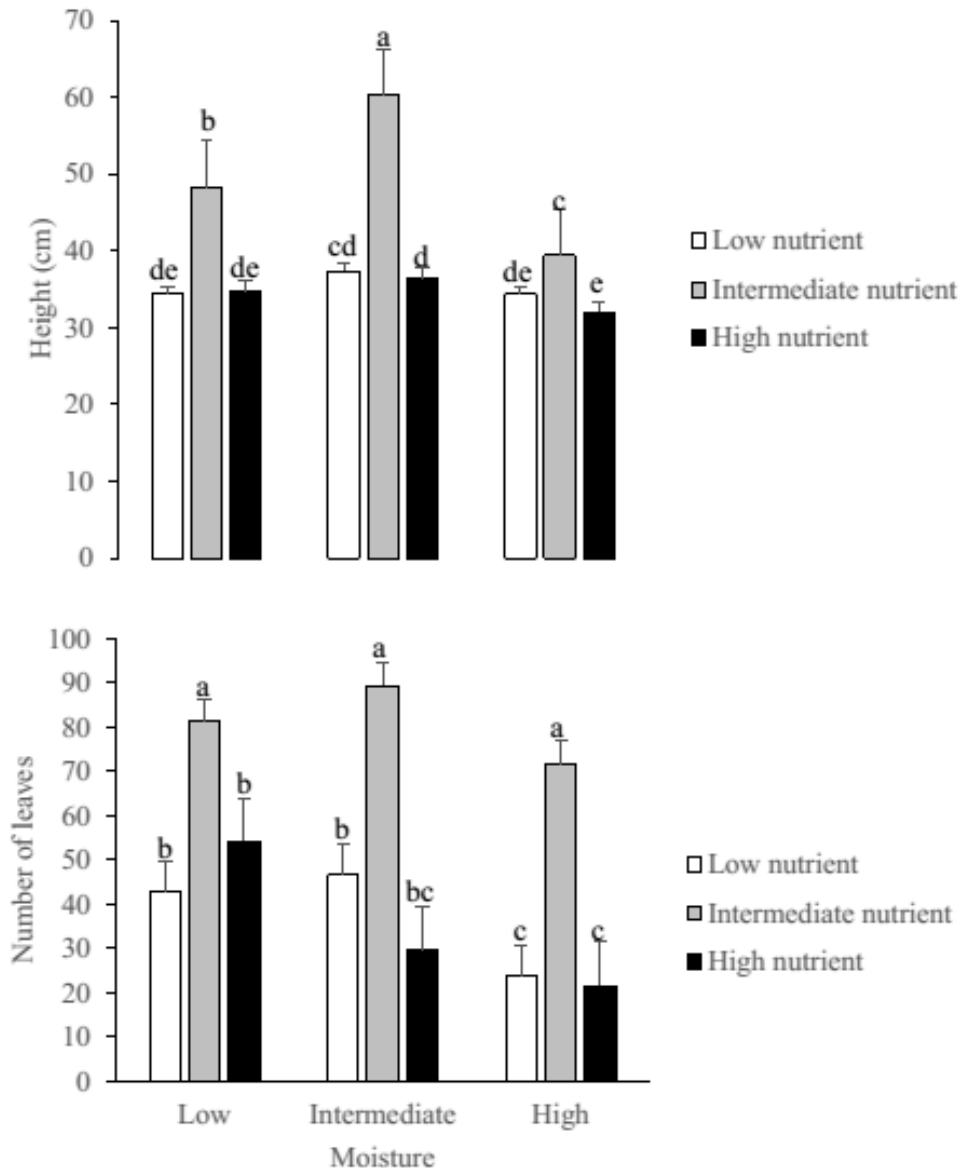
In addition to main effects, there was a significant interactive effect of moisture and nutrient availability on height (Table 1). Values of the trait were highest in the intermediate nutrient treatment at the intermediate moisture regime and lowest in the high nutrient level at high moisture (Figure 1).

**Table 1. ANOVA p-values for the effect of moisture and nutrient availability on growth**

Source	Moisture	Nutrient	Moisture×Nutrient
Height	0.0024	0.0003	≤0.0001
No. of leaves	0.0038	0.0018	0.0031
Leaf biomass	0.0045	≤0.0001	0.2043
Stem biomass	0.0007	≤0.0001	0.3196
Root biomass	0.1157	0.0003	0.8744
Total biomass	0.0037	≤0.0001	0.4540
Leaf Mass Ratio	0.2269	0.0763	0.1505
Stem Mass Ratio	0.0003	0.0001	0.3882
Root Mass Ratio	0.0628	0.1126	0.7856
Root:Shoot	0.0810	0.0966	0.8703

Height increased from the low to the intermediate moisture at the intermediate nutrient regime and then declined to the high moisture level to an extent that was significantly lower than the response at the low moisture (Figure 1). However, the difference between the high moisture level at intermediate nutrient and intermediate moisture at low moisture regime was statistically insignificant. There was no significant difference between the low and high nutrient regimes at any moisture level. Apart from the high moisture treatment which resulted in lower height growth at high nutrient supply than the intermediate moisture at either low or intermediate nutrient regime, there existed no significant differences between any other treatments (Figure 1).

Significant main effects of both treatments and their interactions on the number of leaves were detected (Table 1). There was no significant difference between moisture treatments at the intermediate nutrient regime (Figure 1). The intermediate nutrient treatment resulted in a significantly greater number of leaves than the low and high nutrient levels at each moisture level. However, the margin of difference was strongly dependent on the moisture level. It was 25.3% in the low as opposed to 40.3% and 51.9% at the intermediate and high moisture regimes, respectively. Although not statistically significant at a high nutrient regime, the number of leaves was decreased by the high moisture level at the low and high nutrient regimes. The low and intermediate moisture treatments did not differ in the number of leaves at the latter nutrient levels (Figure 1).

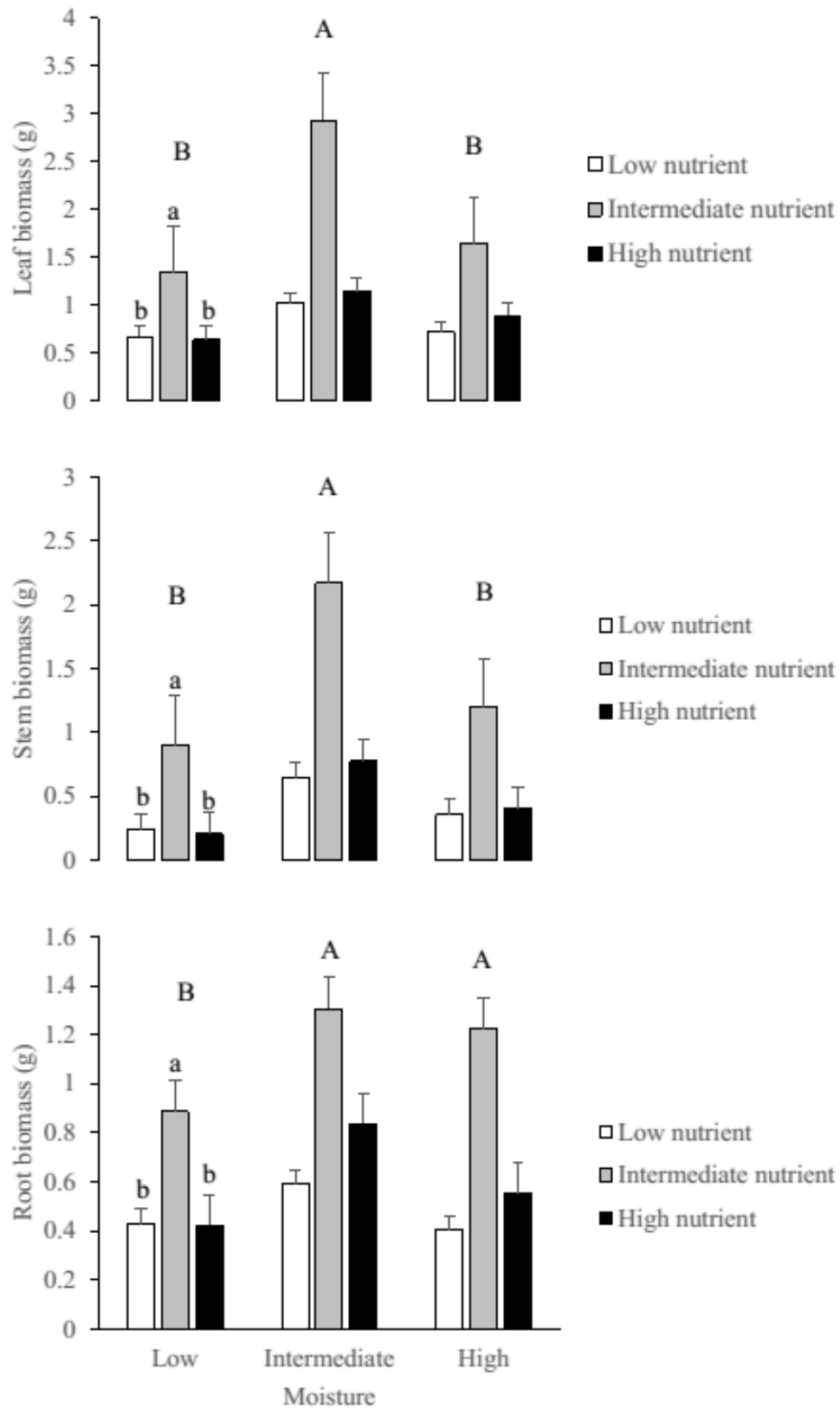


**Figure 1. Effects of moisture (M) and nutrient (N) availability (mean + se) on morphology. Letters above means indicate M × N effects. Different letters indicate significant differences**

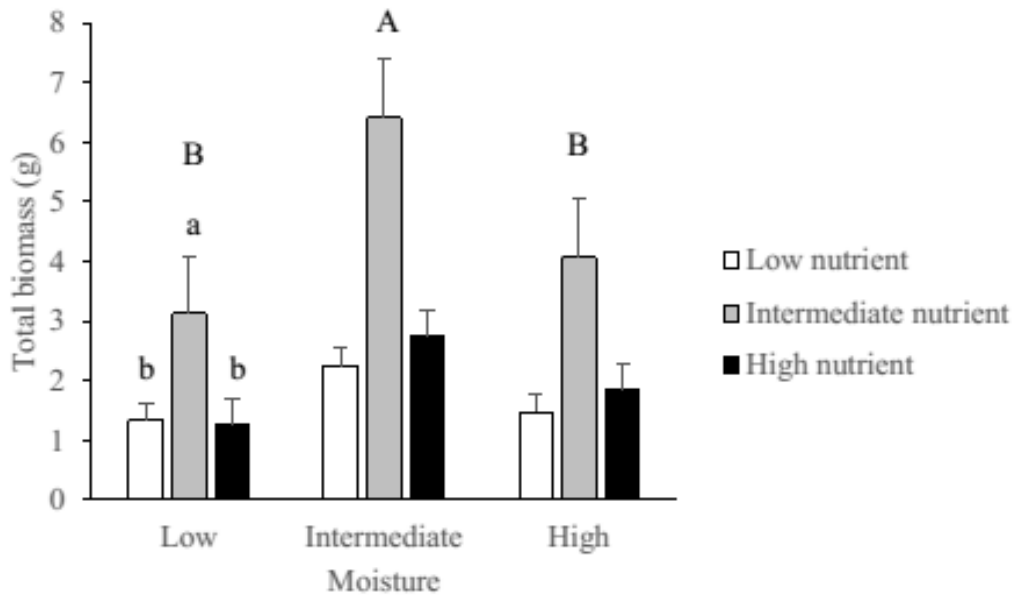
### 3.2 Biomass production

The biomass of leaf, stem, and root was significantly affected by moisture and nutrient supply but not by treatment interactions (Table 1). Leaf and stem biomass were significantly higher at the intermediate than the low and high moisture levels that showed statistically comparable responses (Figure 2). In the case of root biomass, it was significantly reduced by low moisture availability. The pattern of response to nutrient supply was similar for all the three parameters – they were significantly lower at the low and high than the intermediate nutrient level (Figure 2).

There was a marginally significant effect of moisture and a significant effect nutrient supply on total seedling biomass. In contrast, the factors did not interact in affecting this attribute (Table 1). The trend of response to moisture and nutrients was as described for the biomass of leaf and stem (Figure 3).



**Figure 2. Effects of moisture (upper-case letters) and nutrient (lower-case letters) availability (mean + se) on biomass of plant fractions. Different letters indicate significant differences**



**Figure 3. Effects of moisture (upper-case letters) and nutrient (lower-case letters) availability (mean + se) on total biomass. Different letters indicate significant differences**

### 3.3 Biomass allocation

With the exception of the leaf mass ratio, the ratios of biomass components were significantly affected by moisture availability. In addition, nutrient availability had a significant effect on all biomass ratios (Table 1). The intermediate moisture level resulted in a higher stem mass ratio than the other two moisture levels (Figure 4). On the other hand, the root mass ratio was highest at the low and lowest at the intermediate moisture level. However, the difference in response between the high moisture treatment and either the low or intermediate moisture regimes was insignificant (Figure 4). Leaf mass ratio and root mass ratio displayed a similar pattern of response to nutrient supply; values were least under intermediate and highest under high nutrient supply. The low nutrient level did not differ with either of the other nutrient treatment levels for this trait. As for stem mass ratio, it declined from the intermediate to the other two nutrient levels which did not vary in response (Figure 4).

Although not interactively, the effects of moisture and nutrient availability on root: shoot ratio were significant (Table 1). The responses to the low and high moisture treatments were comparable and significantly greater than that of the intermediate moisture level (Figure 5). Similarly, the intermediate nutrient treatment yielded significantly lower values than the other two nutrient treatments.



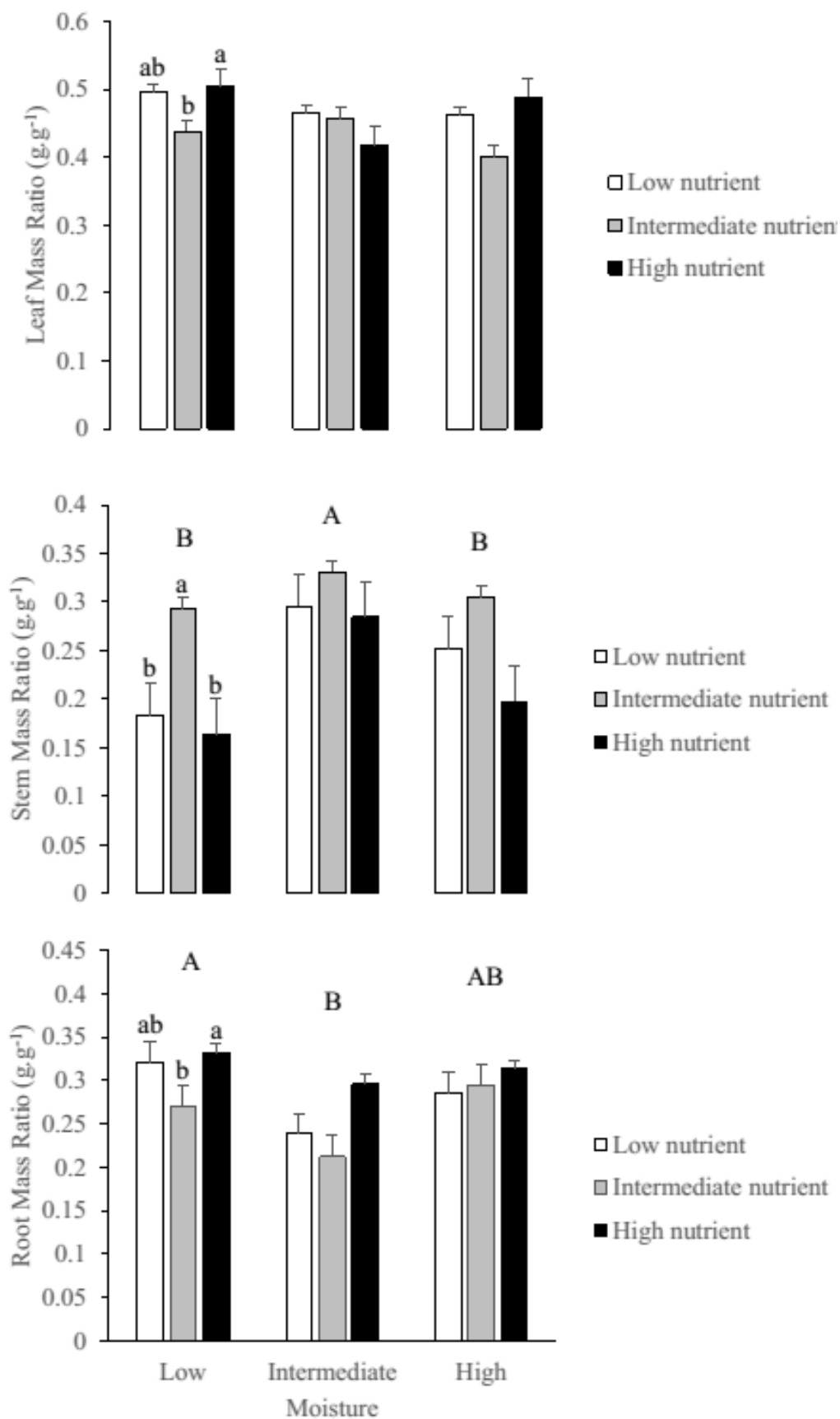
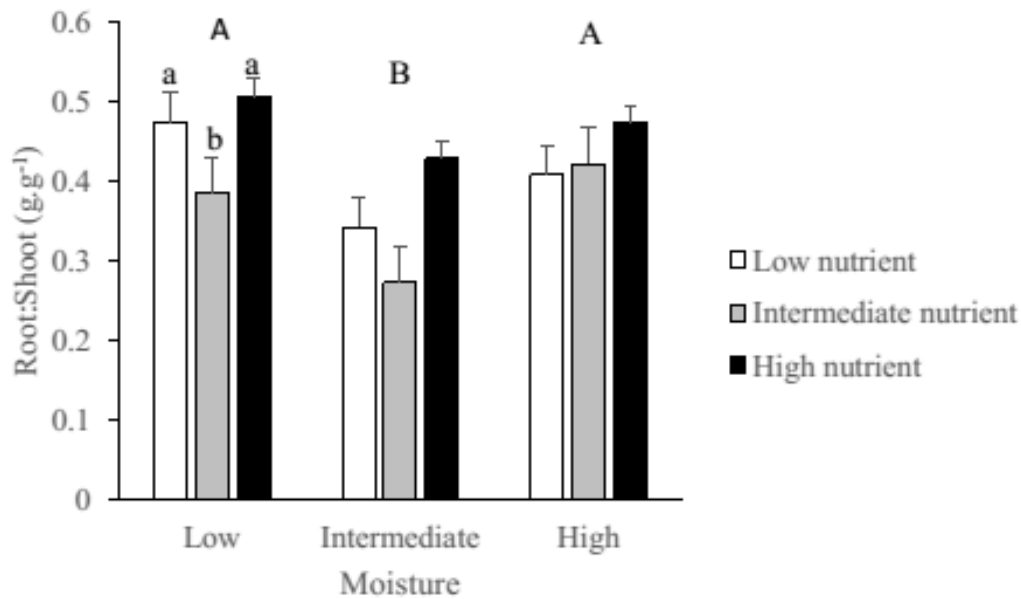


Figure 4. Effects of moisture (upper-case letters) and nutrient (lower-case letters) availability (mean + se) on biomass ratios of plant fractions. Different letters indicate significant differences



**Figure 5. Effects of moisture (upper-case letters) and nutrient (lower-case letters) availability (mean + se) on root:shoot ratio. Different letters indicate significant differences**

#### 4. DISCUSSIONS

According to the nutrient limitation hypothesis, an increase in soil nutrient content below the optimum for a plant should result in an augmentation of growth. The observation of the present study that the intermediate nutrient treatment had a beneficial effect on morphological and biomass traits agrees with this prediction. In other studies, nutrient addition was found to increase height, diameter and biomass production of *Betula papyrifera* Marsh. (Ambebe *et al.*, 2009), height, biomass production, specific leaf area and relative growth rate of *Rumex* spp (Kolodziejek, 2019), and root length, root surface area and root volume of *Pistacia chinensis* Bunge (Song *et al.*, 2019) seedlings. The nutrient effect may result from an increased capacity to capture photosynthetic active radiation due to leaf expansion. Although leaf area was not recorded here, there were visual signs of larger leaves at the intermediate nutrient level. On the other hand, non-limiting N and P conditions are known to increase the amount and activity of ribulose-1,5-bisphosphate carboxylase/oxygenase as well as foliar contents of ribulose-1,5-biphosphate with the outcome that rates of CO<sub>2</sub> assimilation and growth are favoured (Ambebe *et al.*, 2010; Guo *et al.*, 2016). Furthermore, the reading of the genetic code in plant cells for the production of proteins and enzymes that regulate all plant growth processes is influenced by K availability (International Plant Nutrition Institute, 1998; Hasanuzzaman *et al.*, 2018). A lower growth of plants in media subjected to limiting nutrient conditions may also be explained by higher root respiration. Up to ca 50% of the total daily carbon gain in photosynthesis can be expended in the process (Lambers *et al.*, 2002; Atkin *et al.*, 2000).

The ability of high soil nutrient contents to either reduce growth rates or suppress growth has been reported (Mohidin *et al.*, 2014; Ambebe and Tanwie 2020). The observation that the responses of growth to the highest and lowest nutrient levels were comparable is in line with the conclusion of Taiz and Zeiger (2010) that growth increases initially with an increase in nutrient supply up to the ‘adequate zone’ where nutrient addition does not result in an increase in growth but is reflected in increased tissue concentrations. In the ‘toxicity zone’ which follows the former, a further increase in nutrient concentration translates to a decline in growth due to toxicity.

We expected the positive effect of a modest increase in soil moisture to be attenuated by the stressful nutrient conditions. The finding that the magnitude of increase of height by the intermediate moisture level was restricted to the intermediate nutrient regime is in support of the hypothesis. That the margin of difference in a number of leaves between the intermediate and the other two nutrient levels was least at low moisture also partially agreed with the prediction. Similar moisture  $\times$  nutrient interactions have been reported previously for *Epilobium hirsutum* L. (Lee *et al.*, 2017). Plants growing in both low and high soil moisture environments exhibit low leaf water potentials. While this is attributable to high water tension in low moisture soils, high soil moisture reduces the exchange of oxygen between the soil and atmosphere, and causes declines in root growth and water uptake. Respiration is the main metabolic process affected by hypoxia in high moisture soils (Kaur *et al.*, 2020). The reduction of root growth may also result from a decrease in temperature of wet soils (Irmak and Rathje, 2008). Generally, responses to low leaf water content include a decrease in stomatal conductance, transpiration, CO<sub>2</sub> assimilation rate and ultimately growth. Since water is the medium of nutrient transport in soil, the absorption of water and nutrients are inextricably linked to each other so that plants growing under unfavourable moisture conditions may additionally suffer nutrient inadequacies (Viets, 1972).

The theory of functional balance predicts that limiting nutrient and water conditions will result in an increase in biomass partitioning to root growth (Brouwer, 1963; Thornley, 1972). The high root mass ratio and root: shoot at the low and high moisture and nutrient regimes are consistent with this model and lend credence to the claim that tissue levels of the resources due to the treatments were stressful. While the two traits indicated a high capacity for water and nutrient uptake, the root: shoot conveyed additional information pertaining to a low capacity for water loss by transpiration. The lack of an elevation of leaf mass ratio by the low and high moisture levels was likely associated with the low water loss potential. A relatively high allocation of biomass to the root is critical for the growth and survival of plants under unfavourable supply of underground resources (Lambers *et al.*, 2013).

## 5. CONCLUSION

There are wide variations in moisture in the western Cameroon highlands ecosystem ranging from wetlands to sites with very low soil water potential. In addition, the soil nutrient conditions may be modified under climate change by inputs from anthropogenic sources. The responses to these factors and their interactions will likely be important controllers of the growth and distribution of plants across the landscape. It is, therefore, encouraged that silvicultural practices that moderate soil moisture and nutrient conditions be implemented on less favourable sites to improve plant performance.

### Acknowledgement

We would like to thank the management of RETAFO for generously accepting to host this research.

### Conflict of interests

The authors declare no conflict of interest.

## REFERENCES

- Alpert, P. (1993). Conserving biodiversity in Cameroon. *Ambio*, 22: 44-49.
- Ambebe, T.F., & Tanwie C.N. (2020). Responses of growth and chlorophyll fluorescence of *Gmelina arborea* Roxb. ex Sm. to light are not influenced by mild moisture stress in non-nitrogen-limited soil. *International Journal of Development Research*, 10(1): 32900-32906.

- Ambebe, T.F., Dang, Q.L., & Li, J. (2010). Low soil temperature inhibits the effect of high nutrient supply on photosynthetic response to elevated carbon dioxide concentration in white birch seedlings. *Tree Physiology*, 30: 234-243.
- Ambebe, T.F., Dang, Q.-L., & Marfo, J. (2009). Low soil temperature reduces the positive effects of high nutrient supply on the growth and biomass of white birch seedlings in ambient and elevated carbon dioxide concentrations. *Botany*, 87: 905-912.
- Atkin, O.K., Edwards, E.J., & Loveys, B.R. (2000). Response of root respiration to changes in temperature and its relevance to global warming. *New Phytologist*, 147: 141-154.
- Brouwer, R. (1963). Some aspects of the equilibrium between overground and underground plant parts. Jaarboek IBS, Wageningen.
- Chadha, A., Florentine, S.K., Chauhan, B.S., Long, B., & Jayasundera, M. (2019). Influence of soil moisture regimes on growth, photosynthetic capacity, leaf biochemistry and reproductive capabilities of the invasive agronomic weed; *Lactuca serriola*. *PLoS ONE*, 14(6): e0218191.
- Clark, C.M., & Tilman, D. (2008). Loss of plant species after chronic low-level nitrogen deposition to prairie grasslands. *Nature publishing Group*, 451(7): 712-715.
- Daniels, L.D., & Veblen, T.T. (2004). Spatiotemporal influences of climate on altitudinal treeline in northern Patagonia. *Ecology*, 85: 1284-1296.
- Fang, F., Smith, P., Moncrieff, J.B., & Smith, J.U. (2005). Similar response of labile and resistant soil organic matter pools to changes in temperature. *Nature*, 433: 57-59.
- Fierer, N., Gruine, J.M., McLauchlan, K., & Schimel, J.P. (2005). Litter quality and the temperature sensitivity of decomposition. *Ecology*, 86(2): 320-326.
- Guo, Y.-P., Guo, D.-P., Zhou, H.-F., Hu, M.-J., & Shen, Y.-G. (2016). Photoinhibition and xanthophyll cycle activity in bayberry (*Myricarubra*) leaves induced by high irradiance. *Photosynthetica*, 44(3): 439-446.
- Harris, J.M., Roach, B., & Codur, A.M. (2017). "The economics of global climate change". A GDAE teaching module on social and environmental issues in economics. Global Development and Environment Institute, Tufts University, Somerville.
- Hasanuzzaman, M., Bhuyan, M. H. M.B., Nahar, K., Hossain, M. S., Al Mahmud, J., Hossen, M.S., Masud, A.A.C., Moumita, & Fujita, M. (2018). Potassium: A vital regulator of plant responses and tolerance to abiotic stresses. *Agronomy*, 8(3): 31.
- Huho, J. M., Ngaira, J.K., Ogindo, H., & Masayi, N. (2012). The changing rainfall pattern and the associated impacts on subsistence agriculture in Laikipia East District, Kenya. *Journal of Geography and Regional Planning*, 5(7): 198-206.
- International Plant Nutrition Institute. (1998). Functions of potassium in plants. *Better Crops*, 82(3): 24-25.
- Irmak, S., & Rathje, W.R. (2008). Plant growth and yield as affected by wet soil conditions due to flooding or over-irrigation. UNL Extension publications, G1904. <http://extension.unl.edu/publications>. (Accessed on 28 December 2020).
- Kaur, G., Singh, G., Motavalli, P.P., Nelson, K.A., Orłowski, J.M., & Golden, B.R. (2020). Impacts and management strategies for crop production in waterlogged or flooded soils: A review. *Agronomy Journal*, 112: 1475-1501.
- Kołodziejek, J. (2019). Growth and competitive interaction between seedlings of an invasive *Rumex confertus* and of co-occurring two native *Rumex* species in relation to nutrient availability. *Scientific Reports*, 9: 3298.

- Lambers, H., Atkin, O.K., & Millenaar, F.F. (2002). "The respiratory patterns in roots in relation to their functioning". In Waisel, Y. Eshel, A. and Kafkafi, U. (Eds.), *Plant Roots: The Hidden Half* (pp. 521-552). Marcel Dekker.
- Lambers H., Chapin F.S. III, & Pons T.L. (2013). "Plant physiological ecology". Springer Science and Business Media.
- Lee, E.-P., Han, Y.-S., Lee, S.-I., Cho, K.-T., Park, J.-H., & You, Y.-H. (2017). Effect of nutrient and moisture on the growth and reproduction of *Epilobium hirsutum* L., an endangered plant. *Journal of Ecology and Environment*, 41: 35.
- Lipson, D.A., Zona, D., Raab, T.K., Bozzolo, F., Mauritz, M., & Oechel, W.C. (2012). Water-table height and microtopography control biogeochemical cycling in an Arctic coastal tundra ecosystem. *Biogeosciences*, 9 (1): 577-91.
- Misra, A. (2003). Influence of water conditions on growth and mineral nutrient uptake of native plants on calcareous soil. Aparna Misra, Department of Ecology, Plant Ecology and Systematics, Lund University, Sweden.
- Mohidin, H., Hanafi, M.M., Rafi, Y.M. Adullah, S.N. A., Abu, S.I., Sulaiman, M., Juferi I., & Sahebi, M. (2014). Determination of optimum levels of nitrogen, phosphorus and potassium of oil palm seedlings in solution culture. *Bragantia Campinas*, 74(3): 247-254.
- Ndenecho, E.N. (2011). Local livelihoods and protected area management: Biodiversity conservation problems in Cameroon. Langa RPCIG, Bamenda, Cameroon.
- Nyunai N. (2008). *Eucalyptus grandis* W. Hill ex Maiden. In: Louppe D, Oteng-Amoako AA, Brink M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands.
- Pregitzer, K.S., & King, J.S. (2005). "Effects of soil temperature on nutrient uptake". In: BassiriRad, H. (ed.), *Nutrient acquisition by plants: an ecological perspective*. Springer, Berlin, Heidelberg.
- Shidiki, A.A., Ambebe, T.F., & Mendi, A.G. (2019). A comparative evaluation of Indole-3-Butyric Acid and plant extracts as potential rooting enhancers in cuttings of *Vitex diversifolia* and *Cordia milleneii*. *International Journal of Forest, Animal and Fisheries Research*, 3(4): 154-159.
- Song, X., Wan, F., Chang, X, Zhang, J, Sun, M., & Liu, Y. (2019). Effects of nutrient deficiency on root morphology and nutrient allocation in *Pistacia chinensis* Bunge seedlings. *Forests*, 10: 1035.
- Song, K.Y., Zoh, K.D., & Kang, H. (2007). Release of phosphate in a wetland by changes in hydrological regime. *Science of the Total Environment*, 380 (1): 13-18.
- Ssenku, J.E., Ntale, M., Backeus, E., & Oryem-Origa, H. (2014). Assessment of seedling establishment and growth performance of *Leucaena leucocephala* (Lam.) De Wit., *Senna siamea* (Lam.) and *Eucalyptus grandis* W. Hill ex Maid. in amended and untreated pyrite and copper tailings. *Journal of Biosciences and Medicine*, 2:33-50.
- Stuart, S.N. (1986). Conservation of Cameroon montane forests. International Council for Bird Preservation, Cambridge, UK
- Taiz, L., & Zeiger, E. (2010). *Plant Physiology*. The Benjamin Cummings Publishing Company, Redwood City, California.
- Thornley, J.H.M. (1972). A balanced quantitative model for root:shoot ratios in vegetative plants. *Annals of Botany*, 36: 431-441.

Tropical Plants Database, Ken Fern. [tropical.theferns.info](http://tropical.theferns.info).  
<[tropical.theferns.info/viewtropical.php?id=Eucalyptus+grandis](http://tropical.theferns.info/viewtropical.php?id=Eucalyptus+grandis)>. (Accessed on 04 January 2021)

van Heerden, K., & Yanai, R.D. (1995). Effects of stresses on forest growth in models applied to the Solling spruce site. *Ecological Modelling*, 83: 273-282.

Viets, F. (1972). Water deficits and nutrient availability. Water deficits and plant growth. Academic Press, New York, pp: 217-239.



This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).